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Early Warning Systems for Natural Disaster Reduction

Jochen Zschau
Andreas N. Küppers
Editors



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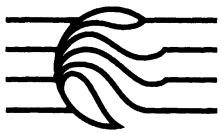
Early Warning Systems for Natural Disaster Reduction

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Preface

This volume is the result of the International IDNDR-Conference on Early Warning Systems for the Reduction of Natural Disasters, held at the GeoForschungsZentrum in Potsdam, Germany from 7–11 September 1998. Endorsed by the United Nations International Decade for Natural Disasters Reduction which had been established by the United Nations General Assembly in December 1989, it was jointly organised by the GeoForschungsZentrum Potsdam and the German IDNDR-Committee. The event brought together 370 scientists, public officials, and representatives of the United Nations system, non-governmental and international organisations and diverse professional, commercial, and civic individuals from 86 countries. Together they comprised a wide and multidisciplinary range of experience, as both providers and users of early warning and preparedness information related to natural disasters. The Potsdam Early Warning Conference represented the first major thematic component of IDNDR's concluding evaluation. It provides recommendations to ensure disaster reduction into the 21st Century.

The conference dealt with an essential goal of the decade, expressed as a major priority of the Decade's Scientific and Technical Committee. It was included in the Plan of Action adopted at the 1994 World Conference on Natural Disaster Reduction in Yokohama, Japan, and was the subject of three subsequent UN General Assembly resolutions on the improved effectiveness of early warning between 1994 and 1997.

The German Minister for Foreign Affairs, Mr. Klaus Kinkel, opened the conference as an expression of Germany's support for disaster reduction in line with his initiative delivered at the UN General Assembly session in 1993 calling for improved early warning capacities for disasters which have an adverse effect on the environment. Early warning as a core component of national and international prevention strategies for the 21st Century was confirmed in all subsequent discussions and presentations at the event. The conference ended with the release of the "Declaration of the Potsdam Early Warning Conference"[1].

The Early Warning Conference has identified major strengths and weaknesses in early warning capacities around the world. Participants repeatedly emphasised the multidisciplinary and multi-sectoral character of the early warning process. Although based on science and technology, early warning must be tailored to serve people's needs, their environments, and their resources. Successful early warning requires unrestricted access to data that is freely available for exchange. Ultimately, all resulting information must be credible, and emanate from a single officially designated authority.

The conference participants stressed that early warning is effective only to the extent that policy makers at national levels of authority have the will, and

[1] The full document is available at http:/www.gfz-potsdam.de/ewc98.

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make a sustained commitment of resources that will establish protective measures. It is crucial that these measures support the development of early warning capabilities at the community level and that they be based on local vulnerability and risk assessments. In all of these respects, the importance of training was stressed, as was the requirement to provide resources for ongoing training activities, public education and the development of both technical and operational capabilities essential for early warning.

The benefits of partnership in the development of technological innovation and related commercial opportunities should be realised by public authorities and private organisations concerned with early warning and related practices. This may include the expanded use of technologies related to earth observation, telecommunications, and other information technologies, including geographical information systems. In order to extend the benefits of current applied research on early warning, there is a need to promote continued development and practical use of commonly accepted standards for data acquisition, management, and exchange. Additionally, research is required to improve prediction capabilities and other methods which can reduce the consequences of natural hazards. Finally, it is important that available data and other scientific information are adequately converted into early warning systems and forecasts of potential natural disasters, so that protective action can be taken by concerned authorities.

The conference would not have been possible without the support of the Foreign Office of the Federal Republic of Germany, the Federal Ministry of Education, Science, Research and Technology (Germany), the Ministry of Science, Research and Culture of the State of Brandenburg (Germany), the GeoForschungsZentrum Potsdam (GFZ), the Special Committee for the IDNDR of the International Council for Science (ICSU), the International Telecommunications Union (ITU), the United Nations Development Programme (UNDP), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Meteorological Organization (WMO), Daimler-Benz Aerospace-Dornier Satellite Systems, MNET Computer Components GmbH, Hannoversche Rückversicherungs AG, and Münchener Rückversicherungs AG. Their sponsorship is gratefully acknowledged.

Besides the official members of the International Advisory Board, the Programme Committee, and the Local Organising Committee listed in the annex, many people have contributed directly and indirectly in the organisation of the conference and in the production of this book. The editors wish to thank in particular the helping hands of Peter Bormann, Katrin Clauß, Dirk Dessaules, Oliver Fox, Heike Gerighausen, Otto Grabe, Christine Haas, Antje Hahn, Thomas Heldt, Renate Karstädt, Mary Lavin-Zimmer, Jan Marie Lindsay, Karsten Matern, Elina Palm, Maren Pees, Hannelore Podewsky, Aleks Sherbatshenko, Regina Stromeyer and Birgit Zumkley, who made it happen.

Potsdam, Spring 2002 The Editors

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Introduction

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Natural Disasters and Early Warning

EUGEN SEIBOLD
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Having been invited to introduce this rather dramatic topic to you, I hope that you will find comfort in having gathered on a hill, the "Telegrafenberg" in Potsdam. Of course there is no hazard-free area on earth and life is full of risks, but you can be sure that no real earthquake, no volcanic eruption, no tropical storm and no flood from the river Havel will occur here on the hill in the near future; and for me as a geologist, "near" means the next million years.

As I understand it, I have not been invited as an individual representing any organization, but as an interested generalist. Therefore, each of my points may provoke comments by colleagues with specific experience regarding both disciplines and particular regions on our globe. Also, there will be some gaps in my presentation – ranging from the lack of detailed bibliographic references to the lack of whole chapters, like one on droughts with or without El Niño, or one on manmade hazards including possible global warming, or one on finance including insurance matters. However, you are certainly less interested in these gaps than in the following considerations.

They will include

1. some ideas about the general situation of all researchers confronted with an increasingly critical public attitude towards science and about the special situation of this audience,
2. some thoughts about the increasing threats caused by global population growth, especially in developing countries,
3. the permanently necessary message that fundamental science, the understanding of principles as the basis for all progress, should be improved.
4. Finally, as long as exact hazard predictions are and will remain difficult, provision should be especially promoted, ranging from risk maps to public education.

All in all, I may hopefully contribute indirectly to the formulation of your recommendations which are to be set up at the end of this week.

1 Early Warning in a Historical Context

Scientists involved in early warning deal with risks. Safety is a common ideal but risk cannot be completely eliminated from our lives. Risk management involves the difficult task of reducing threats to life, property and the general environment posed by hazards. It may, however, fail, because it is largely based on science, and by definition science always involves risk.

For several reasons our present situation is not very comfortable. In the course of its history, mankind has changed its attitude towards natural disasters. In ancient Greece each city had its special god or gods protecting it. But gods and goddesses had their moods or their fights – and everybody depended on them.

God and natural disasters: You will find it in the Bible, too, and you know the story of Noah, complete with prediction and provision and clever management. Psalm 18 gives another example of God's interventions:

> "Then the earth reeled and rocked, the foundations also of the mountains trembled and quaked, because he was angry. Smoke went up from his nostrils and devouring fire from his mouth; glowing coals flamed forth from him... Then the channels of the sea were

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seen, and the foundations of the world were laid bare..."

Medieval Christians also understood natural catastrophes as God's punishments. And as late as 1772 Sir William Hamilton, the famous British Envoy to the court of Naples, pointed out on the basis of his observations of Vesuvius and Etna that volcanic heat resembles hell fire and is meant to warn sinners.

The disastrous earthquake of Lisbon in 1755, which was accompanied by a tsunami rushing into the Tejo estuary with a ten meter wave, was a dramatic signal for change. Why is this kind of thing possible in the "best of all worlds" as described by Gottfried Wilhelm Leibniz (1646–1716) some decades before? Why should God punish this pious city with its 90 monasteries and over 40 churches and with its king, highly decorated by Pope Benedict XIV? More and more natural causes were consequently discussed and in the course of the Enlightenment God was replaced by inescapable fate.

However, with growing scientific success fate looks less inescapable, and scientists will be increasingly blamed if they are not able to warn at least earlier, or with more emphasis, or with greater precision about the "where," the "when" and the magnitude of an impending disaster.

So much to the more general situation.

2 Early Warning and Population Growth

New difficulties are added by global population growth. By 1850 the population of the earth had reached its first billion. It had taken something like 3 million years for this number to be reached. Adding the next billion took only 100 years, the next 30 and the third and fourth just 11 years each. This incredible situation is what exponential growth is all about. And it reminds us of an early warning, by Thomas Malthus. Exactly 200 years ago, in 1798, he stated in his "Essay on the principles of population," that exponential growth has to be matched against what would remain linear growth in agricultural production. Therefore starvation would be inevitable. Fortunately he was too pessimistic, because it turned out that agricultural productivity could be improved by mechanization and the use of chemical fertilizers. In Europe, emigration to other continents reduced the pressure. However, at present emigration to the moon or to other planets seems unrealistic and to look at the annual 255 000 deaths by natural disasters as compared to the daily global growth rate of about 200 000 is cynical. But the figures illustrate that early warning and the reactions of people are very different topics.

We may hope that, thanks to various improvements, food in general may not become a severe problem during the next decades – at least if the energy supply can be guaranteed in all countries.

However, when we consider our specific problems, two aspects in particular have to be discussed. (1) We need more space, not only for food production but for housing, industry and traffic as well. Therefore we are forced to use even hazard prone areas. (2) There is an ongoing trend of migration from rural to urban environments, and consequently a trend to form huge aggregations.

We have much evidence for the first point in historical reports. In Switzerland, for example, population growth in the 16th century forced settlements to expand up the mountains and to use more alluvial plains which were prone to being flooded. Traffic increased, too, and deforestation produced more damage by causing erosion, avalanches, mudflows, landslides and river floods.

Regarding the second point, concentrations tend always to lead to critical situations. Look at the concentration of energy in nuclear plants, of dangerous materials in chemical factories or of traffic on bridges or in tunnels.

But the situation is even worse because about 90% of the future increase of our population will take place in the Third World. Today the population of Africa is about equal to that of Europe, but by 2025 Africa will have three times as many people. The burgeoning Third World population will be concentrated in perhaps 90 mega-cities. Today about a billion people live in Third World cities, by 2025 this number will exceed 4 billion.

Migration essentially by the poorest section of a population often ends in marginal lands exposed to landslides on steep slopes, or to floods in low lying plains. Low income countries can afford less provision, warning, disaster management than high income countries. Therefore, between 1980 and 1988, tropical cy-

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clones caused 23 deaths per event in Japan, whereas in the Philippines they caused 196 and in Bangladesh 1341 (Smith 1992). This is one reason for the responsibility of industrialized, high income countries to help.

But even in these countries with increasing economic growth, problems are increasing, too. The ongoing concentration of highly expensive installations like factories or traffic lines adds vulnerability, and fashionable second homes for leisure in mountains or on hazardous sea shores are in greater danger than cities in less exposed areas.

For geological reasons, developing countries are especially prone to natural disasters, because many of them are situated near plate boundaries, where earthquakes and active volcanoes are concentrated. There are also meteorological reasons: tropical climates are not always very friendly.

All in all, many old and new tasks are challenging us at present. Nobody can escape our global responsibility. In former times only very few cared for what happened on the other side of our globe. Modern communications and the fact that disasters, even those which killed the dinosaurs 65 million years ago, make good news for television and other media, have changed everything.

3 Early Warning and Fundamental Science

Scientists in general are increasingly confronted with the expectation that they have to help mankind to manage and even command nature. This attitude, too, has deep roots in our western culture, in Judeo-Christian civilization as well as in Aristotle, Bacon or Descartes. But even Bacon knew that "we can command nature only by obeying her laws." To me this seems to remain our most important task. Therefore, the first step to improve early warning is to know these laws: that is, to get a better understanding statically of materials and structures and dynamically of processes.

However, to be realistic and at the same time duly modest as human beings, we cannot control natural hazards. We have to improve defensive measures, a passive approach. *Nature* commands earthquakes or severe storms and we have to react. Of course we can be quite proud if we were able to dissipate a thunderstorm locally and stopped hailstones damaging our harvests. But truly obeying nature's laws means trying to avoid high risk areas or planning suitable manmade structures for protection.

Fundamental problems are not primarily a special topic of our meeting. Unfortunately we face many gaps in the solution of these problems, and we have to live with these. In spite of this, we have to give advice which directly touches on many often weighty decisions and actions. For example, in spite of much effort we do not really understand the mechanism of rock failure in different materials. Or: What are the messages from mantle magma and how do they come to the surface? What, in terms of quantity, are the critical parameters for slope stability? Or, in general: Are there any cyclical factors involved in all these examples? Any answers would help us in our predictions.

I am told that in meteorology and climatology we should get far more knowledge about hydrodynamics and generally about chaotic processes.

Nevertheless, we have learned a lot concerning *regional aspects*. Take mass movements as an example. These include a variety of phenomena, from rock falls to mudflows, which are generated by slope instabilities:

1. if weight is added to a slope formerly in equilibrium, for example by human constructions, or by rain.
2. If rain additionally penetrates into the slope and reduces internal friction.
3. Slope steepening either by river erosion, by slides themselves, or again by man's activity are other possibilities.

Therefore the overall picture of occurrences is a pretty simple one: The most likely regions for mass movements are mountainous areas with seasonal heavy rainfalls or thawing of winter snow.

The overall picture painted with a broad brush becomes more pointillistic if we go into details, because many factors influence slope stability and failure.

These may be *geological* (such as the material or the structure of the slope or its ongoing or former deformation), *morphological* (such as slope angles, or former landslides with their particular features), *climatological* (such as frequencies of heavy rainfalls with, or without, previous wet periods, or other seasonal effects

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like frost), *biological* (such as the type of vegetation protecting the slope, thus reducing the penetration of water or even increasing soil cohesion thanks to tree roots). Finally, failure may originate from *seismic* or *volcanic* events or even *traffic vibrations.*

I do not intend to continue with similar lists for other natural hazards, but I use this relatively simple example to demonstrate how *many* factors are involved and how *many* disciplines are needed to understand specific situations. On the other hand, this list is quite enough to enable us to predict that a country like Japan is especially prone to mass movements: Loose volcanic ash and young sediments, high relief, cyclones with tremendous rainfall, together with possible shocks from the deep! We are well informed about potential single factors, but to put them together for an individual prediction is the next, much more difficult, step.

The same discrepancy, but on a much broader scale, exists when we look at earthquakes and volcanic eruptions. With the help of the new theory of plate tectonics we can define those regions on our globe which are most prone to earthquakes or volcanic eruptions. They occur essentially along plate boundaries, less often – and not as easily understood – in the midst of plates.

Again, the overall picture has been familiar for some three decades, but not the details. As I see it, *earthquakes* pose the most difficulties. There was a marvelous success in 1975, when the Chinese town of Haicheng got a shock of magnitude 7.3 on February 4 at 19.36 hours. 90% of the town was destroyed but only very few inhabitants out of the 100 000 were killed, because exact and timely warning and strict regulations permitted a successful evacuation. Everybody was disappointed that this case proved to be a sensational exception, a lucky coincidence of many factors even allowing a step-like warning, culminating in an alarm with a final lead in time of about 10 hours before the event (Seibold 1995).

Everybody has the chance to be lucky and throw eight "sixes" in an eight-dice game, but the basic probability in any one trial is about one in two million. Therefore, on geological time scales nearly everything is possible.

It seems easier to predict *volcanic activity* because you can concentrate your efforts on one spot, the volcano, and you can even place an observatory on it. Several well known precursor phenomena can be observed, such as seismic activity, ground deformation, hydrothermal and chemical changes. However, only some two dozen such observatories exist on earth with its more than 500 "active" volcanoes and their roughly 50 eruptions per year (Seibold 1995). But continuous monitoring of the volcanoes' behavior is now even possible from satellites with thermosensors. Excellent examples of successful predictions are reported from Vesuvius, Etna, Kilauea, Mt. St. Helens, Pinatubo and other places. But you can never be sure whether active volcanoes are more dangerous than dormant ones.

Prediction, if well carried out, is an essential component of the protection of people and environment. If it is wrong it contributes to public disappointment and to criticism of science, as illustrated by a faulty prediction of an eruption in Guadeloupe (Soufrière) in 1976. Fortunately it did not happen, but 72 000 people were evacuated for several months (Plate et al. 1993).

4 Predictions and Provision

Predictions are defined to be largely based on statistical theory and historical records of past events resulting in average probabilities for future events. Forecasts like those in meteorology are based on well understood and monitored individual events. There are different definitions for long-term, intermediate term and short-term predictions. The same holds true for the definition of disasters when we set thresholds such as "more than 100 deaths" or even "damages of more than 1 million US Dollars, corrected by inflation." I feel that we should not try to be too precise here, because such limits depend on many diverse factors.

Auguste Comte, who is regarded as the founder of sociology and was born 200 years ago, once said: "Savoir pour prévoir, prévoir pour prévenir." We may use this sentence in our discussion here, or in the somewhat similar situation of encouraging preventive and not only reactive medicine. One possibility for us to put Comte's words into practice is to continue publishing risk maps.

Such a risk or hazard map would, for example, sum up all the above-mentioned factors

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causing landslides. The first step in drawing it would have to be a historical approach. Former landslide features in morphology or typical sediments provide the best warning for planners to be cautious. Field work, aerial or satellite photographs clarify the local situation. Additionally, investigations of vegetation history or climatological changes are helpful.

Of course, people have always tried to prevent or to mitigate losses and damage on the basis of historical experience alone, without any risk maps. The traditional system of constructing houses in the earthquake prone Japanese islands relies on organic materials like bamboo, wood, hemp, straw or paper, which reduce weight. In contrast, old fortresses there are built of huge blocks of rock intelligently put together instead of dangerous brick fabric. The frequency of earthquakes in Japan has promoted lifelong learning for generations, but unfortunately, normally our biological program is usually more directed to the immediate future, with a "short-term strategy" satisfying natural urges like hunger and thirst. These cannot escalate endlessly because they are satisfied on many individual occasions – unfortunately, the wish to obtain money or power is in quite another category.

Of course climates outside tropical paradises have forced people to exercise foresight, and to be prepared with stocks on a seasonal scale even in Paleolithic times. But up to now, we have normally been only interested in the fate of our children or perhaps grandchildren. With the increasing awareness of global changes fortunately many more people are becoming interested in a much longer time-span.

Recurrence times of most natural disasters are however a matter of decades or even centuries. This fact may mislead people who stand in front of their damaged home to rebuild it in the hope that it may be safe for the next generations. "Repair, rebuild, but never remove!" Maybe risk maps can correct some such decisions.

The construction of risk maps is easiest if a hazard exists due to topographical features. The extent of river floods can be estimated with the help of maps with isohypses. Valleys cutting into volcanoes are conspicuous candidates for debris or pyroclastic flows. Coasts exposed to a long fetch of waves or bays open to tsunamis are further examples. Let me take the plains of Bangladesh as an illustration. They are threatened both by tropical cyclones and by river flooding from the Ganges–Brahmaputra–Meghma systems. High floods may cover half the country. More than 110 million people live relatively unprotected on these flood plains (Smith 1992). Additionally, the Bay of Bengal is famous for disastrous tropical cyclones. These strong winds produce not only surges invading the coasts, but also heavy rainfalls. Therefore the death toll may reach the 100 000s per catastrophe. These figures are only surpassed by river floods in China: Yangtse summerfloods in 1931 killed 1 400 000 people and in 1959 in North China even 2 million. Hopefully the giant Yangtse dam can withstand even the strongest earthquakes and will eliminate some such catastrophes. But how can we construct reliable risk maps for these huge areas and how can we make them work?

When the nature of a hazard is not due to topography, as for example with tropical storms over oceans or with earthquakes if there are no landslide risks involved, experience gained in former disasters is very helpful.

Risk maps should be the base for intelligent land use planning by governments, regional and local authorities.

However, we should not be too optimistic. The construction of such risk maps is a scientific procedure which aims at excluding emotional aspects, whereas in reality there are many such aspects involved. Risks are perceived differently, depending on whether certain hazards cause havoc frequently or infrequently. There is also the tangible and often falsely reassuring presence of existing developments, which combine with widespread public resistance to land use control. There is the influence of economic or political pressure groups. Finally careful mapping seems costly – but in fact it is extremely cheap when you consider input/output relations, the avoidance of deaths, injuries and multimillion dollar damage.

To sum up: In spite of the fact that we urgently have to improve short-term warning, and that we have to devote much effort to this essential topic for the sake of the survival of many people, we should also strengthen the idea of provision and related activities.

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5 Short Term Predictions

Precise indications of the where and when and the magnitude of an event causing a natural disaster remain the greatest challenge for us. Normally, highly technical approaches are needed, and such warnings are a task for particular agencies, such as meteorological or geological surveys. They organize continuous monitoring, if this is suitable, plus a communication network to prepare decisions.

Warnings are organized on different scales; earthquakes threatening wide areas or mass movements of only local importance are approached according to the magnitude of the respective risk.

For instance, monitoring can be concentrated on selected slopes which potentially threaten settlements or important traffic lines. Often carefully repeated field observations indicate changes. Fissures grow continuously. Tree roots burst and may be monitored automatically even by acoustic devices. Rocks fall down. Slope deformations can be observed geodetically. Normally, all these indicators accumulate shortly before the disaster. But how can we predict the exact time it is going to strike?

Furthermore, the velocity of the downrushing masses of soil and rock varies, depending on whether we are dealing with rockfalls or avalanches (m/sec), mud flows (m/min), rotational slumps or creeping masses (m/months to m or even cm/year). In Peru debris has traveled 16 km at up to 360 km/h (Yungay 1970) (Smith 1992).

But even careful monitoring sometimes cannot prevent catastrophes. Such as was the case in Friaul, where on October 9 1963, 2000 people were killed by a slide (Plate et al. 1993).

On the other hand, there have also been very successful predictions, for instance around San Francisco (Keefer et al. 1986). On the basis of empirically and analytically established relations between rainfall and landslide generation, real-time monitoring of rainfall with the help of 45 telemetering gauges, precipitation forecasts and delineation of areas susceptible to landslide generation, warnings were issued twice in 1986, when cumulative and anticipated rainfall reached threshold figures. In both instances the warnings were followed by debris flows and other sliding. However, regional real time warning systems are still rare because of the complexity of the processes mentioned above, and because of the high cost. Specialists may add other examples but perhaps they – and others here – may enjoy an extremely good description of our landslide phenomenon, given by Rudyard Kipling in his Second Jungle Book's story about the "Miracle of Purun Bhagat." In a general introduction it may be allowed to introduce an essayistic feature, too.

This wise man lived in a shrine high up in the Himalayas and high above a village whose inhabitants offered him food. After long lasting rains, when water "fell in sheets," monkeys which used to visit him regularly got nervous in the "black heart of a night" and an antler "pushed him towards the door, and as he did so Purun Bhagat heard the sound of something opening with a sigh, and saw two slabs of the floor draw away from each other, while the sticky earth below smacked its lips." Immediately he rushed down with his animals and warned the villagers.

> "Then the people ran as only Hill folk can run, for they knew that in a landslip you must climb for the highest ground across the valley ... At last the deer stopped in the shadow of a deep pine-wood, five hundred feet up the hillside. His instinct, that had warned him of the coming slide, told him he would be safe here...
> There was a sigh in the air that grew to a mutter, and a mutter that grew into a roar, and a roar that passed all sense of hearing, and the hill-side on which the villagers stood was hit in the darkness, and rocked to the blow. Then a note as steady, deep, and true as the deep C of the organ drowned everything for perhaps five minutes, while the very roots of the pines quivered to it. It died away, and the sound of the rain falling on miles of hard ground and grass changed to the muffled drum of water on soft earth. That told its own tale.
> When (the day) came they looked across the valley and saw that what had been forest, and terraced field, and track-threated grazing ground was one raw, red, fan-shaped smear, with a few trees flung head-down on the scarp. That red ran up the hill of their refuge, damming back the little river, which had begun to spread into a brick-colored lake. Of the village, of the road to the shrine, of the shrine itself, and the forest behind, there was no trace. For one mile in width and two thousand feet in sheer depth the mountain-side had gone away bodily, planed clean from head to heel."

Therefore, why not bring a bit of emotion to a scientific audience and why not mention early warning by animal behavior, a field which has been neglected by us scientists up to now in spite of many observations around the world and historically best reported in China. For

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rural environments where people live in direct contact with animals it may well become a real tool if investigated more carefully.

But back from methods to principles. The success of short-term warnings also depends on the character of the hazard. If nature is generous, it gives us sufficient lead time between the event and the damage caused by it.

We can follow the path of *tropical storms* using several methods like satellite imaging, weather radar and aircraft observation in space and time. We can only hope that they do not get out of control by spreading further. The only valid very general features are that they move westward and normally with a velocity of about 15–30 km/h. Therefore, the lead time for landfall sites may add up to several days, like in Florida. There, step-like warning systems could be developed with watching – and then warning phases.

Tsunamis triggered by earthquakes offer optimal possibilities for an early warning system across whole oceans. These ocean waves propagate at velocities of some hundred kilometers/hour and need 4 to 5 hours to travel from Alaska to a place like Hawaii. Seismic waves can do it in less than 10 minutes and modern communication needs a split second for the message to reach its destination – if things are well organized. This is the scenario behind a very successful warning system.

The same holds true for *river flood* warning. Weather forecasts, measuring storm rainfall and given runoff conditions eventually confirmed by modeling, may be a great help in improving warning, again up to days ahead of the event. But the installations and communication systems are not sufficient everywhere.

Seismic waves may reach 8 km/sec. Therefore the lead time for warning between the focus of a shock and the area prone to damage is not hours but seconds or less. Nevertheless, the Japanese ultrarapid train Shinkansen can be stopped underway if necessary, again because the transmission time for radio waves is much shorter.

Volcanic eruptions pose different problems. If seismic waves or other signals indicate that rising magma is threatening to erupt, lead times may reach some days or "unfortunately" even longer. The most convincing recent success story comes from the Philippine volcano Pinatubo (Seibold 1995). For 600 years no activity had been reported, but since April 2 1991, some small explosions and gases were observed by farmers. Specialists from the Philippines and the USA then investigated these activities in detail and worked out a step-like alarm plan culminating in the possibility of a 24-h prediction of the beginning of a disastrous eruption, which eventually happened on June 9 1991. Because evacuation of a larger population at risk normally lasts a few weeks, warnings were given far in advance, and, most importantly, they were effectively disseminated not only by the media but by direct education in the villages as well. General experience tells us that mouth-to-mouth propaganda is optimal – if hysterical rumors can be excluded.

Predictions weeks before a catastrophe include the risk that the catastrophe *may not* occur because the activities of a volcano sometimes stop suddenly. Overwarning based on inadequate knowledge of the phenomenon or on inadequate data often leads to false alarms and lack of compliance with warning and evacuation attempts. Such false alarms result in a loss of faith in the capability of scientists and others involved, and result in reluctance to take action in subsequent events. As mentioned above, Guadeloupe's 72 000 evacuated people have been disappointed in this way since 1976.

This last-mentioned aspect, i.e. hazard perception and reactions to warnings, could easily open the door for a whole series of lectures (Plate et al. 1993, Smith 1992). What is the situation in rural as opposed to urban environments? Seen by sociologists, by economists, seen legally or politically? What is it like in countries like Japan, where major damage has been occurring regularly and where, because of this, a sense of fatalism could develop? What is it like in countries where the belief continues that gods create earthquakes, or that volcanoes erupt because they have not been offered sufficient sacrifices, or because they disagree in some other way with the behavior of the people?

What a chance to go on with research in these numerous fields!

I would like to finish my lecture with just one idea: In 1984 Anthony Michaelis, editor of Interdisciplinary Science Reviews, proposed the foundation of an International Disaster Research Laboratory (Michaelis et al. 1984) and I may add: or a network of such laboratories.

This should not only be a facility to obtain information regarding the state of the art in

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prediction, relevant technologies, case studies, first aid organization or in insurance matters. It should also include research into human behavior before, during and after disasters, including the role of the media. Why not discuss this idea during the next couple of days?

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I Bringing Early Warning to the People

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CHAPTER 1.1

Bringing Early Warning to the People – Public and Partnership Responsibilities for Early Warning

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Throughout the 1990's, the improved access and greater effectiveness of early warning have been fundamental issues leading to the accomplishment of the IDNDR objective: the reduction of loss of life, property damage, and social and economic disruption caused by natural disasters, through concerted international action, especially in developing countries.

From the beginning of the decade, it has been recognised that early warning needs to bring scientific and technical abilities of hazard identification and forecasting together with effective communications, the commitment of public policy, and the understanding and active participation of local communities. It is for that reason that the IDNDR's international advisory Scientific and Technical Committee declared one of the decade's three programme targets to keep encourage countries by the year 2000, "to have in place, as part of their national plans to achieve sustainable development, ready access to global, regional, national and local warning systems."

Throughout the decade, the IDNDR has worked to promote a wider understanding of early warning among more people, and to establish the importance of seeing early warning as a process relating activities that involve scientific endeavour, public policy decision-making, commercial interests, and ultimately, community understanding and commitment within local communities. To succeed, early warning must necessarily become a partnership tied together by timely communication at several levels of activity.

From that time to the present, IDNDR has pursued a programme of study, policy formulation, and practical encouragement for improvements in early warning effectiveness. The IDNDR secretariat has been fortunate in the recognition and consistent support which the government of Germany has provided through the IDNDR Trust Fund, so that a continued and coherent process of improvement in early warning could be pursued. This has enabled early warning issues to become an important component of IDNDR, and a key link to many of the professional disciplines represented in the IDNDR International Framework for Action.

A special topical session on early warning was convened jointly by the World Meteorological Organisation (WMO) and UNESCO at the World Conference on Natural Disaster Reduction held in Yokohama, Japan in May, 1994. The outcome of this special session resulted in the recognition of both the opportunities provided by modern technologies, and the challenges posed in addressing the human factors on which effective early warning ultimately depends. The conference stressed that, for early-warning to be successful, in addition to the technical and scientific analysis of hazards, a commitment in public policy decisions was also required. In this respect, pertinent scientific knowledge and a public awareness of early-warning capabilities were recognised as being essential for viable political initiatives.

Following the World Conference, a first investigative phase of early warning activities was undertaken by the IDNDR secretariat which resulted in the first Secretary General's Report on Early Warning to the UN's 50th General Assembly in 1995. This report highlighted the importance of incorporating advances in science and technology with enhanced commitments of policy-makers and a better informed population. Practical limitations to timely or effective warnings and the related needs of special environments such as scattered populations or small island developing states were also noted.

The UN General Assembly then requested IDNDR's international programme advisory

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body, the Scientific and Technical Committee, to undertake a further study of ways to improve the effectiveness of early-warning for natural and similar disasters with an adverse impact on the environment. The IDNDR secretariat continued to work through an inter-agency and multidisciplinary approach. Six international expert working groups were organised by the IDNDR secretariat to study aspects of early-warning as they relate to geological hazards; hydro-meteorological hazards including drought, wildfire and related environmental consequences; technological hazards; the use and transfer of modern technology; and national and local capabilities pertinent to early-warning. The conclusions of the expert working groups reflect global experience, and form the basis of the Secretary General's Report on Improved Effectiveness of Early-Warning Systems With Regard to Natural and Similar Disasters presented to the 52nd General Assembly in November, 1997. Detailed information reports from each working group are available on the IDNDR website at *http://www.isdr.org*, or at the Potsdam Early Warning Conference website at *http://www.gfz-potsdam.de/ewc98*.

In order to capitalise on previous developments, the IDNDR secretariat seeks to direct the lessons of effective early warning to a wider global audience, and in so doing, equally to engage a larger community of interest in the subject. To ensure the integration of improved procedures and community involvement into practical early warning measures, the IDNDR secretariat continues to link improved early warning practice with related fields such as:

1. global climate variation and change, including El-Niño events;
2. global environmental issues such as regional consequences of fire, smoke and haze;
3. international collaboration on telecommunications for disaster prevention;
4. space technology applications for hazard identification and disaster mitigation;
5. public-private partnerships for preparedness and risk management at local community levels; and
6. social science and public information activities to increase local comprehension and response to early warnings.

The IDNDR secretariat continues to promote the interests and cross-cutting linkages of effective early warning practices as a key element of sustained reduction of natural and similar disasters which have an adverse effect on the environment. In this respect, the secretariat has organised the session on "Bringing Early Warning to the People – Public and Partnership Responsibilities for Early Warning." Speakers have been selected who can demonstrate both the diverse nature of their individual responsibilities, as well as together presenting the full range of functions that need to be present within successful early warning systems.

There are presentations that cover early warning responsibilities seen from the policy perspective of national authorities (in China and Bangladesh), from the standpoint of Non-Governmental and community organisations (in Bangladesh and Kenya), addressing scientific interests (UNESCO and UNEP), and from technical practitioners in both the social and environmental fields (United Kingdom and Nicaragua). Finally, a presentation on a possible global network for disaster information (GDIN) is presented following some initial developments to have countries share a common access to information that can contribute to improved early warnings world wide.

As a part of the closing process for the decade, the IDNDR secretariat has an obligation to follow-up and disseminate the results of the International Early Warning Conference (EWC 98) and other related international events, through national disaster reduction committees and focal points, professional networks and regional organisations concerned. The specific objective must be to engage the range of framework partners, together with the technical, scientific and academic communities, and most importantly, those professionals engaged in the actual use of early warnings at the decision-making and local community levels. We trust that these collected papers may serve that purpose.

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CHAPTER 1.2

Early Warning Systems for the Reduction of Natural Disasters in China

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1 Introduction

Early warning systems are an important means to reduce disaster losses. Damage caused by a disaster can be effectively contained if disaster warning can be given and communicated to disaster management departments, decision-making officials, and to all those who might be affected by a coming disaster or a tragic event, and if the correct decisions made and carried out, i.e. to ensure that everyone is aware of and prepared for it (preparation includes emergency evacuation of people and valuables, and training people in what actions are to be taken when facing a disaster, e.g. hiding, self protection and first aid skills).

Close attention has been paid to early warning system development in China. During the past four decades, several executive disaster management agencies have established their specific monitoring and early-warning systems, which have gradually evaluated during this time. Each of these networks consists of the following four component parts: (1) the network for observation of natural hazards, relevant elements and phenomena; (2) the telecommunication system for real-time collection, transmission and exchange of the observation data; (3) the system for data processing, analysis and diagnosis, modeling and formulation of forecasts or warnings; and to the system for services, including the transmission and dissemination of such forecasts or warnings. Generally speaking, the monitoring and early warning systems relating to sudden or abrupt hazards, e.g. in meteorology, oceanology, hydrology and seismology, are relatively more comprehensive.

In addition to the above, a great number of non-governmental or auxiliary observation, monitoring or forecasting stations and their staff workers have begun operation, thereby making up for the deficiencies of the state-run professional stations and networks to some extent. In recent years, China has made remarkable achievements in monitoring floods and waterlogging, droughts, forest and grassland fires, sea ice, desertification, crop diseases and insect pests, landslides, mud-rock flows etc. through the application of aviation/satellite remote sensing and land-based remote sensing technologies.

Currently, the major real-time data transmission networks of different systems are mostly hooked up through medium-speed transmission links (satellite, wire or microwave), and some are collecting data from observatory stations by means of satellite receiving and transmission. Computers have in the main been applied to automatic real-time dissemination and exchange of real-time data.

The departments in charge of the management of different categories of natural disasters have established their forecast mechanisms at national, regional, provincial and prefectural or even county levels, to take charge of the pro-

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cessing, analysis, diagnosis, modeling, forecasting and warning operations. In addition to publicly issuing disaster forecasts and warnings covering the whole country or the relevant big regions, the national and regional centers also offer analytical and diagnostic data, and various pre-disaster guidance output to relevant operational units, and in the meantime carry out global or trans-national forecasts. Below the provincial level their respective administrative areas are generally in charge of forecast and warning.

2 Meteorological Observation, Forecast and Warning

2.1 Meteorological Observation System

In addition to regular surface and upper-air observation, the meteorological observation and monitoring system also encompasses different multi-functional automatic weather-stations, meteorological radar-sets, weather satellites and meteorological rocket and airplane detection. These have an effective range from several meters underground to dozens of kilometers or even higher in altitude. Currently, the meteorological observation and monitoring network in China consists of 2490 surface meteorological weather stations, 957 precipitation observation stations as well as 143 radio-meteorological stations and radar wind observation stations. Thus the nation's meteorological network density has met the requirements set by the World Meteorological Organization (WMO). In addition, the nation has various kinds of weather radar-sets and satellite information receiving installations currently in use. All in all, about 20000 professionals are now engaged in the nation's meteorological observation and monitoring networks.

2.2 Meteorological Prediction and Warning System

With respect to weather forecast, comprehensive analysis and multiple prediction methods based on digital prediction have been used to make long, medium and short-term and imminent forecasts. The accuracy of these forecasts has improved markedly.

In China, the long-term forecast is the weather tendency prediction over more than 10 days and it can be classified into one month, one quarter and one year term forecasts etc. The accuracy of long term prediction is showed in Table 1.

The medium term prediction involves weather forecasts for periods of 4 to 10 days, e.g. the everyday weather forecasts in 4 to 5 days, the weekly weather forecast and ten day forecast. It focuses on specific atmospheric movement and predicts the rainfall, temperature and catastrophic weather.

The short term prediction involves daily weather forecasts covering 3 days, and focuses on the monitoring and early warning of strong wind, storm rain, sudden drops of temperature etc. The short time prediction however involves the weather forecast of the next 12 hours, and it modifies the short-term prediction. In this way, the small range atmospheric phenomena such as heavy rain, hailstones, strong-wind and tornadoes may be predicted with good results. According to the statistics, the prediction accuracy on local, heavy rainfall is about 20–30% for a 24 hour period and about 80% for a 3 hour period.

The early warning services regarding tropical cyclones in China are categorized into information, warning, and emergency warning. When a particular tropical cyclone may influence the local area in 3 days time, information would be issued, which includes the location, intensity, movement direction and speed of the cyclone. If it could influence the local area in 48 hours time, warning would be issued, in which the possible arrival time and area as well as the influence range would be reported. Moreover, if the possibility exists that it will influence the

Table 1. The accuracy of the long-term prediction

Prediction Items	Monthly Precipitation	Monthly Temperature	Precipitation in Flood Period	Tropical Storm	Cold Air Movement
Accuracy	61%	67%	62%	52%	52%

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local area severely, emergency warning would be issued which is the highest emergency warning issued by the meteorological stations. Commonly, the 24 hour forecast for cyclones has a range of about 200 km while the 48 hour forecast has a range of about 400 km. People should carry out preparation work according to the forecast issues.

3 Hydrologic Observation and Forecast System

Due to large-scale water conservancy undertakings, China has also been able to rapidly develop its hydrologic observation and forecasting capacity. At the end of 1997, China already had 3006 hydrologic stations, 1107 hydrometric stations, 14158 precipitation stations, 61 hydrologic experimental stations and 11179 metering wells of underground water responsible for reporting hydrologic information on rivers, lakes and reservoirs, with 8843 stations being equipped with a total of 12000 wireless walkie-talkies. Currently, all the flood control departments from central down to local levels are engaged in the hydrologic forecast/prediction.

Flood prediction has been the major information resource for decision makers and disaster managers because of the severe flood disaster risk in China. For example, on 21st August 1994, typhoon No. 9417 hit Rui An, Zhejiang Province, with a maximum wind speed of up to 40 m/s and accompanied by heavy storms. It happened to be July 15 by the lunar calendar, the time when the tide rises. The water level along the coastal area of Shanghai and Zhejiang exceeded the warning line, and in Rui An and Wen Zhou City, the water level reached a local new record. More than 900 km of dams were destroyed, and human causalities were close to 1000. Direct economic losses were calculated at USD 2145 million. Prior to the occurrence of this typhoon, warnings were given by the local meteorological department, and the Zhejiang provincial government had mobilized millions of police and civilians to help strengthen endangered coastal dams and reservoirs; and 600000 endangered people were evacuated to safety. All these actions were very important in avoiding greater losses, and proved to be quite effective.

4 Marine Observations, Forecast and Warning

The nation's marine and coastal disaster analysis, forecast and warning system consists of 3 tiers of forecast organization: (1) the National Marine Forecast Center, (2) 3 sea regional centers, and (3) the Hainan Center. They issue forecasts and warnings relating to typhoon storm-surges, temperate-zone storm-surges, sea waves, sea ice, tsunami along with marine accidents and oil spills etc.

With renovation and upgrading in recent years, marine environment and disaster monitoring networks have developed automation in their monitoring, observations as well as in data collection relating to tides, waves and sea temperature. At present, the nation has 60 coastal and inland oceanic stations, with 30 of these stations equipped with automatic wave metering systems, and 40 with automatic tidal gauge systems. These stations, together with the stations under the Ministry of Water Conservancy and other relevant departments, form the national tide-observation network with 104 stations, which are effectively monitoring coastal storm-surge and sea level changes.

The State Oceanic Administration sates that oceanic prediction services began on October 1, 1966. Since 1974, storm-surge and tidal hazards warnings have been issued. Although some technical difficulties have arised during this time, storm-surge prediction and warnings, have been useful in saving the life and property.

5 Seismic Disaster Observation, Prediction/Forecast and Warning

The seismic precursor observation system comprises of 1300 professional and local stations of 3 different levels, namely the national, regional and provincial levels.

The main methods of observing and monitoring seismic precursors involve application of technologies in the fields of seismic metering, geomagnetism, deformation, and meteorology and the monitoring of the physical and chemical dynamics of underground water, terrestrial electricity, crustal stress, gravity, ground temperature and anomalies in living beings.

China's current state of earthquake prediction can be summarized as follows: some, though not all, types of earthquake can be pre-

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dicted with a reasonable degree of certainty and long- and medium-range earthquake prediction has attained a degree of reliability, though the successful rate for prediction of imminent earthquakes is still relatively low.

Compared with the developed countries, earthquake prediction research efforts in China are still lacking in several aspects, for example, in observation methods, measurement equipment, telecommunication and data processing technologies. There are, however, several advantages of the seismic monitoring, prediction and warning system: (1) There exist plenty of catastrophic earthquake instances, precursor data and the rich experiences in earthquake prediction earned by the Chinese people. Since 1966, thousands of precursor data have been collected from more than 70 moderate and severe earthquakes, and much experience has been gained in earthquake prediction. (2) On the basis of the prediction experience, the judgment, index and method of earthquake prediction have been standardized, and their procedure formulated. (3) During the period 1966–1976, there were several successful predictions of the Haicheng, Shongpan earthquakes etc. which were effective in reducing disaster losses.

Although much progress has been achieved in earthquake prediction and several instances have been successfully predicted, prediction level is still very low. In fact, among all of the earthquakes, only in a few cases can they be predicted correctly.

6 The Observation and Monitoring of Geological Disasters

Geological disaster monitoring involves the observation and monitoring of landslides, cave collapse, mud-rock flows, underground water levels, subsidence, underground water contamination and pollution, ground fissures or cracks, etc.

China has set up 3 tiers of geological disaster monitoring stations, namely, the National Monitoring Headquarters; the 30 monitoring stations at the provincial level, and the 160 substations at prefectural (municipal) levels, with a total staff of 2000 people. In addition, the nation has 19000 subterranean water monitoring posts or stations.

During the last few these years, much attention has been paid to the research and monitoring of landslide and cave collapse, and several large landslides have been successfully predicted or closely monitored. The most cited case is the massive landslide in Zi Gui County, Hubei Province on June 12, 1985. This landslide covered over 3000 m^2 and the township of Xin Tan Zhen was destroyed. With forecasting and evacuation measures, however, there was no human causality related to the event.

It is, however, still a worldwide problem to accurately predict landslides and much work, should be done in this field to find satisfactory solutions.

7 Monitoring and Early Warning of Biological Disasters in Agriculture and Forestry

The nation has set up more than 1900 monitoring and forecasting stations which are responsible for the forecasting and warning of crop disease, pests and rodents, with nearly 10000 full-time staff members. With the National Plant Protection General Station under the Ministry of Agriculture as the core, the monitoring and forecasting network is responsible for the monitoring, forecasting and warning of major biological disasters caused by plant diseases, pests, and rodents in the country.

To prevent the importation and spread of dangerous diseases, pests and noxious weeds, the nation has set up more than 240 animal and plant quarantine posts or stations at the ports of entry (in relevant harbors and airports etc.) and has, in addition, set up more than 1800 plant quarantine stations nationwide, with a total staff of more than 8000 professionals.

Concerning forest and grassland fires, China has set up, in major forest areas, a comprehensive network consisting of forest fire prevention stations, observatory stations and forest fire risk weather forecast stations.

To improve the quality of disaster prediction, monitoring and early-warning, and to increase disaster information exchange efficiency, the China National Center for Disaster Reduction will be established within the China National Committee for IDNDR, and bilateral and multi-sectional cooperation is hoped for. We are sure that the disaster early warning system in China could develop more quickly in the future.

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CHAPTER 1.3

The Human Factor in Early Warnings: Risk Perception and Appropriate Communications

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How much human *behaviour*, whether the interactions between persons themselves or between groups and groups, is intelligible in terms of human *experience*?

R.D. Laing

1 Introduction

The aim of this paper is to highlight one of the most important factors influencing the effectiveness of early warning (EW) systems – that is, how those who are at risk from hazards perceive that risk, and how this in turn influences their response to warnings. It takes particular note of how vulnerable people, principally in the Third World, assess risk in the context of their lives and livelihoods as a whole. The paper goes on to consider how, by taking such factors into account, EW systems might be made more effective. To achieve this, it is argued, conventional ideas about how to communicate with communities at risk need to be updated by drawing upon approaches that are used in many long-term development projects in the Third World.

This is a simplified overview of a complex topic and many of these ideas will be familiar to experts in this field. Nevertheless, it is useful to restate them at the EWC '98 conference, which has to consider how to overcome the challenges that lie ahead in improving the impact of EWs.

2 Early Warnings: the Process

Looked at very simply, the EW process has three inter-related stages (Smith 1996):

1. Evaluation/forecasting (observation and prediction), based on scientific expertise and advanced technologies (e.g. mathematical modelling, remote sensing). A great deal of effort and resources have gone into this stage, resulting in significant advances in some areas of forecasting. This stage is the scientific and technical dimension of EW.
2. Warning/dissemination, where forecasts are turned into messages and transmitted by appropriate agencies as recommendations for action. There has been considerable investment in this stage too. In particular, rapid advances in communications technology have greatly improved the speed with which warnings are transmitted. At this stage, EW acquires institutional and political characteristics.
3. Response, where warnings are turned into actions. The actors in this process are more numerous and diverse. They include officials at national and local levels, non-governmental organisations (NGOs), communities and individuals. This third stage sees the institutional and political aspects of EW broadening out and the EW process acquiring an essentially social dimension where the 'human factor' of risk perception and decision making plays a crucial part. It has not received as much investment as the first two stages.

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3 Community Responses

Two key elements in the success of an EW system are:

1. Forecasts must be accurate in predicting the location, time and severity of a hazard event.
2. Warnings must be disseminated in time for populations at risk to make themselves safe.

There have been great advances in both of these areas in recent years. However, even where EW systems do deliver timely and accurate warnings, people at risk may not respond as desired or expected. This indicates that there is a third key element of success in EW systems, that is often missing: appropriate communication of warnings, based on an understanding of communities' perceptions and needs.

4 The Social Context of Risk Perception

People at risk do make rational choices about protecting themselves from disaster. They do have a view of that risk. We cannot understand responses to EWs without first having a good understanding of this. Although hazard risk perception has been studied and debated since the 1960s (Smith 1996, Cutter 1993), further research remains a priority, particularly in Third World contexts (Rogge 1992). Here we should note two important points: the social dimensions of risk perception, and the diversity of views that this generates.

In vulnerable communities, events relating to hazards interact with a variety of social, psychological, institutional and cultural processes in ways that can heighten or attenuate perceptions of risk and thereby shape risk behaviour. This is known as the 'social amplification' of risk. It implies that the experience of risk is both one of physical or potential physical harm *and* the result of the cultural and social processes through which individuals or groups interpret hazards (Stephens et al. 1995; see also Cutter 1993). Individuals have their own 'worldview' or understanding of how the world works based on a combination of observations, information and ideas (conscious and unconscious). Within communities, there are many different worldviews and hence many different perspectives of risk which vary according to socio-economic differences in such aspects as wealth, social standing, level of education, age, religion, ethnic group and gender (Newton 1995). Personal and collective experience plays a significant part here.

We can see from this that risk perceptions are likely to vary considerably between different communities, and even within communities. This diversity presents a particular challenge to those who have to transmit EW messages over wide areas.

5 Lives, Livelihoods and Early Warning Response

It has been recognised for a long time that institutional response to EW forecasts is influenced by a variety of external factors – political, attitudinal, legal, economic or financial, logistical, ideological and institutional – that are unrelated to the scientific data (the recent study by Buchanan-Smith & Davies (1995) demonstrates how these have affected the functioning of famine EW and response systems in sub-Saharan Africa). If such factors influence institutional responses, it is only natural that they should also influence communities' and households' responses to EWs, yet our knowledge and understanding of this area remains limited, especially in Third World locations.

One of the principal socio-economic factors affecting response to disaster warnings in much of the Third World is, surely, the vital need to protect assets and maintain livelihoods.[1] The poorer and more marginalised a household is, the more important it becomes to hold on to its assets and property (such as livestock and household goods) and income (for a day labourer, every day's wages are vital in feeding the family or paying off debts to moneylenders). A household may perceive the risk of evacuation, in terms of losing control of its assets and resources, as more devastating than the risk of the hazard (especially where warnings are frequent but do not necessarily lead to disaster). The remark of a woman inhabitant of a *char* is-

[1] Some experts in this field have argued that there is no close correlation between levels of material wealth and response, and that social and cultural structures are the main determinant (Horlick-Jones & Jones 1993).

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land on the Jamuna River in Bangladesh is revealing here: 'During the '88 floods I remained alone here. Someone obviously had to look after the farm' (Schmuck-Widmann 1996).

But the picture is not that simple. Poverty is not necessarily a constraint on effective response to EWs. A study of risk perceptions among slum dwellers living in flood-prone districts within the city of Indore in India found that, in choosing where to live, the slum dwellers made a rational trade-off between the social and economic benefits of their location and the risk of monsoon floods. But the residents had also developed sophisticated monitoring and warning routines and had clear priorities for action in response. They believed these strategies were sufficient to cope with the floods (Stephens et al. 1995).

Two short case studies follow to illustrate the complex interplay of factors influencing people's response to warnings: some strictly technical, to do with the delivery of the warning message; others related to the response options available; others more contextual. The examples also demonstrate the diversity of local attitudes and responses to a single hazard event. They are chosen as contrasting examples of different reactions in quite different contexts. One is a well known and well documented example: the Bangladesh cyclone of April 1991. The second is not well known: the threatened outburst of a glacial lake in Nepal in 1997.

Bangladesh cyclone 1991

In April 1991 a major cyclone struck the coast of Bangladesh and 138000 people died. One major study carried out after the cyclone found that 95% of households surveyed were aware of the official cyclone warnings but only 17% of these responded by seeking shelter before the approach of the storm surge. Of those who did not respond, 45% did not believe the storm would be as severe as the warning asserted, 16% did not understand the warning and a further 16% had been prevented from seeking shelter by the high winds and floods. Other, less frequently given reasons included fear of losing property (i.e. from looting) and previous false warnings (Bern et al. 1993). A second study found that 70% of those who did not take refuge had not believed that a cyclone and storm surge of that magnitude would actually come, and while 36% of households had located places nearby to take refuge (such as shelters, private houses, public buildings, embankments and trees) most people 'did not move until the water was in their courtyard'. Some felt the existing cyclone shelters were unsafe or unpleasant and were unwilling to go to them until they were convinced of imminent danger. Previous false alarms were a major reason for refusal to trust the warning, and many did not believe a severe cyclone would strike at that time of year (Chowdhury et al. 1993).[2]

Notwithstanding the relatively low profile of economic factors in the two surveys, it is surely reasonable to assume that many people could not afford to abandon normal economic activity until the last minute, when there was no longer any doubt that the cyclone was about to arrive. The published surveys did not explore this dimension and did not differentiate responses according to wealth or types of economic activity. Closer attention to these aspects might have modified the picture.

In addition, the methods of data collection appear to have allowed the voice of male informants to dominate. Mortality rates from the 1991 Bangladesh cyclone were relatively high among women and children, for reasons which are not entirely clear. It may have been partly because of domestic and childcare responsibilities keeping women in the home, but was probably also a consequence of the culture of *purdah* which makes them reluctant to go far from their homes without their husbands, who may be away at work (Mushtaque & Chowdhury 1993; Bern et al. 1993; Haider 1992; Kabir 1995). Perhaps they also felt the cyclone shelters would be unsafe, or feared the lack of privacy there (cf. Shaw 1992). These and other possible contributory factors deserve further investigation.

[2] Subsequent research indicated that even where local inhabitants drew on their indigenous knowledge in observing natural phenomena to warn themselves about cyclones, few people took substantive precautions to survive at an early stage. (International Voluntary Services/CCDB 1994). Apparent disregard of warnings has been a notable feature of other cyclones, for example that in Andhra Pradesh in India in November 1996 (TARU 1996).

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Nepal glacial lake outburst 1997

In June–July 1997 there was considerable concern in Nepal about the risk that the natural dam holding back the Tsho Rolpa glacial lake could burst at any time during the imminent monsoon season, causing a sudden, massive and highly destructive flood that would hit some 4000 people in the river valleys below. Alarm spread quickly among government officials, NGOs and communities. Local officials advised thousands of people to evacuate in the lower valleys, prices shot up and down in local markets, traders and large numbers of villagers moved to higher ground, and flights to the local airport were suspended. There was general confusion. A large number of the people at risk had never heard of the lake and few had any idea of what to do or where to go if the dam burst. However, many did move from their homes, farms and shops, with all the attendant economic hardship that entailed (there were also incidents of theft and looting from abandoned properties). Other people were more cautious. They waited to see what wealthier people did before deciding. Some people with large amounts of fixed property chose not to evacuate because, they said, they could not survive if they lost their land. At the top of the valley, near the lake itself, villagers refused to heed the warnings and told the officials they were speaking nonsense. They trusted in their own observations of its rising water levels which were based on many years of experience. Some believed the lake was protected by God.

Overall, there was a rapid if sometimes rather chaotic response to the threat – but it was not in response to an official EW, because none was issued. There was not even an EW system in place for the Tsho Rolpa glacial lake at the beginning of the alarm. Scientific studies of the lake and the potential threat were carried out. However, the response of officials, NGOs and communities alike was triggered by media stories and politicians' public statements. The media and politicians were not technical experts but jumped to their own conclusions from the scientific data. There was no flood (Gyawali & Dixit 1997).

6 Problems in Understanding

If we can better understand the contextual factors and constraints that generate such diverse perceptions of risk and hence such diverse responses to all kinds of warning, this should enable us to make EW systems more effective. We should also be able to identify appropriate complementary interventions to reduce the impact of disasters. It is conceivable that, in some locations, we are putting too much blame for failure to respond onto the EW systems themselves when we should really be addressing contextual constraints through wider mitigation measures.

It is *very* hard to acquire this better understanding. A community's view of its own risk is very different from that of an outsider. Outsiders will find it very difficult to understand how communities perceive and react to hazards and risks. EW specialists are often not well equipped to understand such factors. There are several reasons for this.

The first is that EW specialists and communities look at a potential disaster from a completely different starting point. EW systems (forecasts and warnings) start centrally, at international and national levels, and then move outwards and downwards through the administrative system towards districts, sub-districts, and villages or neighbourhoods. In this perspective, individual villages or neighbourhoods are on the periphery. But for the individual at risk, their home and immediate locality are at the centre of the picture. This means that factors that are of primary importance to the villager or householder at risk are likely to be invisible to the system managers, who work on a much larger scale, while the manager's national or regional perspective appears irrelevant to the individual at risk.

The second reason is that the two groups measure and describe risk in quite different ways. Technical specialists draw upon scientific and engineering methods of analysis to quantify risk, principally in mathematical terms of probability. This esoteric language of risk is not understood outside the scientific community; it may not even be understood by officials and NGO staff who are responsible for disaster preparedness and response. It is not easy to translate such mathematical calculations into everyday language (such as 'high,' 'medium' or 'low' risk) for operational usage; indeed, this may only

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add to the confusion (Salter 1995/6). Disaster victims and potential victims measure and describe risk in more varied, qualitative terms.

A third reason is the common assumption among some disaster professionals that they alone understand and assess risk objectively (i.e. scientifically) whereas the disaster victims' understanding and assessment is merely subjective, even irrational, perception (Salter 1995/6). There are a number of problems with this attitude. One is methodological: it is not possible to maintain a clear distinction between 'objective statistical' and 'subjective perceived' risk because 'objective' risk estimation itself involves value judgements such as the definition of hazard events and the time/space sampling frame chosen for the events (Smith 1996). More important in the context of this discussion, such a perspective undervalues the knowledge of those who actually experience hazards on the ground. It also overlooks the social and economic forces that make some groups of people more vulnerable to natural hazards than others.

Anthropologists and others who try to immerse themselves in local cultures come closer to understanding community perspectives of risk but even here it may be hard to obtain evidence because communities do not express or explain themselves in the same way as researchers. For example, an anthropologist in a landslide-prone village in the Indian Himalaya was repeatedly told by villagers that landslides were not a problem even though from observation it was evident that they were. To find clues to their perspectives he had to interpret their religious rituals (Pilgrim 1996). A project looking at indigenous knowledge of house building in the Philippines found that local builders appeared not to understand the question when asked what design features they incorporated into houses to withstand high winds from typhoons. The considerable extent to which such houses were designed to be typhoon-resistant only became clear to the researchers when they watched a house being built (Hall & Bellers 1996).

7 Improved Communications

If we are going to acquire a better understanding of such matters, we will have to modify our approach towards communicating with communities at risk. It is commonly assumed that if people fail to respond to EWs, this must be because they do not fully understand the risk. Therefore, the argument runs, they must be better educated about risk, and where existing messages are not understood these must be repackaged in a way that makes them easier to understand. This approach sees risk education as a kind of public relations or public information exercise, where messages are transmitted from small groups of experts to the uninformed masses. This is still the dominant approach to risk communication (Salter 1995/6). Nobody would deny that improved public education is very important, but this, by itself, is insufficient because the dominant communications approach is not informed by communities' experiences and perceptions of risk or their socio-economic context – yet these are the factors which have such a powerful influence on their response to EWs.

Here we can learn from agencies working in Third World development. For many years, they assumed that by distributing information among poor communities they could stimulate social and economic progress. If new ideas and technologies were not taken up by communities – which happened all too often – this was because the communities did not understand them properly, and so the challenge was to find better ways of presenting the information. Although there were debates about the most effective techniques for delivering information, the basic approach was not seriously challenged until the 1980s when it became increasingly evident that one of the principal reasons for project failures was that the development specialists had themselves failed to understand the communities they were trying to help: their needs, priorities, and indigenous knowledge and capacity. The information and ideas that they were promoting were, therefore, often quite inappropriate. During the 1990s there has been a growing emphasis in Third World development on dialogue with communities; development workers accept that they have to listen to the people, that problems and solutions must be identified collectively (Melkote 1991).

A similar approach is now needed for developing and improving EW systems so that they meet the needs of those they seek to protect more effectively. This will not be easy. It involves cross-cultural communication between outsiders (disaster professionals) and people at

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the grass roots. There are many difficulties and potential pitfalls here (Fuglesang 1982). It involves some humility on the part of the outsiders, in that we have to recognise our own ignorance of other people, and accept that we can never fully understand the disaster victim's perspective (M. Bhatt 1998). But, when given suitable encouragement, vulnerable people can explain their perspectives clearly to outsiders (e.g. E. Bhatt 1998).

Appropriate communications tools are needed to open up this kind of dialogue. We will have to adopt new tools and methods. Conventional surveys of public opinion on EWs are valuable in identifying strengths and weaknesses of systems; so too is the newer stakeholder analysis approach of interviews and focus groups; and there has been some good work in these areas.[3] In general, though, these tend to be one-way information-gathering processes.

In order to fully understand vulnerable people's views – and especially the all-important social, economic and cultural contexts of their perceptions – we need to develop the dialogue much further, beyond stakeholder analysis and towards stakeholder participation, which is an essential element in making EW systems effective and sustainable. 'People at risk need to be involved in the design, development and operation of *their* warning system. This develops confidence in the system, understanding of the roles of various agencies and how people can assess the information they need.' (Bureau of Meteorology and Australian Emergency Management Institute 1993).

The 'process' approach used in Third World development provides us with an effective set of tools for doing this. The approach is based on Participatory Rural Appraisal and similar techniques applied at local (i.e. village, community) level. Participatory appraisal techniques are a package of different activities in which community members analyse the various dimensions and dynamics of their society. By drawing on people's understanding of their own situation it produces data that is usually more comprehensive than that acquired through conventional survey methods. In addition, the process serves the community by structuring its understanding of problems and priorities, and enabling it to identify possible solutions (Hall 1998). Ideally, it is a dynamic, iterative process stimulating regular rethinking and improvements, not just a one-off assessment. There is no shortage of appropriate participatory techniques available, and there are many development experts who can advise on how to use them. There would be added value here in getting disaster professionals and experts in long-term development to work together – this has happened all too infrequently during the IDNDR.

The Benfield Greig Hazard Research Centre is currently working on a project to improve analysis of risk and vulnerability at community level. The project is testing and adapting some of the participatory techniques used in long-term development. One of the techniques tried out by the project during an earlier pilot phase was a simulation exercise with villagers in the Philippines to find out how they had coped with a major cyclone, Typhoon Ruping. The simulation provided valuable insights into how villagers had learnt about the impending typhoon, their subsequent actions to protect property and assets, and their evacuation plans (Bellers 1996).

We can also learn from development agencies' experiences of using a range of different communications techniques and media (such as radio, theatre, exchange visits and photography) to reach the poorest and most vulnerable groups in society. However, further research and testing is needed to identify which of these are best suited for work with hazard-prone communities.

All of these methods require more emphasis to be put on work at local level, recognising that risk patterns can exhibit great variations even over small areas, and that individual communities have different structures, attitudes, economies and needs. The need for more decentralised systems was emphasised in the United Nations Secretary General's recent report on EW (United Nations 1997).

[3] For example, the public surveys for flood warnings commissioned by Britain's Environment Agency (Bye & Horner 1998: Appendix C), the public opinion survey in Costa Rica following Hurricane Cesar (Molin Valdes 1997), the community interviews carried out in Montserrat on volcano warnings (Sanderson & Buckley 1988) and the stakeholder analysis of cyclone warning systems in Mauritius (Parker & Radwan 1998).

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8 Conclusion: Towards Consumer Choice

Most EW systems take a supply-side approach to communication, seeing it as a process whereby experts at the top or centre issue information outwards and downwards to target groups. In the modern age we need to move away from this to a more demand-led approach that sees communities at risk as *consumers* of information from different sources, exercising a right to choose what information to use and where to obtain it.

Experts are often concerned about the growing diversity of unofficial sources of hazard and EW information, especially satellite and cable television and the Internet. They fear that this will lead the public to act upon inaccurate information, or that information from one source will contradict that from another leading to confusion and hindering emergency preparedness efforts. This is a valid concern. The case study from Nepal cited above shows the damage that misinterpretation can do. However, market forces are now as influential in information dissemination as they are in other walks of life. The globalisation of information is a fact of life. Access to information cannot be controlled as it has been in the past (except perhaps under authoritarian regimes where in any case the public may not trust 'official' sources). Disaster managers in future will have to acquire extensive skills in media management.

We can gain a more optimistic glimpse of how such a consumer-led world might work at its best from an important study carried out recently for the British NGO SOS Sahel. This looked at the dissemination of information on the 1997–8 El Niño event and its likely impact on drought in Sub-Saharan Africa. Although the researchers looked principally at responses by governments and international agencies, they also found that in some African countries, farmers were acquiring information independently from a variety of sources, including the Internet and cable television; they were forming their own judgements on the validity of that information; they were then making calculated decisions about what types of seed to plant, and when; and they were acting upon those decisions. This was despite the fact that it is not easy for the layman to interpret some of the available meteorological data on El Niño, and despite African farmers' often sceptical view of the accuracy of weather forecasts (Thomson et al. 1998).

For all the potential problems, we should take a positive view of such developments. Participation empowers people and makes experts accountable. If EW information systems are developed on the basis of dialogue with stakeholders, they will not only be more reliable but they will be more credible as a result. They will then become the consumer's preferred choice of forecasting and warning advice.

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CHAPTER 1.4

Scientific Contributions to Effective Early Warning in an Environmental Context

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Abstract

Whenever there is an environmental disaster, efforts are made in every direction, largely to manage a crisis situation. Often there is no time to attribute blame or indeed to determine where the system went wrong. But ultimately, when the crisis is over, it helps to take stock of what happened, what should have happened and why it did not happen or why it was not effective if it did happen. Then finger pointing starts. The policy makers, scientists and public begin to blame each other, but in the end, the public is left bewildered and compromised.

This paper seeks to highlight the role of science in Early Warning Systems for environmental disasters. It will flag the problems in, and indeed barriers to, communications between scientists, policy makers and the public. The paper starts off on the premise that science needs to be the basis of most policy responses to environmental disasters. It then attempts to identify communication barriers between the policy maker and the scientist; and the public and the policy maker. It is suggested that impact and vulnerability assessments could constitute a possible avenue to bridging the gap between the scientist and the policy maker; the policy maker and the general public and, the scientist and the public. The capacity to respond to a given environmental disaster, is also an essential ingredient for effective use of Early Warning Systems. It is argued that in many cases the finger pointing is the result of a system that lacks the resources to respond to a disaster and would wish to ascribe inability to be proactive to limited or unavailable information from the specialist. The need for political will, proper governance and accountability are also identified as barriers to effectiveness of Early Warning Systems.

Examples, largely from weather/climate related disasters are cited to support some of these hypotheses.

1 Introduction

It is only recently that scientific inquiry has received the attention it deserves in addressing national issues especially national development needs. But even this realisation has yet to spread to much of the developing world. It is often very unpopular in most developing countries to seek resources for scientific research for an organisation, it being generally assumed that research is, by and large, irrelevant theorising that offers no immediate remedy to pressing national needs and problems. It is further generally believed in some circles that funding for scientific research should be limited research of an applied nature: that is, research that addresses immediate national needs and problems. The view here is that a developing nation can ill-afford the luxury of theoretical research

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often attributed to scholars who appear more interested in theoretical gymnastics that in the solution of immediate national problems.

There are other problems related to the use of science in the development process. These problems relate to the nature of scientific inquiry. It is slow, albeit sure, but the policy maker is impatient for results because he has to deal with real problems usually in a crisis mode. There is also the problem of communication. Science when it informs policy is hedgy. The policy maker disregards the hedging, takes the findings as gospel truth and when it fails abandons the need to refer to the scientist for future policy application in the solution of any problems.

We suggest that there is a critical need to bridge the science/policy interface, and that impacts and vulnerability assessments provide the necessary bridge. These assessments, however, must be based on well-known scientific facts, hence the need to continue to support scientific inquiry. While economic issues take precedence in early warning, we suggest that the natural environment is equally important. Sustenance of ecosystems and preparedness to protect these systems indeed constitute an effort to protect the economic well-being of a nation.

Natural disasters can be predicted, some to a greater and some to a lesser extent. Notwithstanding their predictability, an assessment of their impact, i.e. determining that the disaster's intensity and spatial spread, is important. Response strategies and preparedness measures can, however be expensive, and hence the need for science to inform policy on the intensity and specific locality where the disaster will take place. This paper analyses the issues attending early warning and its relevance for environmental wellbeing. It addresses the problem of communication breakdown between scientists, policy makers and the public.

2 Science and Early Warning in Natural Disasters

Our understanding of many natural disasters is not necessarily complete. The scientific community is in a continuous state of flux with regard to our understanding of these natural disasters. Occasionally we experience quantum leaps in our body of knowledge, but by and large the understanding curve is gradual. Because of this, predictions of the intensity, spatial extent and timing of specific disasters are not definitive. Droughts and floods resulting from such natural climate events as the El Niño or La Niña can be predicted reasonably well, but the intensity of impacts of such events on weather is difficult to predict with much degree of accuracy in as far as such impacts are region specific.

2.1 Scientific Limitations and the Problem of Communication

Science develops gradually, but in the meantime natural disasters occur, and response measures must be taken using available knowledge. Often times, after a few wrong or inaccurate predictions of the timing, intensity or location of a natural disaster, a confidence crisis develops between the scientist and the policy maker. Furthermore, because the policy maker took a public stance on a particular natural disaster on the basis of scientific prediction which did not verify, a confidence crisis develops between the policy maker and the general public, leading to a three-way breakdown in communication.

While the confidence crisis develops, leading to breakdown in communication, the science improves but continues to be disregarded by the policy maker and even the general public. The tragedy here, is that while science was developing and improving, nobody noticed, and when it could have been taken advantage of, it was disregarded as inaccurate and irrelevant. A case in point relates to the prediction of the impacts of the recent El Niño in Kenya. Prediction had been made of possible floods. Radio and television interviews had been given to forewarn of the impending heavy rains. Not much notice was taken of these forecasts at the policy level. The devastating floods that attended the short rains seemed so unexpected that the usual response "the scientists did not tell us it would come, or that it would be this intense." This is partly true and partly false. They were told it was coming, but the exact intensity and impacts were not predicted.

Tapscott (1993), in a paper on early warning, specifically states that early warning must "warn," and be "early." He means that any early warning must be communicated accurately and in a manner that will be interpreted unequivocally by the target audience. The most current

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scientific understanding of the natural phenomenon must be brought to bear in the early warning process. Despite the fact that some scientific mistakes and shortcomings may have been noticed earlier, the policy maker must, "keep the faith," as it were. This is important because science evolves gradually, sometimes too gradually for an impatient policy maker who must deal with crises that arise out of natural disasters.

A good example of "usable science" is the work on El Niño Southern Oscillation (ENSO) and its resultant impacts on weather throughout the world. Scientists have recognised ENSO as a coupled ocean-atmosphere phenomenon which plays an important role in seasonal-to-interannual climate variability (Wallace et al. 1998). This realisation was not the result of a single dramatic scientific breakthrough, rather it has developed out of a series of studies carried out over a period in excess of sixty years.

The breakdown in communication seems to arise out of the caveats that scientists put on their predictions. Such caveats depend on the degree of confidence the scientists attach to their prediction of an impending natural disaster. Not well versed in the specific science, the policy maker may take a forecast as given, disregard the caveats, and proceed to prepare for the disaster. After a forecast fails, the policy maker considers in retrospect the investment in preparedness measures, which are found to be not cost-effective. The enthusiasm for scientific guidance dies, and the tendency is to proceed without reference to expert opinion.

2.2 Scientific and Policy Research Priorities

We have already made reference to a confidence crisis that could arise out of previous failed application of scientific predictions and information on impending natural disasters. We have observed that, most of the time, this is the result of limited scientific understanding which improves only gradually. Limited or not such information is very important, providing that the confidence level of the information is known, and its application made within that limitation.

On the scientific front, continuous and persistent efforts should be directed at:

- improving the data bases for further research,
- greater spatial and temporal resolution,
- more refined assessment of the probability of occurrence of specific natural disasters.

With regard to policy research, emphasis must be placed on preparedness measures, and on policy formulation and response processes. It is often the case that policies are formulated without involving all stakeholders. Such policies are difficult to implement in response to a natural disaster because the stakeholders most vulnerable or most capable of responding were not party to the policy formulation. The result is a disorganised, panicky approach in responding to a disaster. In such a situation more damage is done than good by adhering to a policy whose origin or essence is not well-known.

In the case of climate-related natural disasters such as floods and droughts research should address issues that for example, enable, (Parry et al. 1988):

- the screening of environments or ecosystems on the basis of rainfall variability and enable the identification of broadly homogenous agro-climatic zoning as a basis for agricultural planning;
- the tracing of the effects of altered climate (drought or floods) on crop yields, on gross production, on farm profitability and on regional competitiveness – to mention just two.

From the point of view a policy, particular attention must be paid to other constraints such as national agricultural policy, pricing of agricultural products and other social considerations such as stable foods and how this will affect vulnerability of societies to impending drought or floods.

3 Impacts and Vulnerability Assessments

Notwithstanding the emphasis that has been laid on the need for science to inform policy, policy decisions are best made when the risks associated with an impending disaster are known, and when the impacted systems or communities are known as specifically as possible.

Recent work on impact assessment emphasises an integrated approach, focusing on the interactions between a potential natural disaster and human activity. Earlier work concentrated

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on assessing the direct impact of a disaster, say drought, on an exposure unit say, food crop. As much as specifying the exposure unit helps identify primary impacts and define natural vulnerability, secondary impacts and overall vulnerability are the result of considerable interaction between natural processes and human activities. The IPCC (Watson 1998) has defined vulnerability as "the extent to which a natural or social system is susceptible to sustaining damage from climate change" (call it natural disaster in our case here).

However, if we discuss the vulnerability of the Amazon forest to drought, we must consider the social and economic stresses that such a forest is subjected to. A drought introduces an opportunity for arson for those adjacent communities that wish to exploit forest land for agricultural activities. Its vulnerability is therefore enhanced by these socio-economic pressures. The vulnerability of the Congo forest to any severe weather event is also governed by the ongoing internal civil strife in the country. Much as the Indonesian forest fires have been blamed on the 1997/98 El Niño, there is some suggestions that the need for logging played some role.

3.1 Impacts and Vulnerability Assessment in Early Warning

A disaster results when an event such as a drought, flood or earthquake strikes a vulnerable population. A vulnerable population is one which, because of geography, economic situation, or limited access to resources, finds itself susceptible to such a disaster. A highly vulnerable population will be seriously affected by an even less severe natural disaster. The impact of a natural disaster on infrastructure and community is specific to the nature of the infrastructure, its location and degree of vulnerability. But vulnerability is not static, it is dynamic. A very vulnerable community can be made less vulnerable by simple policy intervention. Similarly, a community that was not vulnerable to famine can quickly become vulnerable in the event of war or other civil strife. Impact and vulnerability assessment can therefore provide the bridge between science and policy.

3.2 Bridging the Gap

How do impact and vulnerability assessments bridge the gap between science and policy? The study of the nature of natural disasters falls in the realm of scientific inquiry. Such inquiry delineates the nature of a phenomenon, its origin and possible predictability. In itself, such information does not particularly help the policy maker to take action. The necessary information on El Niño is not how it forms, interesting as it may be at the scientific level, but what it will do when it forms. Where it will have impact and the nature of such impact. The prediction of the evolution of El Niño in time and space, its intensity and potential impacts are the essential elements in the information package to the policy maker. Decisions on what to do are governed by:

- An assessment of the impacts of any natural disaster.
- An assessment of the vulnerable communities, structures or ecosystems.
- An estimate of preparedness needs and associated costs.
- An estimate of possible response options, their respective costs and modes of strategic intervention.

To make the above assessments, it is critical that a whole array of players, scientists, sociologists, anthropologists and policy makers join in an integrated partnership to address the threats posed by an impending disaster. Insufficient understanding of what science has to offer, or poor communication between the decision maker and the scientist inhibits the effective use of scientific information for early warning and disaster management. Dialogue between the scientists and policy makers is essential, but it is also necessary that such dialogue be regular as part of national disaster preparedness planning and the multidisciplinary implementation process.

3.3 Early Warning and Disaster Forecasting

We started off by pointing out that early warning must have two attributes. It must be "early" and must "warn." The scientific community seems to confuse the forecasting of an impending natural disaster with early warning. There

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is always the risk that the forecasting process will focus on the natural determinants of impacts, and distract attention from factors which shape vulnerability to such impacts – namely those related to human activity. A lot of attention may be focused on prediction of an extreme event, but the ultimate determinant of impact of such an event will be the socio-economic status of communities, government policies, cultural attitudes and attributes, etc.

Early warning systems allow short-term actions to be taken which either reduce vulnerability, such as evacuation from the risk area, or that increase preparedness (Dilley 1994). Walker (1989) identified four key elements of an effective early warning system, namely:

- detecting, evaluating and predicting a hazard. This involves the array of "tools" used in the process of forecasting a disaster including those related to say climate (remote sensing) and food availability (nutritional surveillance, food balance models etc.);
- constructing a forecast or warning message: this entails the preparation of warnings that are easily understood, which specify the exact nature of the impending threat, identify those most at risk, and are consistent in their emphasis (i.e. not contradictory);
- spreading the warning message: to be effective, information on an impending hazard must not only be accurate, but must also be communicated through the correct (call it appropriate) channels;
- creating appropriate preparedness and mitigating responses.

4 Early Warning and its Environmental Significance

In order to discuss the relevance of Early Warning in the environmental context, we shall refer specifically to recent experiences of the El Niño Southern Oscillation (ENSO) event. Fire hazards to ecosystems, notably forests, are strongly influenced by climatic factors such as precipitation, temperature and wind. It is, however, also site specific. Fire risks are weather driven, but in opposite directions, especially when we consider moisture as a specific parameter. Plant growth provides the fuel for fires, and to have plant growth you need rain. And the more fuel you have the greater bio-mass you generate and, therefore, the more potential fuel you have for combustion. Less moisture means more dead plant matter, drier fuel and greater fire potential. A climate that oscillates between wet and dry provides the best potential for fires such as those that occurred in Indonesia.

ENSO, by facilitating alternation between El Niño and La Niña, provides the oscillating force necessary for fires (Robinson 1994). It is this characteristic of ENSO events that makes the study of ENSO "Usable Science." For the science to be usable, there is a need for the research community to remain in close contact with the user community.

5 Conclusion

This paper has attempted to discuss issues relating to Early Warning in an environmental context. The discussion has focused on the science/policy interface and identified some of the problems related to communication. It has been suggested that impacts and vulnerability assessments might provide the necessary linkage between science and policy. It should, however, also be recognised that the interface is something of a continuum, and that the impacts and vulnerability assessments themselves provide an opportunity for science/policy interaction.

Early Warning could greatly benefit from science, but it is important that policy takes advantage of such science, with its limitations, in decision-making. Examples exist now where science has informed policy on many natural disasters. There is, however, still room for improvement in communication between the scientist and the policy maker.

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CHAPTER 1.5

Natural Disaster Early Warning: The Role of NGOs

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Abstract

Inadequate information, poor infrastructure and lack of sufficient human and financial resources are hampering the implementation of early warning systems in Africa. Most African countries rely heavily on donor funds to carry out research and modelling activities necessary in the early warning systems, and donor aid to assist disaster victims. Currently, donor funds have declined substantially.

In Kenya, for instance, research centres involved in natural hazards studies and monitoring are donor funded. Information regarding impending disasters is communicated to the government through the Office of the President. The government then uses available mechanisms to send warning signals to the public. However, in many cases the information hardly reaches the public. Yet the public are the main victims when the disaster occurs.

Non-Governmental Organisations (NGOs) work at local level with the communities and policy makers. They mobilise communities, provide training, information and advocacy services. They are in a better position to abridge the link between researchers, policy makers and the communities in sending early warning. There is need to empower local NGOs through capacity building so as to play a greater role in providing relevant information on natural disaster, linking scientists and policy makers with communities and advocating on behalf of the communities on effective natural hazards management.

1 Introduction

Despite advancements in technologies used in forecasting and predicting natural disasters, many developing countries, including Kenya, have not been able to reduce the severity of predictable natural hazards. This is perhaps due to the fact that the warnings of impending catastrophes are either ignored or the needed resources are not mobilised early enough before the disaster occurs. Some of the known natural disasters include wildfires, earthquakes, landslides, volcanic eruptions, floods, hurricanes, tsunamis and tornadoes. Many developing countries are prone to high degrees of vulnerability to these natural disasters. When these occur there is loss of lives, loss of livestock, destruction of property and infrastructure and outbreak of diseases.

Natural disasters affect the public in various ways such as loss of lives, loss of livestock, destruction of property and infrastructures, The recent El Niño rains which affected many parts of the world is a very clear pointer. The El Niño rains of 1997/1998 in many parts of the world disrupted agriculture, water resources, fisheries, forestry, and infrastructure, caused loss of human life and livestock and destroyed personal properties worth large amounts of money. However, the World Meteorological Organisation (WMO) which undertakes the generation and exchange of information on weath-

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er and climate says that with a better understanding of El Niño, farmers could sow and harvest following its seasonal predictions and thus reap enormous benefits from the phenomenon. One of the positive scientific advancements in the past years is the ability to forecast the evolution of El Niño 6 to 12 months in advance (Ogalo & Ambeje 1998). These forecasts are available at many global climate centres. These forecasts can be used to minimise the socio-economic impacts of El Niño. Studies aimed at the early prediction of El Niño would facilitate early preparedness for its effects.

El Niño is a recurrent phenomenon, although with variability, but has tendencies on which decisions can be based. Research is needed to study periods leading to El Niño events that are critical for preparedness. With the current studies it is becoming feasible to develop policies to bridge the effects.

A report in the Daily Nation of 12th February, 1998, quoting a UNEP report on the El Niño phenomenon tells how Ethiopia managed to avert a national famine by taking early precautionary measure. Meteorologists in Ethiopia studied US data on El Niño to assess how it would affect the weather conditions in their country between 1986 and 1987. On the basis of a prediction of good spring rains and a failure of summer rains, the government issued seeds, fertilisers and other agricultural assistance to farmers in good time for the spring planting and production increased by one third.

2 Role of NGOs in Natural Disaster Early Warning

Non-Governmental Organisations (NGOs) are known world-wide to be involved in activities with communities. NGOs work at local level with the communities and policy makers. They mobilise communities, provide training, information and advocacy services. On the natural disaster front, NGOs are known to be involved in evacuation, distribution of foodstuff, medicine, clothing and other relief supplies to the affected people. However, most of the NGOs involved in these are often international NGOs such as OXFAM, ACTION-AID, Médecins Sans Frontières, the International Red Cross, because they have the financial and human resource capacity to undertake these activities. Due to lack of financial and human resource capacity, local NGOs play only a minor role despite the fact that they know the local conditions better. Local NGOs are in a better position to abridge the link between researchers and the communities in sending early warning systems. There is a need to strengthen NGOs capacity to play a key role in information dissemination at the community level.

2.1 Justification for Local NGOs Participation

There are several main areas of activities where local NGOs have strong contributions to make, such as:

- Information and awareness promotion;
- Preparation of community actions;
- Monitoring and evaluation of natural disasters;
- Partnership building with stakeholders;
- Establishing mechanisms to link communities with policy makers.

2.2 Constraints to NGOs Efforts in Early Warning Systems

- Lack of access to information: For NGOs, lack of access to scientific information in good time is a major problem. In Kenya, the scientists concerned relay such information to the Office of the President. This system dictates that only the government has the knowledge of the likely occurrence of a natural disaster in advance. This can frustrate NGOs efforts to send out early warning. Lack of information thus reduces NGOs access to other tools necessary for assisting communities such as relief facilities and technology until the disaster has occurred often with serious consequences.
- Lack of decision making: NGOs are rarely represented at the committees that address natural disasters, and therefore have no access to the decision making process even on matters that concern the people they work with.
- Lack of clear coherent policies drawn-up to involve people living in potentially dangerous zones.
- Lack of awareness of the natural hazard.
- Lack or ignoring early warning.

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- Lack or inadequate capacity for NGOs and CBOs to facilitate community participation in early warning systems.

3 Strengthening the Role of Local NGOs

- Involvement of NGOs in research and decision making process is not only justified from the moral point of view, but can also be demonstrated that to curb severe impacts of a natural disasters requires full participation of all stakeholders.
- Strengthening NGOs through capacity building and training programmes aimed at better informing decision makers and the general public on natural disasters and other environmental problems.
- NGOs assist in the inventorying and documenting of natural disasters and updating them.

4 Conclusion

Despite the various constraints, NGOs play an important role in disaster early warning, consequently help minimise the damages likely to be caused. NGOs are involved in education and training and awareness raising activities at community level, as well as such activities like supply of food and other relief supplies during disasters.

- NGOs increased participation is thus inevitable, if we are to succeed in the early warning. There is need for deliberate action to be made in order to strengthen their participation. One key action is to provide them with training and information. Because NGOs have a wider knowledge and experience with working with communities, they are potential cornerstones for minimising destruction, but they need training in such areas as evacuation. Once trained, NGOs can play a key role.
- Public awareness is critical in disaster preparedness. NGOs need to be strengthened in terms of capacity building so as to be fully able to carry out disaster monitoring and assessment.
- NGOs should serve as a member of disaster preparedness committees.
- More accurate disaster magnitude information is needed to define more precise action to be taken. Unfortunately such information is never available and magnitude is only assessed based on extent of destruction caused.
- Efforts to effectively pass on forecasts and advise those at the community level are hampered by shortages of manpower.
- Many developing countries preparedness to cope with disasters such as El Niño is very wanting. Accurate weather and climate information provides an essential support to general public in their development activities.
- Given details of the anticipated disaster, the public would be able to be prepared and thus avoid heavy loses.
- Need for education and awareness programmes targeting the vulnerable public.
- Governments has not been prepared in dealing with emergency situations alluding to natural disasters.
- Currently there are no clear policies that address occurrences of natural disasters. The lack of policy regarding natural disasters makes it difficult for hazards to be addressed in other policy documents.

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Community Mobilisation for Early Warning in the Philippines

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Abstract

With regard to certain hazards the communication of an early warning to the population at risk could save lives and mitigate damage, but only if the warning actually reaches the people in danger and if they in turn heed the warning before the threat occurs. What happens if the specific warning fails to reach the vulnerable communities? How should the people respond to the impending threat?

This paper is about how a community in the Pinatubo affected areas managed to survive in the midst of lahar[1] threats by using community-based approaches to disaster preparedness. It deals with the people's capacity to take upon themselves the responsibility of monitoring hazards and issuing warnings to save the entire population of their respective communities.

1 Introduction

As dramatically demonstrated by the Mt. Pinatubo eruption, the aftermath could be even more threatening and devastating than the eruption itself. With this in mind the population of the endangered communities acknowledged the necessity for disaster preparedness with the increased threat of lahar events during the rainy season. The residents of two communities in the towns of Porac and Bacolor, both in the province of Pampanga were saved by the timely warning issued by their People's organisation (PO). The PO leaders and members, who were earlier trained by Non-Government Organisations (NGOs) alerted the residents to evacuate the region during the most critical time. After an hour, large portions of the two villages were completely under lahar, but no one died. The early and timely warning saved the lives of people of both villages.

The main argument of this paper is that early warning could be more effective if the threatened population is made aware of the hazards they face and community-based approaches in disaster preparedness are put into practise.

Information used in this paper is based on data from reports of the NGOs who implemented disaster preparedness programs in the affected areas and from various reports of government agencies directly involved in Mt. Pinatubo. Non structured interviews were also conducted, with local residents of the affected communities and with NGO staff who assisted

[1] An Indonesian term defined as a rapidly flowing mixture of rock debris from a volcano, and may refer to one or more discrete processes such as debris flow and hypoconcentrated stream flow (Smith & Fritz in PHIVOLCS).

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them. However, gathering of the details of the specific events was somewhat limited because some key informants are now relocated to different resettlement sites. Likewise, there were no documents to refer to with regard to the experiences of the people. The purpose of this paper is to encourage the recognition and practice of community-based planning methods for disaster preparedness. This paper also presents some lessons learned from the experiences of both local residents and those who were involved in helping them.

2 Today's Imperative: Effective Warning System

Disasters associated with natural phenomena are major human and development issues. For the past twenty years, UNESCO (1993) estimated that up to three million people have been killed and up to one million people have been affected by these disasters. Consequently, these tragedies have resulted in incalculable human sufferings and reversed years of development gains. Therefore, there is a pressing need to accurately predict hazards and reduce the devastating effects of disasters. Early and timely warning plays a significant role. Likewise, it is essential that vulnerable groups can understand and interpret warnings, and thus save their lives and their possessions.

Early warning is an important activity within the general scope of disaster preparedness. An early warning is issued only after detecting the forthcoming hazard based on careful analysis of geological, meteorological, and atmospheric interactions and processes. Monitoring and predicting hazards involves scientific and technical skills, knowledge and expertise. Issuing alerts involves communicating the forecast by translating the findings into terms understandable to the general public.

2.1 Purpose of Early Warning

The purpose of early warning is to alert the population-at-risk or vulnerable sectors of a community of an impending threat and thus, to bring about an appropriate response that could minimise exposure to hazard. However, an appropriate response is possible only if the target population is prepared and have the capacity to take timely action. Warning is intended not only for the would-be-affected population but also for the Government and Non-Government Organisations (NGOs) whose mandate is within the scope of disaster management.

Early warning is an opportunity to educate people about hazards, its causes and consequences. In Mt. Pinatubo affected areas, the warning authority has two types of warning: the lahar hazard maps which serve as an intermediate or long-term warning issued weeks, months, even years ahead; and short-term lahar alerts intended to warn endangered inhabitants hours to minutes before hazardous lahars (Tayag et al. 1994). The long term warning, which explains the areas to be affected by lahar flows and floods, can be used by concerned agencies to create risk scenarios. It then guides them in formulating their preparedness plan. From the NGOs perspective, this long term warning can also be considered an early warning.

Early warning also serves as an entry point for Disaster Response NGOs to pursue their mandate of assisting vulnerable communities. It gives them an occasion to conduct training on disaster preparedness and organise target communities. It then becomes a learning opportunity both for the NGOs and the communities.

Though most disasters are natural in origin, it is also an acknowledged fact that disasters occur because of the vulnerability factors such as physical environment and socio-economic conditions. In this regard, early warning can be considered another opportunity to undertake development interventions that will reduce current and prevent future vulnerabilities.

2.2 Early Warning System (EWS)

The early warning system consists of several processes: monitoring hazard, forecasting events and communicating information through warning and alerts. "While hazard monitoring consists of measuring the probability of a hazardous event with determined attributes, occurring in a given place within a given period of time, hazard forecasting involves in addition, predicting or warning that an event with given parameters may actually occur" (Maskrey et al. 1997). In the Philippines official monitoring and forecasting related to weather disturbance

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and volcanic activity is the responsibility of the Philippine Atmospheric, Geophysical, Astrological and Services Administration (PAGASA) and Philippine Institute of Volcanology and Seismology (PHIVOLCS) respectively, both national government agencies. Their messages are relayed to the public through the mass-media, government agencies and NGOs, which have access to them.

The progress in modern communication technology has made imparting a warning message easier. Properly and correctly communicating the warning can help the concerned agencies in activating its counter disaster plan and can contribute to overall risk reduction. However, most of the people in the developing countries, (the most probable victims of disasters), do not have access to the sophisticated communication technologies. Thus, community based timely warning system should be in place. It does not mean, however, that the local people should be knowledgeable of the scientific and technical aspect of monitoring and prediction. It means that the local residents should be informed in general, of the probable disasters that may happen in their respective areas based on the geophysical, environmental and economic vulnerabilities present as well as on the historical and experiential information on hazards that normally occur in their villages. From this information, the community can draw a hazard map, formulate a counter disaster plan and set up its own structure or organisation focusing on disaster preparedness. The system should be practical, relevant and useful to the most vulnerable groups.

2.3 Effectiveness of Early Warning

The effectiveness of early warning highly depends on peoples' perception of the coming danger, level of understanding of the hazard type and acceptance of the warning issued to them. Equally important is the credibility of the agency, whose reliability in alerting the public is measured according to its track record in prediction and warning. Moreover, "the usefulness of an early warning system is judged not on whether warnings are issued per se but rather on whether warning facilitates appropriate and timely decision-making by those at risk" (Maskrey et al. 1997).

Smooth Information flow to and from the warning authority can contribute greatly to the effectiveness of an early warning system. Through the information flows in the communication system, data can be validated or corroborated at the local level as in the case of a tropical cyclone in India (Box 1). Information on a threat could also come from the threatened people themselves as in the case of the Mt. Pinatubo eruption (Box 2). A disaster Information System should be active all the time prior to any disaster event.

Box 1: Experience of CASA India
The first forecast (early warning) of the 1990 cyclone (4th of May) immediately set off warning signals in the organisation. The Director called for a meeting of the senior staff to work out CASA's tentative response. Most decisions were immediately executed on the phone to meet the demands of the potential emergency situation. Reports from staff in the likely disaster areas started streaming in and they corroborated the cyclone forecast. It became clear that they were in for a major disaster. Vulnerable people from the shoreline and low lying areas in Madras and Machilipatnam started to evacuate. CASA's emergency response machinery was all set. The field staff actively participated in evacuating and feeding the 7000 potential victims.

Source: Fitzpatrick 1994 "Communicating Emergencies"

Likewise, since all disasters are local, early warning's effectiveness is determined at the local level, by how the authorities and residents respond to the warning of impending threat. Due to their experience residents of disaster-prone communities are familiar with the hazards that usually hit their locality. They have developed a disaster culture, which can be both an advantage or a disadvantage. If they become watchful of the danger that looms before them, they could be prepared when the alert is issued. However, if they are complacent either because of their doubts as to the accuracy of forecast or because of their "expertise" in dealing with hazards, they could be in danger of becoming victims.

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Box 2. How the eruption was predicted
As Mount Pinatubo was considered dormant before it erupted in 1991, it was not covered by the regular monitoring network of PHIVOLCS. Consequently, the initial signs of restiveness which the volcano manifested in April 1991 might have been overlooked had these not been promptly reported to the PHIVOLCS by Sister Emma of LAKAS Foundation, a local-based NGO. On April 4, Sister Emma travelled all the way from Zambales (around 120 km away) to the PHIVOLCS office to report the explosion which occurred at Pinatubo's crater on 2 April. According to her, the explosion was accompanied by rumbling sounds and steam/ash ejection from several events. PHIVOLCS immediately dispatched a Quick Response Team to conduct ocular and aerial observation. On 5 April, a temporary seismic station was installed at a place about 12 km. WNW of Pinatubo.
Source: PHIVOLCS

A long-term or early warning message is a part of the public information system that should include among others: timely information about the hazard; action that should be taken to reduce loss of life, injury, and property damage; and consequences of not heeding the (immediate) warning (NDO 1992). There are two problems that hinder the effectiveness of communicating the warning. One is the failure of the short term or immediate warning to reach the target population and the other is failure of the population to heed the warning. Both entail a huge responsibility for the authority issuing warning. On the one hand, warning the threatened population alone without projecting risks, may not encourage them to heed the warning. On the other hand, if the projected risks do not happen, they may consider the warning as false alarm and not at all valid. To ensure that forecast is accurate and early warning reaches the population on time requires a huge informational and communication task.

Table 1. Disasters in the Philippines, 1997

Disaster	Affected			Casualty		
	Freq.	Families	Persons	Dead	Injured/ Afflicted	Missing
Nature-triggered Disasters:						
Landslide	2	29	150	6	10	1
Tornado	2	1627	8623	3		
Red Tide	3	32553	172554	3	91	
Epidemic	36		15868	1029	14934	
Infestation	13	49869	248406			
Volcanic Activity	1	76	401	1	400	
Tropical Cyclone	6	460541	2301740	88	40	8
Flood/Flashflood	7	204591	1043559	42	6	6
Drought	1	1396251	7400223			
Fishkill	2	3100	16430		7	
Subtotal	73	2145637	11207944	1172	15488	15
Human-made Disasters						
Dev't. Aggression	47	26426	141286	10	39	
Labour Repression	24	6583	34889			
Militarisation	9	27388	158652	206	23	
Mining	2		11	80		
Subtotal	82	60397	334838	296	62	
Total	155	2206034	11542782	1468	15550	15

Source: CDRC

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Every disaster prone community should have a counter disaster plan or community preparedness plan that includes risk scenarios and early detection of hazards that may possibly come their way. This is more relevant and necessary especially in cases when the official warning, for some reason or other, does not reach their area. Local hazard maps including all types of risks threatening the community should also be drawn. Finally, a structure or organisation that will see that all tasks and responsibilities in the counter disaster plan are carried out should also be in place. These will facilitate an effective and appropriate response at local level to the early warning issued to them. This should be practised in Mt. Pinatubo and other areas, where lahar flow is a repetitive cycle and, to a large extent, predictable.

3 Philippines: World's Most Disaster Prone Country

A study conducted in 1992 by the Centre for the Epidemiology of Disasters (CRED) based in Brussels, Belgium revealed that the Philippines was on top of the list of the world's most disaster prone countries from 1900–1991 with a total of 701 incidents followed by India with 369 incidents. In 1997 alone, more than 11.5 million Filipinos were affected by various types of natural and human source-disasters (Table 1). As such, the country needs to reassess its various strategies in disaster reduction.

The result of the CRED's study is not surprising considering the country's geographical location and physical attributes. As the country is located on the western rim of the Pacific Ocean where 50% of the world's typhoons originate, the occurrence of a tropical cyclone is normal. An average of 19 typhoons, most of which are destructive, visit the country every year.

Situated along the Pacific Ring of Fire the country experiences volcanic eruptions and earthquakes which could lead to several physical phenomenon such as ground shaking, ground rapture, liquefaction, lateral spreading, landslides and tsunamis. According to Punongbayan (1993) considering the fact that most large towns and cities of the country are located within the seismogenic zones it is certain that some high population density areas shall be struck by earthquakes with a magnitude of 7.5 or higher in the near future.

The country has 220 volcanoes, twenty one of which are active. The most destructive eruption so far has been the Mt. Pinatubo explosion in June 1991, which covered a radius of 20–30 km. Total damage was between 400–600 million dollars. The total population affected reached 1.4 million or about 2.5% of the Central Luzon's population (MPC 1994).

4 Mt. Pinatubo: Eruption of the Century

Mt. Pinatubo eruption is considered one of the largest volcanic eruptions of this century (The US Army Corps of Engineering 1994). When Mt. Pinatubo exploded in 1991, it emitted about 6.6 km^3 of pyroclastic materials that were deposited on the volcano's slopes and in river basins surrounding the mountain. These materials have served as the main sediment source of lahar. Most lahar flows were triggered by rainfall. For the years 1991–1995, the most destructive lahars were generated during prolonged monsoon rains that were intensified by the typhoons. In 1994, some 1583 million m^3 of lahar source materials still remained on the slopes (DPWH 1995). Lahar generated by heavy rain falling on erodible deposits posed continuing and grave danger to human lives and property in the low-lying areas.

The eruption made a significant alteration to the eight river basins as they were not able to hold the massive amounts of volcanic ash and debris within their banks. As a result, when they overflowed due to heavy rains, nearby communities and farmlands became heavily flooded, which further devastated vast tracts of agricultural lands, destroyed bridges and roads, buried homes and disrupted sources of livelihood. Widespread impacts continued to occur with each rainy season as tens of thousands of residents were forced to leave their homes.

Pasig Potrero River, one of the eight river basins, is an active lahar channel, thus towns within its immediate vicinity are threatened, "Because of their high densities twice that of water, lahars tend to erode channel floors and may lift large boulders, rock filled gabions, vehicles, concrete bridges and even buildings. A single lahar (that) typically moves at 8 m/s or 30 km/h is generally very erosive" (MPC 1994).

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5 An Endangered Community's Response

As Mt. Pinatubo has vividly demonstrated, volcanoes can still pose a grave threat even after their eruptive phase. Having witnessed the destructive effects of dangerous lahar and mudflows in the aftermath of an eruption the population's awareness of the possibility of becoming victims was once more heightened. The displacement of people, destruction, loss of housing and agricultural land caused by lahar flows and flooding has been predicted by PHIVOLCS in some detail. In this sense the situation in Mt. Pinatubo affected areas provides a unique opportunity for effective disaster preparedness.

Since 1991: during the rainy season, which happens every year, lahar deposited in the mountain slopes cascade down to the low-lying communities and silts rivers and creeks. The ensuing flood caused destruction of houses, infrastructures and community's resource base. One by one, the villages of the municipalities of Porac and Bacolor succumbed to the pressure of lahar. These two municipalities were the most affected towns of Pampanga. In fact, between 1991 and the early part of 1995, nineteen (19) villages of these towns were submerged in lahar. Hundreds of people perished. These villages are now deserted (NSO 1996).

In 1994 alone, due to continued heavy rains, a total of 147 674 families suffered from lahar and floods. Total villages affected reached 504 in 41 towns of the seven provinces of Central Luzon. Barangays[2] Manibaug-Pasig and Mancatian are examples for these villages that were completely buried after a lahar flow struck on the evening of September 22 (Concern 1995).

In 1995, there were 11 rain-induced-lahars that affected the Pasig Potrero River system. An intense and prolonged rainfall caused by the passage of various typhoons triggered the worst lahar flows and floods. A total area of 25 km^2 was buried beneath 0.5 to 6.0 m of sediment with an estimated volume of 50 million m^3 (PHIVOLCS 1996). Again, villages were completely destroyed and again lives were lost. However, in two of the ruined barrios not one resident was hurt, all were able to escape bringing some belongings with them. These villages were Manibaug Libutad and Talba.

[2] Barangay or barrio is the basic political unit in the country. This is equivalent to a village.

5.1 The Saga of Manibaug – Libutad

The town of Porac has 29 villages. In 1994, when lahar cascaded from Mt. Pinatubo breaching the Pasing-Potrero earthdike, lahar rushed towards the Gugu Creek, which had a low earthen dike of around two meters already constructed to protect the villages lying along the left embankments downstream. However, the lahar carried by the floods breached the dike in many places and buried the barrios of Manibaug Pasig and Mancatian which lie west of the creek. Many lives were lost. To prevent further destruction of other villages, one of which was Manibaug-Libutad, it was decided that the dike be repaired and strengthened.

5.1.1 The Gugu Dike

The Gugu Creek, about five meters wide, was a tributary of the Pasig-Potrero River. A levee dike runs along both sides of the creek. Still earthen, the dike was raised to around eight meters by dumping volcanic materials on top of the original dike. The levee was about 21 km long and traversed the towns of Porac and Bacolor with an upstream portion towards Delta 5 Watchpoint of the Mt. Pinatubo Warning System. The proposed strengthening called for the cementing of the inner portion of the Gugu Dike. The lack of funds from the national treasury and other sources did not allow this plan to materialise (DPWH 1995).

It was said that the strengthened dike could withstand the onslaught of lahar and that, therefore, the villages would be safe. Some doubts, however, were expressed by residents who thought otherwise since the dike was still made of earth and that other such dikes have already been destroyed by lahar.

5.1.2 Manibaug – Libutad

This barangay or village was situated on a gentle slope which started a few meters above the creek and rose fifteen meters to a plateau. Most of the houses were located along the lower portion of the slope where the farms were situated. Separated by the creek, the villages relied on a bridge to actually reach the town. The bridge was destroyed by the 1994 mudflow. A tempo-

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rary bailey bridge was set up for use by pedestrians and light vehicles only. During rainy times, a circuitous route was the only alternative for the villagers to reach the town hall. Other daring residents would wade through waist-high waters holding up a dry set of clothes into which they would change when they reach the other side of the creek.

There were about 771 households or 3722 people living in the barrio of Manibaug–Libutad. Most were farmers cultivating sugar cane, rice, cassava, various vegetables and fruit trees of guavas and guyabano or sour sop. Others worked as carpenters, laundry women or ambulant vendors. Some residents found employment as contractual or temporary factory workers in the nearby city of Angeles, about thirty minutes away by public conveyance.

The village had constructed a barrio elementary school and a public market on the plateau. About one-third of the houses of the barangay were also situated on the upper part of Manibaug–Libutad. When the heavy rains come and lahar rampages from the mountain slopes of Pinatubo to the Gugu Creek, the people of Manibaug–Libutad know that they are isolated from their town officials, that they are on their own.

5.1.3 The Warning System

The people of Manibaug – Libutad relied on a warning system involving both national and local institutions. This system was centred on the Mt. Pinatubo watch point, where rain gauges and lahar sensors were kept and operated by PHIVOLCS, an institute specialised in volcanoes. Any development regarding Mt. Pinatubo and the lahar were first relayed by PHlVOLCS and the Regional Development Coordinating Committee (RDCC) to the municipal officials who, in turn informed the village officials usually by two-way radios. The village officials transmit the warning or alert to the residents by various means such as by use of whistles and firecrackers. The RDCC has developed the Mt. Pinatubo Warning System (Table 2).

The system counts on the local officials to carry on their duties as expected. Thus, it is assumed that a 24-h watch on movements in the Pinatubo mountain was being kept by the concerned bodies. Miscalculation or any unintended slippage by these bodies could spell disaster for the potential victims of lahar. The Non-Government Organisations (NGOs) working in the area were well aware of this possibility.

Table 2. Lahar warning signals used in Pinatubo

Warning no.	Meaning and appropriate action
1 Ready	Rain is falling at Mt. Pinatubo volcano and vicinity. No need to evacuate at this stage. People residing near river channels and low-lying areas at the foot slopes of the volcano should pack basic items and belongings and be ready for any eventualities. They should turn in to their local radio station for further announcements. At night, it is important that at least one member of the family should stay awake to be able to monitor warning signals.
2 Get Set	Rain continues for at least 30 minutes and rainfall intensity and duration are approaching critical level or threshold value. People will be informed whether or not the rainfall can trigger a lahar.
3 Go	Detection of lahar Residents at risk should transfer to higher grounds.

Source: PHIVOLCS

5.1.4 The Concern Training

In 1991 when Mt. Pinatubo erupted and after the first mudflows, CONCERN was already involved in the delivery of relief goods, education and training of the victims and potential victims of lahar, and in the promotion of community-based disaster response approaches.

Based on the 1994 Pinatubo hazard map, Manibaug–Libutad was considered one of the high-risk villages. CONCERN organised meetings and related activities and conceptualised possible risk-scenarios with the residents. The village officials were receptive to the proposal of CONCERN and agreed to undertake a disaster-preparedness training seminar. Twenty-five volunteered for the training. Among them were three barangay officials including the person responsible for disaster, the officials of homeowners' associations and farmers' cooperatives and officers of women and youth organisations.

On July 23, 1995, the training was carried out. Contents were: Capacity and Vulnerability Analysis, Disaster Response Management (including Hazard Monitoring), Hazard Mapping, Damage-Needs-Capacities, Assessment, Evacua-

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Table 3. Course Module

Topic	Content	Methodology
Framework	Vulnerability and Disaster, Philippine Vulnerable Situation, Disaster Update	Workshop, lectures, discussion and visual aids
Capacity and Vulnerability	Objectives and Aspects	Workshop, discussion and visual aids
Disaster Response Management	Definition and Objectives Types of Responses Changing concepts	Role play, lecture, discussion and visual aids
Hazard Mapping	Definition and objectives methods	Workshop, discussion and visual aids
Disaster Need Capacity Assessment (DNCA)	Definition and objectives methods	Role play, lecture, discussion and visual aids
Evacuation	Definition and objectives methods	Role play, lecture, discussion and visual aids
Counter Plan	Objectives, guidelines/format, planning	Workshop, discussion
Citizenry Based Development Oriented	Concept, BDRO/C framework	Lecture, discussion, open forum

Source: CONCERN/PDRN

tion Drill, Counter Disaster Planning, and the Citizenry-Based Development Oriented Disaster Management (see Table 3 for the course content).

The training was scheduled for three days. However, at the end of the second day, on July 25, the participants requested the CONCERN trainers to temporarily stop the seminar so that they could prepare for the coming barrio fiesta. It was agreed to postpone the training on Evacuation Centre Management to a date right after the village festivities of July 31, 1995.

5.1.4.1 The Training Output

At the end of the two-day training, the community was able to identify where they planned to evacuate; whom to tap in case of an evacuation – such as people and agencies with cars and trucks and with communication facilities, and how the information will flow especially with regard to the warning system.

The training participants also set up their Barangay Disaster Response Organisation (BDRO). Elected as Chairman of the BDRO was Mr. Aurelio "Ka Eliong" Vitug, who was also the president of the Manibaug-Libutad Homeowners' Association. The organisation established various committees to carry out the different responsibilities relating to disaster preparedness. These were the Evacuation Committee, the Warning Committee, the Health Committee, the Information and Education Committee and the Relief and Rehabilitation Committee. It was the responsibility of the Warning Committee to monitor the lahar situation and to warn the people of impending disaster.

Each Committee had immediately started to recruit volunteer members from the village residents and oriented them in their responsibilities. In particular the Warning Committee recruited volunteers on a 3-h shift-basis, covering 24 h, monitoring mudflow movement along designated points of the dike.

5.1.5 The 1995 disaster

It was July 28, three days after the training and also three days before the village fiesta, the villagers were busy cleaning and decorating their houses, checking the utensils and stocking up for the coming event. It was still the monsoon season and there was news of a typhoon expected to enter area.

At 2:00 p.m., "Apung Gue" the local title of respect and endearment for Mrs. Miguela Vitug, wife of the newly-elected BDRO Chairman, was about to leave the village for the Clark Airbase Command (CABCOM) evacuation site. Since the 1994 disaster that wiped out some southern villages lying across the Gugu creek, some of the residents of Manibaug-Libutad had constructed temporary dwellings or tents at the CABCOM.

Apung Gue and a few other villagers had erected such tents but had not completely moved out of their barrios. She had washed clothes in the morning and these were now dry.

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It was a clear day with a very hot sun. With her grandson beside her she walked slowly away from the village. Another old villager greeted her with a tease that she must hurry or the lahar would catch up with her.

Dark clouds were now approaching the village. After 4:00 p.m., a light drizzle was over Manibaug–Libutad. The villagers started looking for the Barangay Captain, Mr. Silos. According to Apong Gue, he was away, at the CABCOM, completing his family's tent. The villagers of Manibaug–Libutad were anxious and worried.

The BDRO Warning Committee had posted men along the dike to keep watch on the rising mudflow. The other barangay officials were glued to their two-way radios waiting for the word to leave the area. No word came from the municipal authorities. The BDRO Warning Committee informed the residents that water in the creek was rising. Ka Eliong, BDRO Chairman, arrived from work at 5:30 p.m., instructed his son to cook for the volunteers monitoring the lahar flow, and went to the dike for briefing with the volunteers.

At a little past 6 in the evening, rain was falling strong and a rampaging mudflow mingled with the waters of the Gugu Creek which rose higher. Suddenly, the upstream portion of the dike started to erode. Ka Eliong gave the word to the Warning Committee: EVACUATE! The BDRO volunteers blew their whistles and at once mobilised the foot patrols, who went from house to house, informing the occupants to leave their homes and run to the marketplace or the schoolhouse, which were identified in the training as a pick-up point for evacuation. Those who had vehicles could proceed to the CABCOM which assigned an area for use by evacuees. The others would be ferried by trucks and buses to the CABCOM. The village chief arrived and also joined in the warning action.

The condition in the area deteriorated so fast from level 1 to level 3 in less than two hours. By 7:00 p.m. about one kilometre of the dike had collapsed. One foot of lahar was sweeping through the northernmost houses but the residents were already on high grounds. Only some BDRO officials and some volunteers of the Warning Committee were left behind surrounded by almost two-foot deep of smoking, very hot lahar. They would be the last to evacuate. They had made sure no resident was inadvertently left behind. A truck, returning from CABCOM, had arrived in time to evacuate the volunteers.

At 8:00 p.m., more than one meter of lahar covered the upstream houses, while more than two meters covered the downstream residences of the Manibaug-Libutad Village. Not one villager was killed, not one was even hurt. They had reached the evacuation area safely. The community depended on their strength and capability; had they waited for the official announcement, they could have been killed.

5.1.6 The After-Event

In the following morning, residents of Manibaug–Libutad returned to their homes, partly buried in lahar, to salvage whatever could be saved. Using picks and shovels, they dug through sand and mud left by the lahar. Were it not for the coming fiesta, they would not have lost so much, yet all were glad that nobody had perished.

On August 23, 1995, about one month after the first lahar intrusion into Manibaug–Libutad, a stronger typhoon crossed the area bringing with it more rains and stronger lahar. More than two-thirds of the village was covered by lahar and buried beneath six meters of sand. The Gugu Creek, silted with sand raising its level by more than seven meters, has disappeared.

In a similar event, in the village of Cabalantian in the next town of Bacolor, many people died when Typhoon Mameng lashed its fury. This was on October 1, 1995, when the typhoon triggered the release of tons of lahar. That breached the same dike and drowned those unprepared or unwilling to move away because of their full trust in the dike.

In the meantime, most of the residents of Manibaug–Libutad have settled in Clark Air Base as their temporary evacuation site for three years. They reminisced the past success with thanksgiving and yet also said that if they had moved much earlier, they would have been able to save more than the shirts on their backs. Others are now relocated to different resettlement sites of Pampanga province such as Sta. Lucia in Magalang and Madapdap in Mabalacat municipality.

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This experience of maximising the early warning is not limited to Manibaug–Libutad. A similar story happened to the residents of the bigger village of Talba in Bacolor municipality, where training and organising effort was undertaken by another NGO, the Pampanga Disaster Response Network (PDRN). All of the 771 families or more than 5000 individuals were saved; not one died although the village was submerged in lahar, in 1995.

Mt. Pinatubo remains a threat. Considering the huge volume of remaining lahar sediment source, lahar hazards are still expected to have significant impact on the region surrounding Pinatubo Volcano in the next decade or two. The lahar hazard maps issued yearly by PHIVOLCS will always be treated by the people of Central Luzon as early warning.

6 Conclusions and Recommendations

The aftermath of the Mt. Pinatubo eruption provided both a dangerous threat and a rare opportunity for the affected population. While they were always on their toes to escape disasters, they also took advantage of the situation as an opportunity to learn, to plan and to organise. People's initiatives along this line should be encouraged and supported. Community-based disaster management approaches derive lessons from the people's experiences.

Early warning in the form of lahar hazard maps issued by a government agency long before the impending threat provided a unique occasion for disaster preparedness, the interventions of the NGOs helped the community to understand and interpret the maps, which encouraged them to participate in the training, draw their specific community hazard map and formulate counter disaster plans, cooperation among the community-at-risk, government agency and NGOs is a must. Resource and information sharing is crucial at all times especially in high risk communities. Information flow to and from the community is important.

Disaster preparedness training gave the participants the knowledge and skills to assess the gravity of the threat, to identify the pick up points for evacuation; to enlist the support of others who have resources that can be used during emergency situations; to ensure information is sent and received; and, to lead and be responsible for evacuation in an organised manner. Efforts on community-based disaster preparedness should be supported by the concerned authority. Early warning should not be treated separately from disaster preparedness as early warning, on its own, would not be effective. Financial resources should be allocated to defray expenses for disaster preparedness activities.

Every village has a particular story to tell and lessons to share about its experience. Yet, there were no documents to speak about their cases. Usually reports inform of the work of the NGOs' or GOs' narrate their activities. Oral testimonies abound, but no written paper was published about their experiences, be it on early warning or on emergency response. Documentation of people's initiatives and case studies of their best practice should be done for references and for learning purposes.

People were living in very high risk areas. The study has shown that people were constantly threatened requiring them to be watchful every minute. They saved themselves but they were forced to leave their belongings, which were necessary for their survival. It took extra effort to salvage even a few of their materials. To avoid this disastrous effect, no one should be allowed to stay in highly threatened villages. In this connection, a relocation site on safe ground should be prepared for the population-at-risk before the lahar flows. Relocation sites should also ensure alternative livelihood opportunities to encourage them to move out.

Community organisations such as the Barangay Disaster Response Organisations were very helpful during the most critical time. They have an important role in monitoring hazards that threaten their villages and in issuing timely warning to the residents. The residents were mobilised to warn their neighbours about the impending lahar flow. The experience showed that these organisations were reliable back-ups to the officials and institutional arrangement for early warning. Cooperation and coordination between the BDROs and the village council should be encouraged and strengthened. This is one of the prerequisites for an effective disaster management.

Evacuation or fleeing from a disaster situation proved to be a positive coping strategy. The fact that the residents helped each other in evacuating prior to the lahar rampage demon-

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strated that people's coping is high during emergencies. This is another capacity that should be enhanced. Community's role in warning, both for long term and short term, should be recognised. Their participation and mobilisation is crucial for their safety.

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CHAPTER 1.7

Disaster Management and Cyclone Warning System in Bangladesh

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Abstract

Due to its geographical position, Bangladesh is one of the most disaster prone countries in the world. Natural hazards, i.e. cyclones, storm surges and floods extract heavy tolls on human lives and animals. Tremendous property damages, and the total disruption of development activities of the country occur almost every year. With about 120 million people living within 144000 km^2 of land, Bangladesh is one of the most densely populated countries in the world. It is estimated that a total 775303 people died in the coastal and offshore islands of Bangladesh within the last 222 years (1775–1997) due to cyclone and storm surges alone. The main causes of these huge casualties were:

1. A weak cyclone warning and weather forecasting system,
2. false alarm with no cyclone/storm event, despite of high warning signals,
3. no disaster awareness programmes were implemented in advance.

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There are about 15.0 million people living in the vulnerable areas, covering 21 000 km^2 of coastal and offshore islands of Bangladesh which comprise 14.8% of the land of the country. Although 1.3 million are accommodated in a total of 1 350 cyclone shelters in these areas, and a further 2.3 million people can be accommodated in school and office buildings, 11.0 million people (about 73.3%) are still unsafe. The Government of Bangladesh has given emphasis and priority to developing of the weather forecasting system using satellite imageries and computer methods. So, now cyclone warning signal can be given and disseminated to the community/vulnerable people as early as possible, by radio, television and information media at frequent interval during the event of a cyclone strike. Bangladesh has already established and set up a Disaster Management Bureau to coordinate disaster management through national to local level to pursue the objectives of the International Decade for Natural Disaster Reduction, IDNDR (1990–2000) to develop disaster awareness. One cyclone event was already successfully predicted on May 19th, 1997, which had a similar intensity to the May 25th, 1985 cyclone (where 11 069 people died on that day), but this time only 127 people died due to the early warning system and taking proper precautionary measures. In this article, disaster management and the development of a cyclone warning system in Bangladesh are discussed.

1 Introduction

The Bay of Bengal is an ideal breading ground for tropical cyclones and storm surges, with mostly poor people living along the coastal region of Bangladesh loosing their lives almost every year. These disasters have been particularly devastating and have caused serious damages. During the past two centuries the low-lying coastal and offshore islands have experienced a tragic history of 35 severe cyclone and storm surges, with more than one million victims dead or missing. People accepted and waited for the next disaster as they had no alternatives. Members of poor families who survived other members experience hard times recovering from damages and losses of their loved ones.

Causes for these huge casualties were mainly:

1. settlements with a high population density,
2. no remarkable cyclone shelter at the disaster/risk areas,
3. a lack of consciousness among the vulnerable people of the disaster/risk,
4. people were mainly deterministic and tended to depend on fate,
5. people were lived on the weak adjustment of their houses,
6. central awareness programmes and weather forecast system were not developed.

After a disaster, different types of epidemic diseases arise in the crisis area. The dead bodies and other decomposed materials create bad smells which pollute the entire environment. Many distressed people are also deprive of services. Providing all sorts of assistance and emergency health preparedness are most essential in facing the situation. After the 1970 cyclone, Bangladesh is now more active in cyclone preparedness as well as warning systems. Since these developments, casualties of recent major cyclones have been reduced substantially.

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2 Hazards, Vulnerability and Potential Impact

Table 1. Hazards and their specific frequency and intensity, their last occurrence, vulnerable elements and potential impact

Hazard	Frequency	Intensity	Last occurrence	Vulnerable elements, and potential impact
Cyclone	3 years	high	May 19, 1997 Nov 28, 1997 May 16, 1998	Loss of lives, houses, crops and properties, development activities disrupted
Storm surges	3 years	high	May 15, 1995 Aug 10, 1998	Infrastructure, normal life hampered, losses of crops
Flood	3 years	high	August, 1995 August, 1998	Development activities disrupted, losses of crops, house holds, land erosion
Tornado	every year, sudden	high	Nov 27, 1997	Losses of lives, cattle, and properties, house holds
River erosion	every year, continuously	moderate	during flood, after monsoon	Losses of agricultural land, home stead
Drought	2 years	moderate	January, 1997 February, 1998	Losses of crops, scarcity of water

3 Major Cyclones and Storm Surges Hitting the Coastal Region of Bangladesh

3.1 Historical Overview of Major Events

Table 2. Major cyclones and storm surges from 1795–1961

Year	Month/Day	Affected areas	Nature	Loss/Damages/Remarks
1795	June	Chittagong Town	severe	Chittagong collectorate building and other only 5 brick made buildings/houses survived.
1822	May	Barisal	severe	40 000 people died, 100 000 cattle lost, houses damaged.
1876	Oct.	Hatiya Island, Noakhali, Patuakhali, Chittagong coastal and islands	severe + tidal waves 10–45 ft.	200 000 people died, 40 000 people missing, 20 000 cattle lost.
1897	24 Oct. Midnight	Chittagong coastal areas, Kutubdia island	hurricane, maximum intensity, with storm waves	14 000 people died, 18 000 people died after Cyclone in epidemic situation.
1909	Oct.	Barisal and Sunderban	severe	
1917	May	Barisal and Sunderban forest area	severe	
1923	May	Teknaf	severe	
1926	May	Cox's Bazar	storm waves	
1941	May	Meghna Estuary, islands	with storm waves	
1960	9–10 Oct.	Noakhali islands	severe, 125 miles/hr.	3 000 people died.
1960	30 Oct.	Chittagong, Hatiya island	130 mile/hr, storm wave 15–20'	5 000 people died, 70% houses blown off, 9 vessels capsized.
1961	9 May	Meghna Esuary islands	severe storm surges 8–10' waves	11 000 people died, railway tracks damaged

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3.2 Major Cyclones and Storm Surges Hitting the Coastal Region of Bangladesh: Recent Events

Table 3. Major cyclones and storm surges from 1963–1998

Date	Topography	Hazard	Impact
1963, May 28	Chittagong coastal areas, Cox's Bazar, Meghna Estuary, Islands	severe, 125 miles/hr width 10–12' waves	13 000 people died, 80 000 cattle lost, 128 000 acres crops and 600 000 households damaged.
1965, May 12	Barisal, Noakhali, Chittagong	severe, wave 12'	19 000 people died.
1965, Dec. 15	Cox's Bazar, Teknaf	severe, waves 8–10', 130 miles/hr	1 100 people died.
1970, Nov. 12	Meghna Estuary, coastal island and Chittagong areas	most severe, severe storm surges, waves 15–20'	500 000 people died, 200 000 cattle lost.
1974, Aug. 13	Barisal, Offshore islands	severe, waves 9–15'	300 people died, 1 000 cattle lost.
1975, May 9–12	Bhola, Patukhali, Cox's Bazar	cyclonic storm	30 people died, 40 fishermen missing.
1985, May 25	Noakhali, Bhola, Chittagong, coastal and offshore islands	severe, 154 km/h, waves 9–10'	4 264 people died, 6 805 missing, 135 000 cattle lost/died.
1988, Nov. 29	Khulna, Sundarban	severe, 200 km/h, waves 8–12'	Same as 1970 Cyclone, hit in Sundarban forest, all preparedness taken, minimum losses.
1991, April 29	Chittagong coastal and offshore islands, Cox's Bazar, Noakhali, Hatiya	most severe, 225 km/h, waves 20'	140 161 dead, 1220 missing, 1 000 000 cattle lost, other infrastructures, houses damages (USD 2.4 billion), 22 volunteers died.
1995, May 15	Hatiya	severe tidal waves 7–9'	Damages.
1997, May 19	Hatiya, Noakhali, Chittagong offshore island	severe, waves 8–10'	127 people died, all necessary preparedness taken.
1998, May 17	Chittagong coastal region	severe	35 People died, 260 missing precautionary measures taken

Source: BBS, Bangladesh Statistical Year Book, 1996, pp 124–128

4 Cyclone Tracks

Records indicate that most of the cyclones hit in May and November. The cyclones originated at the Bay of Bengal and hit in Chittagong coastal and offshore islands. Cyclone tracks are not fixed; one even cannot predict their movement or hit directions. Cyclone movements are very complex, with errors in 72/48-h, even 24-h forecast.

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5 Cyclone Warning System

5.1 Storm Warning Signals

5.1.1 Sea Port Signals

Table 4. Sea port signals

Signal no.	Explanation
Distant Cautionary Signal No. 1	There is a possibility of squally weather in the distant sea where a storm may form. - wind velocity: maximum 50 km/h
Distant Warning Signal No. 2	A storm has formed in the distant sea. - wind velocity: 51–61 km/h
Local Cautionary Signal No. 3	The sea port is threatened by a squally weather. - wind velocity: 51–61 km/h
Local Warning Signal No. 4	The port is threatened by a storm, but it does not appear that the danger is yet sufficiently great to justify extreme precautionary measures. - wind velocity: 62–87 km/h
Danger Signal No. 5	The port will experience severe weather from a storm of slight, or moderate intensity that is expected to cross the coast to the *South* of Chittagong/Cox's Bazar port, or *East* of Chalna port. - wind velocity: 88–117 km/h
Danger Signal No. 6	The Port will experience severe weather from a storm of slight, or moderate intensity, that is expected to cross the coast to the *North* of Chittagong/Cox's Bazar port, or to the *West* of Chalna port. - wind velocity: 88–117 km/h
Danger Signal No. 7	The port will experience severe weather from a storm of slight, or moderate intensity that is expected to cross *Over*, or *Near* the port (Chittagong, Cox's Bazar, Chalna). - wind velocity: 88–117 km/h
Great Danger Signal No. 8	The port will experience severe weather from a storm of great intensity that is expected to cross the coast to the *South* of Chittagong/Cox's Bazar port, or to the *East* of Chalna Port. - wind velocity: 117–250 km/h
Great Danger Signal No. 9	The port will experience severe weather from a storm of great intensity that is expected to cross the coast to the *North* of Chittagong/Cox's Bazar, or to the *West* of Chalna Port. - wind velocity: 117–250 km/h
Great Danger Signal No. 10	The Port will experience severe weather from a storm of great intensity that is expected to cross *Over* or, *Near* the port (Chittagong, Cox's Bazar, Chalna). - wind velocity: 117–250 km/h
Failure of Communication Signal No. 11	Communication with the meteorological warning centre has broken down and the local officers consider that a devastating cyclone is following.

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5.1.2 River Port Signals

Table 5. River port signals

Signal no.	Explanation
Cautionary Signal No. 1	The area is threatened by squally winds of transient nature, expecting nor'-westers and storms. – river ports are to be alerted, but communication will not stop.
Warning Signal No. 2	A storm is likely to strike in the port area, with wind velocity of 51–61 km/h. – all vessels and boats (up to 65 feet length) are to seek shelter immediately.
Danger Signal No. 3	A storm will strike port area soon, with wind velocity of 62–87 km/h. – all vessels and boats will seek shelter immediately.
Great Danger Signal No. 4	A violent sea storm will strike port area soon, with wind velocity more than 87 km/h, but no nor'-westers. – all vessels and boats will take shelter immediately.

5.2 Storm Warning Centre

5.2.1 Development of Information Technology

Bangladesh Meteorological Department is responsible for issuing cyclone warning message. The storm warning centre (SWC), within the meteorological office works round the clock.

The centre has already upgraded the warning system adapting computer methods to warn the vulnerable coastal and offshore island people, thus, representing a new era. Now the warning signal can reach people at their homes, even the fisherman can get this warning message while at sea via radio at least one/ two days advance. Hereby, more human lives can be saved and losses minimised.

The storm warning centre analyses the synoptic chart after plotting meteorological information (i. e. wind speed, wind direction, pressure, cloud, temperature, humidity, rainfall, satellite imageries (GMS, APT, SPARRSO) from three radar stations (Dhaka, Cox's Bazar, and Khepupara, with anemometers, micro-vax-computer, video terminal), 36 observatory stations, and the Delhi-Met office through Global Telecommunication System.

Low Pressure (L) is identified from the chart. Alert messages are quickly disseminated to the coastal people via radio, television, news media and all other agencies when low pressure (depression) is distinct. A Daily Weather Forecast Report is prepared every day by 3:00 p.m. and passed on by 4:00 p.m. by fax, teleprinter, telephone, etc. Moreover a Monthly Forecast Report is prepared within the first week of every month by an expert committee. The warning message (Weather Bulletin) is disseminated by radio, and television at frequent intervals (every 10/15 minutes) during disaster time.

5.2.2 Radar Network and APT Ground Station

Bangladesh Meteorological Department installed its first radar network with a 10 cm RC-32 model at Cox's Bazar in 1969 which has in the meantime, been replaced by modern computer. Now three radar stations have a detective range of 400 km each. The Dhaka radar was installed in 1984 with a digital video integrator, processing system and a colour monitoring display. This is a meteorological-cum-hydrological radar with a computer to calculate rainfall rate at different intervals, connected with another terminal TV monitor located at the Flood Forecasting and Warning Centre, Dhaka. The recorded rainfall data and cloud pictures (in magnetic tape) are transmitted to the Flood Forecasting and Warning Centre through a microwave link. This radar is normally used for monitoring cyclone, nor-westers, tornadoes, etc.

The Cox's Bazar and Khepupara radar, located at the coastal belt are mainly for cyclone warning purpose and were installed in 1988 and provide the same data/observations as Dhaka radar with on-line TV monitoring display connection to the Dhaka storm warning centre. All other data/observations are sent to Dhaka SWC through conventional telecommunication systems, i.e. teleprinter, telephone. The SWC has also an APT ground receiver which was installed in 1973, a

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new auto fax system replaced the old equipment in August 1991, but the pictures are not automatically girded. The radars operate around the clock, so a cyclone can no longer strike the Bangladesh coast without being detected.

The Bangladesh Meteorological Department upgraded its Telecommunication System, in January, 1993, increasing the speed of the Dhaka–New Delhi GTS (Global Telecommunication System) link from 50 bauds satellite circuit to 2400 bps, with a micro-vax-3300 system computer and terminal equipment. A full voice grade telephone type satellite channel has been acquired. Three radar stations installed a set of high gust anemometers with accessories, video terminals, laser printer under the Regional Computer Network Programme of WMO in July 1990. Meteorological Application Software (MAS) and Messaged Switching Software (MSS) have also been installed.

5.2.3 Warning Dissemination

An early warning system is one of the most effective counter measures for the reduction of cyclones. By predicting the possible occurrence of cyclone, its destructiveness may be minimised. A significant reduction in loss of lives and properties is possible through adequately forewarning the coastal people of the path of cyclone (track) and the impending danger. The Bangladesh Meteorological Department is entrusted with the responsibility of issuing warnings and the subsequent dissemination. Early warning for a cyclone is issued as soon as a depression forms in the Bay of Bengal. The warning is immediately passed as Special Weather Bulletins via fax, teleprinter, telephone etc to radio, television, press media/news agency, Cyclone Preparedness Programme (CPP), Disaster Preparedness Programme (DPP) for necessary action and messages to the Prime Minister's Office, Ministry of Disaster Management and Relief, Directorate of Relief, concern Ministries, Airport, Seaport, Naval Base etc.

As soon as a cyclone warning with a symbolic title as Special Weather Bulletin advising to hoist signal number 3 is issued, radio and television put it on air beyond their normal transmission hours. When the depression intensifies into a cyclonic storm, warnings are to be issued at least 18–24 hours, danger warnings 12–18 hours and great danger warnings 6–12 hours in advance before the cyclone crosses the coast.

In case of a danger warning, Weather Bulletins are issued with a code address "Hurricane" to all heads of Government machinery. In case of great danger, warning bulletins are disseminated with a code address "Typhoon" to all concerned, and police stations. Now cyclone warning signals can be given and disseminated to the community people at the earliest time possible by radio, television and other information media at frequent intervals in the event of a cyclone strike.

5.2.4 The Cyclone Preparedness Programme (CPP): The Warning Front Line

The cyclone Preparedness Programme (CPP) of Bangladesh Red Crescent Society (BDRCS) with its 32796 volunteers (male: 27330, female: 5466) plays a leading and crucial role in disseminating the cyclone warnings, evacuation, rescue, first aid, and emergency relief works to the grass root level people in the coastal and offshore areas, under the supervision of the Government of Bangladesh (GOB) local administration. The CPP volunteers cover 710 km of the coastal belt from Teknaf to Sarankhola in 258 Unions under 30 Thanas of 11 Districts, more than 5 million people benefit from this programme. All the CPP unit (total of 2733 teams, each team has 10 male and 2 female members, served for 2 villages having 3000 people) volunteers are equipped with basic warning equipment, i.e. radio receiver, hand siren, megaphone (loud speakers, miking), signal light and signal flags. Moreover almost each Thana (administrative region) is provided with a high frequency wireless set which keeps direct communication with Dhaka and coastal district headquarters.

The unit teams are in the front line of the warning system. The volunteers have the mandate to disseminate the cyclone warning signals among the vulnerable people and to assist in their evacuation. The warning signal and tracks are transmitted to the Zonal (6), and Thana level (30) offices over high frequency radio. The Thana office passes the warning onto the union unit team volunteers, as quickly as possible. The unit volunteers spread out in the villages, disseminate the cyclone warnings almost door to door, using megaphone, hand siren

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and public address systems. When the situation turns serious, the Government of Bangladesh (GOB), local administration gives direction for evacuation. The volunteers implement it and help vulnerable people in taking shelter at cyclone shelters, or other available safer places.

Thus, losses of lives and properties were minimised during recent cyclones as the dissemination of the warning signal in good time to the vulnerable community people, assisted the Government in taking all precautionary measures, thus, achieving a greater success.

5.2.5 Shortfalls of Warning System

The cyclone warning system which prevails in Bangladesh is based on signals. These signals are meant for inland river ports and sea ports (a total of 4 signals for river ports and 11 signals for sea ports). However, with this signalling system the precise location of the cyclone, cyclone intensity, its movement, the possible affected area with depth of inundation are not indicated. Sometimes people are confused in understanding the meaning of the signals. This system is cumbersome, and has been criticised on the ground that people face problems in understanding these signals. People are not aware of the inner significance's of different warnings, nor are they aware of the implications of different kinds of signals, i.e. sea and river port signals. Since the Bangladesh Meteorological Department issues cyclone warnings for "Ports" only, people become confused about the actual signal numbers other than port areas. During the cyclone period of May 1997, warning sea port signal No. 10 was announced in Kutubdia Island, but a river port signal No. 4 was announced in Barguna Sadar, although both had a similar danger level (HKI 1998).

Forecast of the cyclone movement cannot be achieved by watching satellite imageries only. On 16 May 1998 SPARRSO forecasted that the cyclone could cross the Khulna coast when low pressure turned into a depression. But the cyclone crossed the Chittagong coast with 136 km/h wind velocity while 35 km/h was experienced at Khulna. In contrast, the Meteorological Department forecasted earlier correctly that the cyclone could cross the Chittagong coast.

So, early warning signal/bulletins should include messages that provide more specific information to help with precautionary measures. To reduce suffering and losses from the cyclone, present weather forecasts and warning systems need to be improved. The warning signals should not only be for ports, but also for areas likely to be affected by a cyclone, and disseminated in a language that can be easily understood by the community people.

5.2.6 Warning Message for the 19 May, 1997 Cyclone

The early warning system of the Government of Bangladesh had been in place to warn the vulnerable people during the May 97 cyclone. The cyclone was detected three days before, allowing time for a considerable early warning. Human casualties were minimised because of the adequate early warning.

Studies show that more than 90% of the households had received adequate early warning (HKI 1998).

For most local people the warning stated that "Signal No. 10" and "A Big Storm" is coming. Radio, loud speakers (miking) of CPP volunteers, neighbours and television were the main sources of the warning.

Most people of the coastal region and offshore islands took shelter (59.1% in cyclone shelter and 25.4% in a neighbour's home as a safer place during the eve of the cyclone on May 19, 1997 (HKI 1998).

Despite the high coverage of the warning system, respective households of Char Fession (53.6%), Barguna (42.8%), Teknaf (41.9%), and Bashkhali (22.7%) received the cyclone warning first on the day of cyclone (HKI 1998). Those people who received the cyclone warning at least one day in advance were more likely to seek a safer place (shelter) than those who had received the warning on the day of the cyclone. So, timeliness of the warning system needed to be improved.

6 Disaster Preparedness

6.1 Role of Cyclone Shelter

Cyclone shelter plays an important role in the reduction of disasters, and contributes to saving of human lives, minimising the casualties,

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and is treated as a resource centre for the local communities.

A total of 1350 cyclone shelters are now located in the coastal and offshore islands, the disaster high-risk zone of Bangladesh. The capacity of these 1350 cyclone shelters is not more than for 1.3 million people and a further 2.3 million people can be accommodated in different government, non-government offices and local building houses. All together 4.0 million (26.6%) people are covered with shelters, but the rest 11.0 million (73.3%) people are still unsafe. In addition to these shelters, all local schools, colleges, institutions, offices, houses, village community centres constructed with building materials, are used as safe places during a disaster.

It is estimated that more than 1.5 million vulnerable people of the coastal and offshore islands took shelter in the cyclone shelters, occupied by the evacuees with more than their capacity during the eve of a severe cyclone which hit in Bangladesh on May 19, 1997.

The severity of this 19 May, 1997 cyclone was similar to the 25 May, 1985 cyclone (11 069 people died on that day), but this time only 127 people died. So, this 19 May, 1997 disaster proves that the cyclone shelter plays an important role in the reduction of disaster. It was also assumed that the cyclone of April 1991 was considerably more intense (225–240 km/h, casualty: 140 161 people), than that of 1970 cyclone (190–210 km/h, casualty: 500 000 people), but total casualties were 72% less, due to more shelters at the risk areas, people were more aware of the risk and took shelter.

6.2 Disaster Awareness Programme

The Disaster Management Bureau (DMB), Cyclone Preparedness Programme (CPP) of the Bangladesh Red Crescent Society (BDRCS), and some NGOs (i.e. OXFAM, CARE, DUS) are engaged in developing disaster awareness among vulnerable people, students, teachers, community leaders, and local elite by colourful banners, fastoons, leaflets, posturing of disaster issues, arranging rallies, art, debates, essay competitions, evacuation demonstrations, training, short video films on disaster awareness, mourn memoirs of the disaster events, seminars, symposiums and workshops. The vulnerable communities are now being educated to help themselves to save their lives during a disaster.

Disaster Management Bureau has its regular programme for conducting training courses, workshops on public education/awareness at different levels, and has already arranged a total of 136 training programs from January 1997 to April 1998 for field officers, Union Chairman, Members, Teachers, NGO/Social workers, local elite/leaders, journalist at coastal regions where 8 830 participants benefited.

6.3 Disaster Mitigation

The Thana (local) Administration (Head: TNO/Magistrate/Assistant Commissioner) takes responsibility to make all precautionary measures/preparedness, immediate response to rescue disaster victims, providing first aid, first food, drinking water, relief operation, temporary shelters/housing, settlement and rehabilitation programmes with the assistance of law enforcement (Police, magistrate) and NGO-social workers, volunteers, BDRCS-field staff, before and immediately after any emergency/crisis. Police, Army, Navy, Airforce, Fire Service/Brigade are also involved in the rescue/relief operation.

7 Disaster Management: Committees and Responsibilities

7.1 National Policy

The primary responsibility for dealing with a disaster lies with the Bangladesh Government who will mainly ensure optimum utilisation of local resources. Since the majority of organisational resources are with the Government, the organisational arrangement sets on Government structure. NGOs and local communities have the power to participate widely and to contribute in Government efforts.

7.2 Organisation at National Level

7.2.1 National Disaster Management Council (NDMC)

The over all responsibility for policy direction during disaster management is covered by the NDMC Headed by the Prime Minister and Member Secretary by Cabinet Secretary. Other

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members are both Minister and Secretary for Water Resource Ministry, Finance Ministry, Local Government, Rural Development and Cooperative Ministry, Communication (Road and Railways) Ministry, Health & Family Planning Ministry, Food Ministry, Home Ministry, Disaster Management & Relief Ministry, Agricultural Ministry and Water Transport Ministry, Chief of Army, Navy and Air force, Principal Secretary to the Prime Minister, Secretary of Defence, Jamuna Bridge Department, Member (Socio-economic structure), Planning Commission and PSO of Armed Forces.

This Council meets twice a year.

Functions: Direction, Approval of national disaster planning, civil, military, NGO – coordination, legislation coverage, emergency decision.

7.2.2 Inter-Ministerial Disaster Management Coordination Committee (IMDMCC)

The IMDMCC chaired by the Minister of Disaster Management and Relief, coordinates disaster management activities at national level both during normal times and in the event of a disaster/crisis.

Vice- Chairman: Cabinet Secretary, Member Secretary: Secretary of Disaster Management & Relief Ministry.

Members: Secretary of Finance, Local Government, Home, Road & Railways, Jamuna Bridge, Water Transport, Food, Health & Family Planning Ministry, PSO of Armed Forces, DG of NGO affairs Bureau, DG of Disaster Management Bureau,DG of Relief & Rehabilitation Directorate, and Secretary General of Bangladesh Red-Crescent Society, Director of Meteorological Department, Chairman, Water Development Board, Chief Engineer of Road & Highways Directorate, Chairman of T&T Board, DG of Health Directorate, Chief Engineer of Public Health Directorate, DG of Food Directorate, Chairman, BIWTC, Chairman of Bangladesh Railway Authority, Director of Cyclone Preparedness Programme, Director ADAB, President of Federation of Chamber of Commerce and Industries, UN-Resident Coordinator, UN-organisations Representatives, Chief Engineer of PWD and LGED.

Functions: Implementation of Council decision, monitoring of all preparedness/relief/rehabilitation activities, coordination, direction and examination of Disaster Impact Assessment (DIA), development of disaster skill at all levels, analysis of disaster action plan, emergency decision, logistic support in faceing the crisis.

7.2.3 National Disaster Management Advisory Committee (NDMAC)

The NDMAC is composed of both government and non-government professionals and advises Government on disaster prevention/mitigation, preparedness, response and rehabilitation.

Chairman: nominated by the Prime Minister, who is expert on disaster management

Member Secretary: DG, Disaster Management Bureau (DMB) .

Members: Parliament members from disaster risk areas (DMB 1997b), experts from government institutions, University, NGO, Donor Agency, in the field of water resource, weather, seismic engineering, physical structural planning, social anthropology, education, disaster management (total 30 members), Chairman BDRCS, President, Federation of Bangladesh Chamber of Commerce and Industries, President Institute of Engineers, Chairman, Insurance Company Association, DG, Relief Directorate, Agriculture and Grameen Bank, Arrange meetings twice a year.

Functions: Advice, workshop, training and research on risk and mitigation possibilities, expert forum, recommendation, evaluation.

7.2.4 National Focal Point for Disaster Reduction

The Ministry of Disaster Management and Relief acts as a national focal point for disaster reduction including all matters relating to disasters.

- *work before, during and after disaster and during the rehabilitation stage.*

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7.2.5 Disaster Management Bureau (DMB)

This Disaster Management Bureau has been formed as a department in 1992 under the Ministry of Disaster Management and Relief.

Functions:

1. coordinate with the ministries, agencies, NGOs and district level, administration on disaster management planning, preparedness, training, response, and rehabilitation matters,
2. establish a data base for disaster related information accessible for all bodies concerned,
3. advise and assist NDMC, INDMCC, NDMAC in policy formulation and coordination on disaster management,
4. act in close cooperation with the armed forces in utilising their resources for disaster response and rehabilitation (search, rescue, damage assessment, relief and rehabilitation).

7.2.6 Organisation at District, Thana and Union Level

The following committees will coordinate disaster management activities:

7.2.6.1 District Level: District Disaster Management Committee

Headed by: Deputy Commissioner,

Advisor: Parliament Member

Members: district level officer, TNO, Female Representative, BDRCS, CPP/DPP-representative, NGO-representative, DRRO, Fire Service.

7.2.6.2 Thana level: Thana Disaster Management Committee

Advisor: Local Parliament Member

Headed by: Thana Nirbahi Officer (TNO, Senior Assistant Secretary).

Members: UP Chairman, all Departmental Officers, Female Representative, Central Cooperative Society, CPP/ DPP Representative, NGO Representative, PIO, Police Officer.

7.2.6.3 Union Level: Union Disaster Management Committee

Headed by: Chairman Union Parotid (Council)

Members: UP members, Teacher, Union Level Goverment officers, Female Representative, CPP/DPP Representative, NGO Representative, UP-Secretary.

8 Main Elements of Disaster Management

8.1 Prevention

The Government has taken appropriate structural measures for prevention/control of floods and river banks, reduction of damages to life and properties in the event of a cyclone and other disasters.

8.2 Mitigation

The Government has taken structural (road, embankments, afforestation, shelters, telecommunication) and non-structural (training, public awareness) measures for reducing damage to lives and properties during a disaster.

8.4 Preparedness

Disaster Preparedness has ensured through appropriate plans at the national, ministerial, departmental, district, thana and union level.

8.4 Response

A proper coordination mechanism has been established and exercised in normal times to ensure a most effective response by the communities, local administration and NGOs. Government is trying to develop a new warning system, training, communication, logistic support and resources (transport, manpower, hospital, first aid, rescue equipment). All food and first needed items are placed at the disposal of the local administration.

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8.5 Environmental Impact Assessment (EIA)

The Government has already introduced Environmental Impact Assessment (EIA), Geographic Information System (GIS) and Disaster Impact Assessment (DIA) in all development activities, contributing towards a sustainable development in the country.

9 Recent Changes in Disaster Awareness

On the morning of Novembre 23, 1995, just two hours after midnight at 2.00 a.m. during the peak danger period (signal No. 10) of the cyclone warning some shelters near Sagoria on the southern Hatiya island were found empty. The reasons why the evacuees did not come to shelter here despite of the great danger warning were:

1. weak management of the shelters,
2. long distance from the community,
3. no connecting road,
4. security hazards,
5. deterministic and fatalistic attitude (i.e. religious values),
6. fascinating/concern of livestock and personal properties,
7. no consciousness about the disaster/risk, and
8. personal beliefs on reliability of cyclone warning, i.e. often no storm/cyclone came despite of high warning signals.

Studies show that 73% of vulnerable people did not move to shelter on the basis of warning, 56% people indicated that the lack of shelters were their reason for not moving, 19% were unwilling to leave their houses and belongings, 11% did not move due to their fatalistic attitude.

A sudden significant change in the disaster consciousness (awareness) situation among the vulnerable people occurred on the eve of a severe cyclone which hit the coastal and offshore islands of Bangladesh on May 19, 1997 with a great danger signal no-10 (wind velocity: 180–200 km/h). This time most of the cyclone shelters of Hatiya island (also other coastal region) were occupied by evacuees with more than their capacity. It is estimated that more than 1.5 million vulnerable/risk people of the whole coastal and offshore islands took shelter during this disaster (cyclone) time. In Hatiya island a total of 72800 vulnerable people (20.8% of the total population) were evacuated in 105 cyclone shelters.

The reasons for this dramatic change in behaviour were:

1. disaster awareness developed largely among the vulnerable people on cyclone severity,
   - several awareness programmes organised by the Government – local administration, Bangladesh Red crescent Society, and other NGOs,
   - people were fully aware of and mentally prepared to face this disaster,
2. weather bulletin duly broadcasted on radio, television and published in the daily newspapers,
   - people got sufficient time to take shelter,
3. proper steps taken in time by the local administration to face (manage) disaster situation,
   - information, coordination, and team work
   - helped in managing the disaster,
4. heavy work done by the 32796 Bangladesh Red Crescent Society's volunteers,
   - volunteers were involved in awareness and evacuation processes in the whole coastal and offshore islands,
5. disaster hit during day time during low sea tides.

As a result, the numbers of casualties and damages were comparatively lower than earlier expected.

10 Present Activities

The Government of Bangladesh is now aware of the fact that appropriate and comprehensive policies for sustainable development lead to mitigating the sufferings of the people from recurring disasters in the long run. The concept of mitigation lies in disaster management and this policy is crucial in the whole exercise of risk minimisation activities. The managerial activities linked with long-term planning, ensures.

Therefore, the government has given emphasis and priority to the reduction of the adverse effects of disasters and established the Disaster Management Bureau to coordinate disaster management committees through national, district and thana level committees, to pursue the

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objectives of the International Decade for Natural Disaster Reduction (IDNDR, 1990–2000).

Ministry of Disaster Management and Relief, and Disaster Management Bureau published a book on "Standing order for Disaster Issues" in January 1998.

1. thana and Union level Action plan for Disaster Management,
2. guide lines for people during cyclone, tidal surge and flood have been published. Disaster Management National Action Plan is under processing.

Bangladesh observed the IDNDR Day in October every year to develop disaster awareness as well as to link with UN-organisations to share experiences. The National Disaster Management Council (NDMC) is continuously examining various dimensions of the problems, related issues and solutions on short, mid and long term basis.

The Cyclone Preparedness Programme (CPP, with its 32,796 volunteers) is a useful national organisation for cyclone warning dissemination to local communities, in the coastal and offshore islands – the vulnerable risk areas of Bangladesh.

Recently, the government decided to observe the National Disaster Preparedness Day on March 31 every year with the objective to create much awareness about various natural calamities, so that people can take proper precaution to face these, and minimise the loss of properties. In 1998 for the first time in Bangladesh various government and non-government organisations have observed the day in national and district level, under the theme "Cyclone is the Main cause for the loss of lives, Resources and Environment in Bangladesh".

11 Conclusions

The management of disasters in Bangladesh is now a process, run with the community needs, how vulnerable people adapt/face the environment having some tragic experiences in 1970, 1985 and 1991 cyclone.

Nevertheless, disaster awareness, constructing more shelters, new understandings on environment, education on disasters, training programmes and a comprehensive disaster management action plan are needed to overcome any future emergencies/crisis situation. Inter country and regional cooperation in sharing of knowledge, techniques, experiences and other assistances (as described in the objectives of the IDNDR, the UN declaration) with modern technology and experts are also needed.

The management depends on the non-structural elements of initiatives, motivation, decision making, immediate response, participation, sharing of services, team sprit, cooperation, coordination, inspiration, personal interest, dedication and ethics. To make the management process easier, every one should realise the crisis/emergency moment, to save even a human life with humanitarian feelings.

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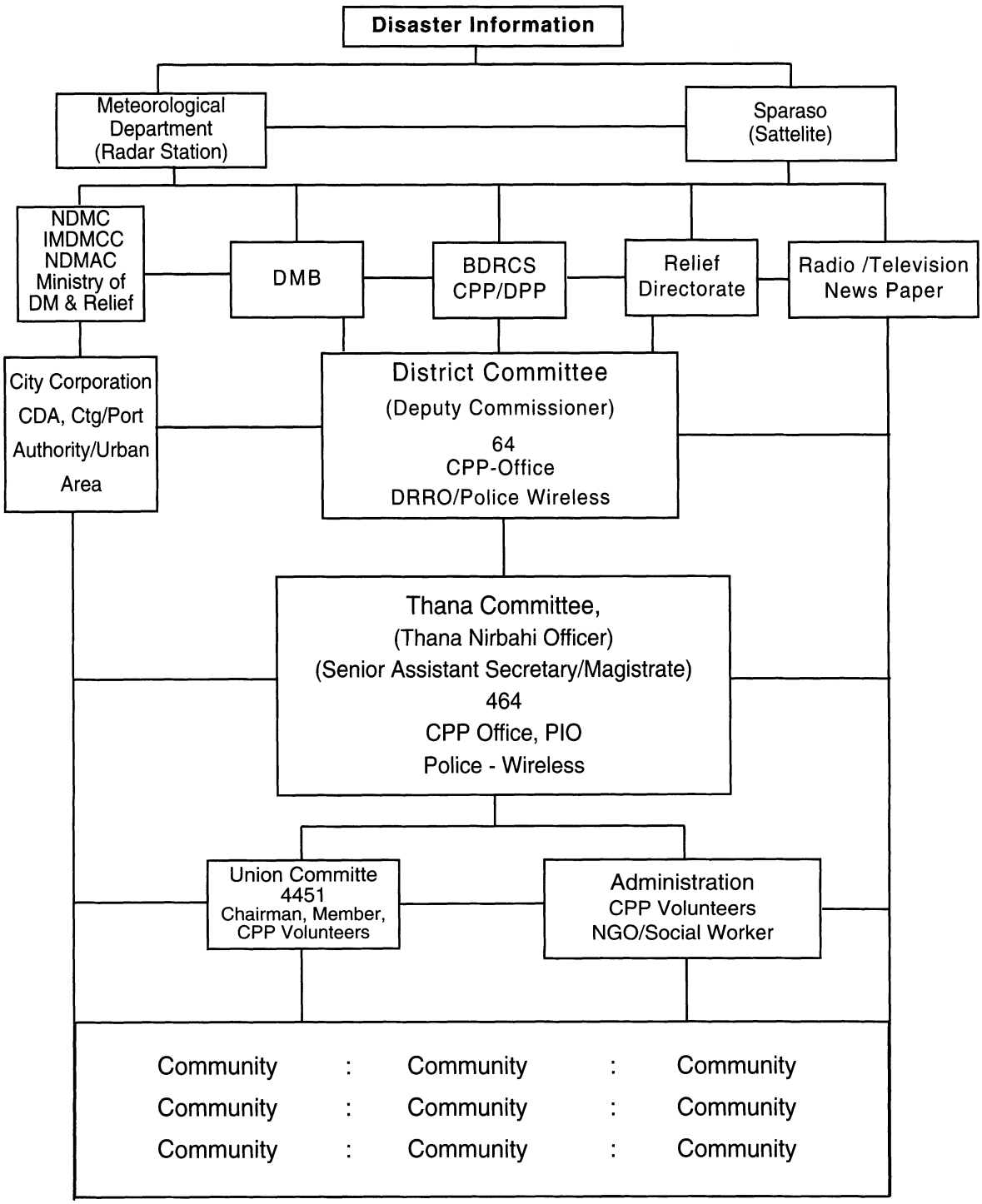
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Appendix 1

ORGANIZATIONAL CHART FOR DISASTER MANAGEMENT



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Appendix 2

Warning Message

From: Storm Warning Centre (SWC)
Bangladesh Meteorological Department, Agragaon, Dhaka.

To: ....., FAX:.....

REUTERS FAX: 832976	BTV FAX: 882927	APB FAX: 9115602	BSS FAX: 9568970	UNB FAX: 9344556	NEWS MEDIA

SUB: WEATHER REPORTS OF BANGLADESH.

DATE:.....

CITY/TOWN	MAX. TEMP (°C)	MIN. TEMP (°C)	R. HUMIDITY (09 a.m.) (%)	R. HUMIDITY (06 p.m.) (%)	24 HOURS RAINFALL (mm)
DHAKA					
CHITTAGONG					
KHULNA					
RAJSHAHI					
BARISAL					
SYLHET					
COX'S BAZAR					
COMILLA					
MYMENSINGH					
FARIDPUR					
JESSORE					
RANGPUR					
DINAJPUR					

SUNRISE (DHAKA) DATE: TIME: BST

SUNSET (DHAKA) DATE: TIME: BST

SUNRISE (DHAKA) DATE: TIME: BST

HIGHEST MAX. TEMP. OF THE COUNTRY WAS: .....°C, AT.....(Place)

LOWEST MIN. TEMP. OF THE COUNTRY WAS: .....°C, AT.....(Place)

WEATHER FORECAST, VALID FOR 24 HOURS TILL 06 P.M. OF .....(DATE)

.....

.....

.....

OUTLOOK FOR SUBSEQUENT TWO DAYS:.....

.....

....

EXTENDED OUTLOOK FOR ANOTHER FIVE DAYS: .....

.....

.....

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Appendix 3

Abbreviations

ADAB:	Association of Development Assistance in Bangladesh
APT:	American Picture Transmission
BBS:	Bangladesh Bureau of Statistics
BIWTC:	Bangladesh Inland Water Transport Corporation
BDRCS:	Bangladesh Red Crescent Society
BMD:	Bangladesh Meteorological Department
CPP:	Cyclone Preparedness Programme
CDA:	Chittagong Development Authority
DMB:	Disaster Management Bureau
DM:	Disaster Management
DPP:	Disaster Preparedness Programme
DRRO:	District Relief & Rehabilitation Officer
DUS:	Dwip Unnayan Sangstha (Island Development Organization)
DIA:	Disaster Impact Assessment
DG:	Director General
EIA:	Environmental Impact Assessment
ESCAP:	Economic and Social Commission for Asia and the Pacific
GIS:	Geographic Information System
GMS:	Geo-Meteorological Station
GTS:	Global Telecommunication System
HKI:	Helen Keller International
IDNDR:	International Decade for Natural Disaster Reduction (1990–2000)
IMDMCC:	Inter-Ministerial Disaster Management Coordination Committee
LGED:	Local Government Engineering Directorate
MAS:	Meteorological Application Software
MSS:	Message Switching Software
NDMC:	National Disaster Management Council
NDMAC:	National Disaster Management Advisory Committee
NGO:	Non-Government Organization
PIO:	Project Implement Officer
PSO:	Principal Staff Officer
PWD:	Public Works Department
SPARRSO:	Space Research & Remote Sensing Organization
SWC:	Storm Warning Centre
T&T:	Telephone & Telegraph
TNO:	Thana Nirbahi Officer (Thana Executive Officer)
UN:	United Nations
UNO:	United Nations Organization
UP:	Union Parotid (Union Council)
VDP:	Village Defense Party
WMO:	World Meteorological Organization

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II Early Warning and Public Communication

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CHAPTER 2.1

Public Communication of Warnings

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3 The Role of the Media 68
4 Emerging Opportunities 68
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1 Introduction

Throughout human history, societies have been subject to the vagaries of their environment. Natural and technological hazards result in major loss of life, social disruptions, and environmental degradation. The ability of a nation to manage emergencies, rather that react to crisis is critically dependent on the availability and flow of real-time information that is linked through a variety of information networks. Today's forms of networking depart from traditional centralization of information and place greater emphasis on international information exchange as a central function.

Warning the public of an impending disaster is the last line of defense in a nation's effort to mitigate the losses that both natural and technological hazards impose on our communities and citizens. In the United States, public warnings of one sort or another are an everyday occurrence. Individuals can act to save their lives even with relatively short notice. Longer lead times allow people to take actions that reduce losses by, for example, relocating moveable property.

Warning systems must be capable of delivering critical information to emergency management officials and the general public in a timely manner, which in turn helps to facilitate good decisions and a timely response by those in danger. In order to avoid confusion and elicit proper response, the national Meteorological and Hydrological Services and those organizations responsible for the issuance of geophysical related warnings, public safety officials and the media must work cooperatively to ensure that a clear and consistent message is provided to the public. It is vital to insure that there is only one single official voice in the issuance of warnings, and that must be the government. This requires not only effective communications and dissemination systems but also an extensive and ongoing public education program.

While working at the National Weather Service I marveled at what promise the new weather radar, satellite and surface observations systems offered in the warning process. How improvements in the numerical weather prediction models, utilizing the new observational technology and increased computational power had resulted in, improvements in the accuracy and timeliness of the weather and hydrological forecasts and warnings. But, no matter how good the technology or how accurate the forecasts and warnings, if the information does not reach the people in danger in a timely and understandable manner, that can be acted upon, then the warning system fails.

An effective public warning service is based on before-the-event emergency planning that produces cooperation, coordination and partnerships between the government and Non-Governmental Organizations, the media and private sector all key players in the warning process.

The panelists at ECW 98 presented a prospectus on the roles being played the Government, the media and the private sector in the warning process. The emerging opportunities and impact of new technology was explored and the unique warning needs of special populations and the difficulties of communicating warnings to dispersed populations was presented. The goal of the programs was to pro-

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vide a better understanding of the issues confronting us and a vision of improved public communication of warnings.

2 Role of the Government

National Meteorological and Hydrological Services (NMHSs), those organizations and agencies involved in the warning process, and their governments have no greater responsibility than ensuring the safety of their Nation's citizens from the ravages of natural hazards. Weather warnings and forecasts along with related hydrological and climatological products and services, geophysical warning and related information can contribute significantly to public safety and security and be of enormous socio-economic benefit if properly understood and acted upon. This presentation focused on the role of the government in the process of publicly communicating warnings, both meteorological and hydrological as well as geophysical.

3 The Role of the Media

The International Association of Broadcast Meteorology is an organization set up with the aim of improving the status of weather broadcasting, and of establishing and promoting appropriate standards and best possible practice in the profession world-wide. Many of the worldwide members, even though focusing primarily on weather presentations, also are involved in the communication of geophysical warnings and related information as well. The involvement of television and radio networks in the international dissemination of weather and other hazard related information has added a new dimension to the issues involving the role of the media in the warning process.

Cooperative efforts with local or national media outlets can greatly expand a National Meteorological and Hydrological Service and other agencies and organizations with a warning responsibility capability to reach the public-at-large with its forecasts, warnings and other bulletins. Cooperative arrangements can also facilitate the direct provision of weather information via live or taped radio or television broadcasts. They enable the responsible governmental organizations to carry out its responsibility to warn and inform the public more effectively while, at the same time, providing media outlets with highly desirable program content. During emergencies and major events such as floods, hurricanes or tropical cyclones, earthquakes, volcanic eruptions, etc. experts both from the media, NMHSs and other responsible organizations interact with the public through live broadcasts. These presentations are an extremely effective way to capture public attention and relay critical information and advice.

4 Emerging Opportunities

This presentation provided some insight on both the needs and the difficulties of communicating warnings to dispersed populations, many of whom are working at basic levels of subsistence economies. It focused on the difficult job to be done and the crucial relevance and interest of doing it to the state – in its own terms of effective resource application and protection of developmental accomplishments. The subject of effective warnings also relate to a number of elements important for developing national capacities – public information and education, environmental understanding and conservation measures, professional training (e.g. engineering, communications, teaching, public administration), emergency services, hydrology, meteorology, food production, agriculture, etc.

5 Warning Special Populations

Some segments of a population require special warnings simply by virtue of their unique character. Special populations can be defined in many ways, and they vary according to their level of risk, their particular characteristics or the amount of time they need to respond. These population segments include those in special facilities such as schools, prisons, old-age homes, hospitals and other institutions. The warnings required by such institutions are probably not different from the sort provided the general public. However, it is likely that such facilities would require more time for warning response than would be required by members of the general public. Consequently, it would be useful if means were provided to spe-

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cially communicate warnings to such facilities, as, for example, over tone-alert radios or dedicated phone lines.

Special populations with unique warning requirements can also exist in non-institutionalized settings. For example, the elderly may occupy a particular geographical region of town. Since older people require a larger effort to convince them to engage in protective actions such as evacuation, special warnings should be provided for their neighborhood, for example, route notification or through the frequent repetition of media warnings. Additionally, people who are hearing or sight impaired may require special alert and notification devices to be delivered effective warnings; and people who have mobility disabilities or who do not read or understand English have special warning needs.

6 Electronic Technology

The emerging development of the so-called information highway provides a new and potentially revolutionary option for the rapid, automatic, and global dissemination of emergency information. A number of individuals and groups, including several NMHSs and other organizations, are experimenting with the Internet for real-time dissemination of its information, including warning. It is already possible for subscribers to the Internet to access a wide array of environmental information and products on the network. Clearly, the advent of the Internet provides both opportunity and challenge in determining how best to harness its potential for dissemination of warnings and for the relay of other data and products while minimizing the problems associated with a new and open communications technology. With the advent of the Intranet for more secure internal distribution and plans underway in the development of the next generation on the Internet, the future use of electronic technology will play an even more important role in the future communication of warnings and other information to the public. This presentation will also demonstrate these capabilities to the audience.

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CHAPTER 2.2

Public Communication of Early Warnings: Role of the Government

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The preparation and communication of warnings of meteorological, hydrological and other geophysical events that have potential for natural disasters require a joint team venture that includes both government and the commercial or private sector, particularly the broadcast media. Traditionally, and in some nations defined by law, the role and responsibility of government is to prepare all early warnings acting as an "official voice;" whereas the private and commercial sector fulfil a responsibility of providing a major role in the actual dissemination to the public and in some cases specifically tailored warnings and forecasts for private and commercial clients. Within government there are, in most of all cases, separation of responsibilities both among scientific and disaster management agencies and within levels of government – i.e. national, provincial, and local – that must insure understandable credible communication to the public particularly during stressful periods. Advice or orders from public officials, and the way they are worded and disseminated have a major effect on reduction of injury and property (Baker 1996).

- THE ROLE OF GOVERNMENT IS TO PROVIDE ONE OFFICIAL VOICE IN THE PREPARATION OF NATURAL DISASTER EARLY WARNINGS WHICH MUST BE UNDERSTANDABLE, CREDIBLE, SOLICIT THE PROPER RESPONSE AND NOT CONFUSE THE PUBLIC.

Organisations such as National Meteorological, Hydrological, and other Geophysical Service Agencies generally have, as a prime mission, the ensuring of safety of their Nation's citizens and the protection of property. Most natural disasters fall within these scientific disciplines and coordination infrastructures have, in some cases, particularly in meteorology, been established to provide support on a global or regional scale to all countries. The need for an intergovernmental structure is apparent, because of the many natural disasters that form and develop in non-national territories, e.g. Ocean areas, or traverse in the course of the event through more than one nation. The important role at the national and sub-national scale is less clearly established for most nations and this is often a function of national sustainable development. In any case, there must be mechanisms to ensure that the many disenfranchised people – i.e. the poor, ethnic minorities, the aged, and those with disabilities – are included in the warning process.

- THE ROLE OF GOVERNMENT IS TO ENSURE A RESPONSIBLE NATIONAL INFRASTRUCTURE AS A PART OF ITS SUSTAINABLE DEVELOPMENT FOR THE ISSUANCE OF NATURAL DISASTER EARLY WARNINGS.

The goal of any warning system is to maximise the number of people who take appropriate and timely actions for the safety of life and property. Mileti (1990) defines a paradigm for successful warning systems that include equally important elements of Detection and Warning, Communication and Response. This suggests that an effective early warning system must consider as a minimum the following four functions: (1) the detection of a natural disaster causing event and its prognosis, (2) a knowledgeable public that understands and is aware of its natural disaster risks and is aware of actions on how to mitigate the impacts, (3) a call to action to the public to respond (e.g. evacuation, going into a storm shelter, etc.), and (4) an infrastructure that can disseminate warnings and forecasts when they are issued. Within government, at both the national and sub national

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level, the responsibilities for functions of preparing a warning, issuing a call to action, educating the public, and ensuring adequate dissemination is given to more than one agency. At a minimum, this would included the National Agency responsible for preparing the warnings, e.g. National Meteorological Service; the agency authorised to order or mobilise public actions, e.g. National Disaster Management Agency.

- THE ROLE OF GOVERNMENT, USING THE EXPERTISE OF ALL NATIONAL AND SUB-NATIONAL AGENCIES INVOLVED IN EARLY WARNING SERVICES, IS TO PROVIDE AWARENESS AND PREPAREDNESS EDUCATION TO THE PUBLIC.

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CHAPTER 2.3

The Role of the Media in Public Communication of Early Warnings

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1 Introduction

My viewpoint is that of a professional meteorologist and journalist. I have been working in the weather-department of ZDF German Television for 10 years broadcasting weather on TV and I am also chairperson of the International Association of Broadcast Meteorology (IABM). ZDF is a national TV station with the governmental mandate of distributing the whole spectrum of information – from cultural aspects to political news to the public.

IABM has been set up with the aim of improving the status of weather-broadcasting by establishing and promoting appropriate standards with a sophisticated data supply for the best possible weather forecasts on radio and TV.

Unfortunately weather plays a big role in history of natural disasters. Therefore, it is very important to find an adequate placement for weather warnings on TV and radio.

The ZDF weather department – similar to many other weather departments in TV stations all around the world – is closely related to the news. We are, therefore, confronted with the whole spectrum of the news, containing quite frequently headlines about severe weather occurrences around the globe with impact on life and property. Therefore, our profession should not be only to have a "nice chat" about the weather, but to compile a broadcast which is serious enough to strengthen our credibility on all weather types.

1.1 Role of the Media in Public Communication of Warnings

The task of the media – consisting mainly of TV and radio (Internet in progress) – is in the widest sense the communication of information to the population.

1.2 Nature and Components of News

The nature of the news should be neutral and should not contain opinions. News consists usually of 5 main parts: politics, sports, hazards (events, disasters), cultural aspects, and weather.

Warning issues should be attributed to the news although there should be possibilities to place warnings in other parts of the program if necessary.

1.3 News Sources

1. Press agencies
2. Governments
3. Other national authorities (e.g. disaster control)
4. Correspondents

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With the help of satellites, TV and radio is the main means of a timely communication of world-wide information to the public. The TV and radio segment is divided into:
- National,
- Regional,
- International,

and should also play a role in the nature and address of warnings.

1.4 Responsibility – Challenges – Risks

As TV has changed the world to a kind of unique planet, where accidents/incidents happening in one corner of the world are reported accompanied by images in many other parts of the world, it is adequate to use this means of communication more frequently to transfer the warnings effectively to the population.

But there are also risks: thousands of TV and radio stations are presenting news from all around the world to their audience. The so called "news"-world in that way has become very transparent, but also very competitive. With the rapid development of communication techniques but also private TV stations, there is a constant battle for the newest and best headlines, and, thus, includes the potential for negligent research and even modified stories.

1.5 Seriousness

The quality of information however depends very much on the seriousness of the TV-station investigating and processing the information. As millions of people are watching weather news and headlines every day, weather broadcasters have a serious responsibility.

1.6 Potential of Influence

With TV and radio large portions of the population could be influenced if desired. Therefore, the quality of weather information combined with the credibility of the weather broadcasters are important.

High standards of information processing together with proper procedures of warnings are essential. These standards are very important with the future challenging us with more news on a changing world, and negative weather events in the world news will play a tremendous role. This needs neutrality and competence in the information transfer.

1.7 Quality and Nature of a Weather Report

- Prediction of day to day weather
- Comment on weather occurrences – headlines
  - Storms
  - Droughts
  - Climate change etc.
- Live coverage of weather events.

2 Role of the Media in Communication of Warnings

should depend on the range of the TV station – (national, internationally)

2.1 Issue of Warnings

ZDF and many other TV stations have not played an active role in issuing warnings. ZDF broadcasts officially publishes warnings "as news" with and without required actions to save life and property, which have been issued by governments or other appropriate originators – but has so far no active role in communicating these warnings. However, TV could play a more major role if it is properly defined.

2.2 Coverage of National Severe Weather

The ZDF weather department – in case of severe weather nationally – does not get any specific warnings from the National Met Service. The procedure up to now has been as follows: when recognising that severe weather might occur – by studying prediction charts – it is carefully addressed in weather reports without advising people to take actions. This is also an example of how TV stations could act without interfering with governmental or other authorised required actions.

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2.3 International Severe Weather

International weather events, sometimes warnings but mostly when an event has already occurred (Hurricane) – are in the headlines all the time, and we might have to comment them – but without any active advice for the people. In the case of a comment on an occurrence, the precondition should be a reliable source of information which is quickly available and in most of the cases so far has been NOAA or WMO.

In cases when weather information is available we just hint to possible occurrences.

3 Requirements for Communication of Early Warnings to the Public

3.1 Source of Information

A reliable single source of information is absolutely recommended, which could be the government, the National Met Service or authorised private institutions. In a lot of countries this is regulated by law. But procedures on how this information could be easily accessible or distributed for the different users are not available everywhere.

3.2 Procedures

Procedures on how TV and radio stations should handle the warnings immediately if required should be clearly defined.

3.3 Adequate Training

There is an essential requirement for properly trained weather broadcasters who can adequately handle warnings and give appropriate comments on the occurrence.

With the potential of influencing large parts of the population, any presenter of weather-information should be aware of the responsibility he has to assume. Therefore, he should have the best and reliable information possible. Especially when informing his audience about severe weather accompanied by an official warning.

There is no doubt, that there should be a single source for warnings. The National Met Services through the WMO organisation respectively the governments have the potential to gather the most reliable information worldwide. They should assume more responsibility in processing the information to appropriate sources for distribution.

This requires a very close cooperation between the people presenting the information to the public on TV or radio and the people deciding to issue a warning.

It should not be a problem, when the presenter reads out an official warning-notice. But on TV and radio information has often to be reduced due to time limits which might result in giving only half the warning, especially when journalists acting without understanding the context of the warning. Proper procedures should be developed.

4 Summary

The authority of professional weather-broadcasters has to be strengthened through a better communication to the Met services, to the governments responsible and to producers on TV. The communicators have to be made aware of their responsibility in information processing.

El Niño, which is a global occurrence, has been a good example for early forecasts about severe weather-activities in some parts of the world. So at least some countries could be prepared, although nobody could prevent the occurrences itself. But it has been very controversially discussed on TV, attempting also to ignore El Niño.

There should be a special official statement for the press dealing with the facts, and the possible damages and also offering contact persons for further questions. Then the media could help in the early warning process.

IABM as an international organisation is prepared to help in this process – with the transfer of relevant questions, aspects and procedures to the international membership. The membership consists currently of weather casters from 24 different nations around the world, and it is growing. IABM is hoping to organising training-initiatives – hopefully together with WMO and the National Met Services – that will help the members to reach or maintain these standards.

A cooperation is also about to start with the AMS (American Meteorological Society).

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CHAPTER 2.4

Early Warning: Community Interpretations and Perceptions – A Case of Recurrent Floods and their Warnings in Delhi (India)

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Introduction

Damages in urban areas due to floods, as due to other disasters, have been showing an increasing trend over the past decades. This is primarily due to increasing economic attractions in urban areas and resulting population pressures where more and more people occupy vulnerable regions of land, that had been left undeveloped hitherto. Governments and the disaster management community have responded by stressing the urgent need for the improvement of forecasting and warning systems for reducing disasters, and as a result, better weather forecasting satellites with higher resolutions are launched every year, and faster and more efficient super computers are commissioned to the task of providing more advanced and accurate forecasts.

However, the reason for increasing damages in spite of timely forecasts does not lie in forecasting and warning technology, but elsewhere. It lies with the last link of warning dissemination, the community link, which is either totally missing, or grossly inadequate. The warnings that the end user, i.e. the community, receives are often neither at the right time, nor in the right format to be effective. Where available, it is often misinterpreted. It does not provide enough information to base decisions on, and is presented in such a manner that it is not easily understood by the target audience.

As a result, the community has lost faith in warning systems, and there is a distinct attitude of indifference towards the warnings. Dependence is still primarily on the local warning mechanisms, which, though reliable at a micro level, are often very risky due to their very tight time margins.

There is, therefore, an urgent need to strengthen warning dissemination mechanisms at community level, and bridge the communication gaps that exist at present. A better public communication system for disaster warnings, coupled with enhanced awareness and understanding of the same at community levels, would go a long way in reducing the impact of disasters.

1 Delhi and her Floods

The river Yamuna originates from the Yamunotri springs of the Bander Punchh glaciers at an altitude of 6300 meters, in the range of lower Himalayas in Uttar Pradesh. Many streams join the river during its course. The river flows in a southwestern direction. About 20 kilometres from its origin, it receives the first major tributary, Tons, near Dak Patther. Another tributary, Giri, joins the river near Paonta. The river penetrates Tajewala, where a weir has been in existence for about 100 years. From this point two major irrigation canals, Eastern and Western Yamuna Canals, take off to Uttar Pradesh and Haryana respectively. No other tributary joins the river from Tajewala upto Delhi. The catchment above Tajewala is hilly and broad, while below Tajewala it is sandy and narrow.

The capital city of Delhi, with a population of over 10 million, has been experiencing floods of

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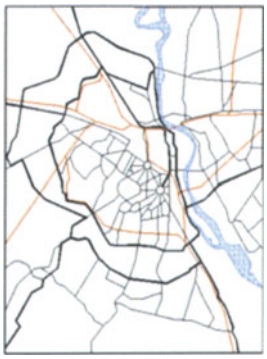


Fig. 1. River Yamuna in Delhi

various magnitudes in the past due to overflowing of the river Yamuna and the major drains in the city (Fig. 1). The Yamuna river traverses about 48 kilometres within the boundaries of the city. The river has risen above its danger mark 27 times during the last 35 years. In the recent past, floods of high magnitude have occurred in 1977, 1978, 1988 and 1995, causing loss of life and property.

The floods of September 1995 caught everyone's eye because the affected population had to abandon their inundated houses, and came to squat on the roadsides, clogging the city's major thoroughfares, such as the ITO bridge. Few understood that these thousands of men, women and children had to leave their homes because they live inside the riverbed – on the wrong side of the embankments.

As Delhi watched with curious interest the rising level of the Yamuna, the life of the evacuees on the city roads, and the efforts of the city government to manage the situation, hardly anyone was aware that six of the seven embankments that protect the city from Yamuna floods had developed cracks and were leaking. Had even a single one of these breached, it would have spelt doom for a large section of the city. Fortunately, this did not happen that year.

Overflowing of the drain systems also causes floods. This happens when there is a backflow in the drains due to high level of water in the river and heavy runoff from the surface areas.

Of immediate concern due to a rise in the river's water level are the informal settlements, which have come up between the river and the embankments, and house an estimated population of more than 150000. Expectedly, these settlements face the threat of total inundation when the river is in spate.

2 The Flood Forecasting and Warning System

Flood forecast formulation and management involves the following processes:

1. observation and collection of data from field stations;
2. transmission of data from field stations to forecasting centres;
3. data processing and formulation of forecasts at the forecasting centres;
4. dissemination of forecast; and
5. forecast monitoring and evaluation.

A pilot project for the improvement of the river and flood forecasting system in India was commenced in 1980 as a UNDP/WMO aided project for the Yamuna up to Delhi. Data acquisition systems using sensors have been installed and further improvement using satellite communication technology has been introduced. Regarding formulation of forecasts, various models have been tailor-made, calibrated and utilized for forecasting purposes (Fig. 2).

The Upper Yamuna Division of the Central Water Commission keeps hydrological observations in the upper Yamuna basin from the origin of the river upto Delhi railway bridge. Flood forecasts are issued during the monsoon season (June 15 to October 15) when the water level at Delhi railway bridge crosses 204 m or is likely to cross this level, which is marked as the danger level. The forecast is disseminated to Delhi Administration, concerned Ministries, Military and para-military forces 48 to 53 hours before the incoming flood so that they can initiate flood fighting plans and arrange evacuation from low lying areas.

3 Warnings at Community Level: *Totally Faded*

At the end of the resource intensive flood forecasting and warning process, the warning that reaches the most vulnerable community, the hutment dwellers in the riverbed, is a cryptic one line statement, saying "the water level is expected to rise, make your arrangements." This community is from the lowest economic strata of society, and as such, access to televisions and radios is low, as well as the level of literacy. The warning that is issued, comes

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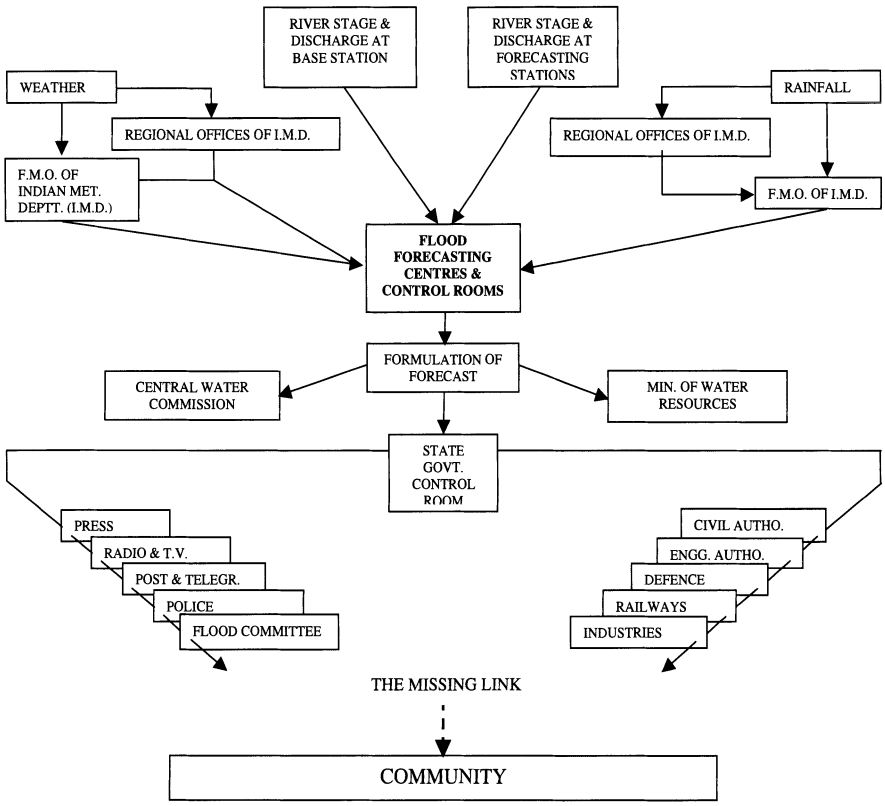


Fig. 2. The Flood forecasting and Warning System

through the local police, and a policeman goes around the settlement, making the announcement. The warning includes no element of expected time of flooding, quantity of water being released from the headworks, areas expected to be submerged, or duration of high flow. As such, it holds little information or meaning.

Furthermore, since the water level in the river crosses its danger mark almost every year (it did so 27 times during the last 35 years), and the warning is issued whenever the level crosses this mark, or is likely to cross it, the community ends up receiving this same flood warning every year. However, floods do not occur every year. Since the warning holds no information on the probability or severity of the expected flood, over time it has come to lose its significance.

In the absence of a reliable warning system, the community residing in the Yamuna river bed has depended on its own local warning system, and continues to do so. In times of the monsoons, a vigil is kept at the edge of the settlement facing the river. The residents have arrived at their own benchmarks: when the water level reaches the last of the farms abutting the settlement, it is time for sounding an alert in the settlement; when it reaches the first drain, it is time to move the household goods to the roadside pavements atop the river embankments; and when the level reaches the first paved lane of the settlement, it is time to abandon their homes and move to the safety of the embankment tops. This warning mechanism is reliable; however, the time margins are very very narrow, and based on on-site observations. As a result, often not enough time is available for the residents to save their property. Not knowing what to expect next, and when, the residents constantly live on the edge during the months when floods can be expected.

The technology based flood forecasting and warning system, established, and constantly upgraded, to serve them, is a waste, and is of no benefit what so ever to these people.

4 Basic Issues and Future Directions

The case of flood warnings in Delhi is representative of the general state of disaster warning dissemination in India, and other developing countries. In order to make the warnings more effective, and make best use of developments achieved in the area of disaster forecasting there is an ur-

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gent need to strengthen the public dissemination link of the disaster warning systems, particularly with reference to vulnerable communities with weaker economic backgrounds.

The warnings issued need to be precise, yet provide all relevant information regarding the impending disaster such as expected time, magnitude and specific areas to be worst affected. The warning needs to be reliable, and should not be resorted to regularly and casually.

Finally, awareness of the communities regarding interpretation of warnings, and appropriate action to be taken on these, is a crucial need.

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CHAPTER 2.5

Disaster Early Warning and Individuals with Special Needs: In Aggregate, the Underserved Represent a Significant Portion of Society

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1 Introduction

Determining the need for warning, or even issuing an accurate and timely warning, is not the end goal of an early warning system. The goal is to save lives and property; the ultimate objective of the warning process is to provide information to individuals at risk so they can make informed decisions and take action in order to avoid, or at a minimum reduce, the risk. The process of effective early warning of natural disasters includes identifying the risk or event (i.e., hurricane, volcanic eruption, wildfire, etc.), identifying populations vulnerable to that risk, and communicating warning so that communities are informed and sufficiently impressed that they take effective preparedness actions before and during the onset of the anticipated event.

In any society there are individuals for whom, from-time-to-time or always, modifications of technologies or routines are necessary to effectively perform everyday functions that to the majority in their community may seem ordinary. It should come as no surprise, then, that in times of emergency, these individuals may require special attention, too, including modifications to the warning messages, adaptation of assistive technologies to receive warnings, or help in responding to warnings once they know the appropriate action that is required.

In the United States it is estimated that there are twenty-six million Americans who are hard of hearing.[1] There are also 20 million individuals with low vision.[2] Further, there is a rapidly growing aging population for whom complying with evacuation or other preparedness directives may be increasingly difficult: for example, in addition to potential decreased mobility, prevalence of visual impairment is age-related. In 1997 there were more than four million individuals in the United States age 55 or over who were experiencing severe vision loss. Prevalence of severe visual impairment is 47 per one thousand in individuals 65–74 and, by age 85, one in four older people cannot read a newspaper even with best corrected vision.[3]

Even though the numbers of disabled persons who may need assistance because of their disability might seem significant, they are still not inclusive of individuals who have no physical or mental disability but are in need of special assistance, nevertheless. These persons include transients, tourists, and others who may not be familiar with the surroundings or even the language of the vulnerable area. In aggregate, these people make up a significant percentage of any society's population. In addition to individuals who are blind or visually impaired and those who are deaf or hard of hearing mentioned above, they include:[4]

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[1] Self Help for Hard of Hearing People, Inc., 7910 Woodmont Avenue, Suite 1200, Bethesda, Maryland 20814, USA 301-657-2248.
[2] National Association for Visually Handicapped, 22 West 21st Street, 6th Floor, New York, NY 10010, USA, (212) 889-3141, http://www.navh.org.
[3] Testimony of the National Aging and Vision Network to the Subcommittee on Post Secondary Education, Training and Life-Long Learning of the Committee on Education and Workforce of the United States House of Representatives, April 23, 1997.
[4] Partial list of disability classifications covered in the Americans with Disabilities Act of 1990.

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- Individuals with varying degrees of mobility impairments, ranging from slow walkers to wheelchair users;
- Individuals with temporary impairments due to recovery from serious medical conditions such as a stroke or traumatic injuries such as a broken leg or a sprained ankle or surgeries such as a knee or hip replacement.
- Individuals with medical conditions such as respiratory disorders or pregnancy, who may tire easily and who may need special assistance or more time to evacuate; and
- Individuals with mental impairments who may become confused when challenged with the unusual activity during an emergency, lose their sense of direction, or require having emergency directions broken down into simplified steps/basic concepts.

In the United States, the Americans with Disability Act (ADA) prohibits discrimination on the basis of disability in employment, programs and services provided by state and local governments, goods and services provided by private companies, and in commercial facilities. The categories of individuals with disabilities listed above are covered by the ADA.

The ADA was signed into law on July 26, 1990, and it contains requirements for new construction, for alterations or renovations to buildings and facilities, and for improving access to existing facilities of private companies providing goods or services to the public. It also requires that State and local governments provide access to programs offered to the public. The ADA also covers effective communication with people with disabilities, eligibility criteria that may restrict or prevent access, and requires reasonable modifications of policies and practices that may be discriminatory.

Dialing 9-1-1 is the most familiar and effective way Americans have of finding help in an emergency. The ADA requires all Public Safety Answering Points (PSAPs) to provide direct, equal access to their services for people with disabilities who use teletypewriters (TTYs), which are also known as telecommunications devices for the deaf (TDDs). Though not specifically identified as an early warning measure, the ADA also provides for the requirement that audio and visual systems be placed in buildings and facilities in restrooms and any other general areas of common public use (i.e., meeting rooms, hallways, lobbies).[5]

Further, systems used for emergency notification must comply with the Underwriters Laboratories Standard for Emergency Signaling Devices for the Hearing Impaired. The signaling devices covered in the UL1971 standard are designed to alert persons with hearing impairments through the use of light, vibrations, and air movement. For hearing aid users, development of these devises must take into consideration that hearing aids also amplify background sounds, and the sound of the emergency alarms may interfere with or even drown out voice announcements of an emergency voice communications system.

An example where technology have been adapted to meet special needs is the Weather Alert Radio program of the U.S. National Oceanic and Atmospheric Administration (NOAA). The newest generation of NOAA weather radios have features that let users preselect the National Weather Service warnings they want to receive based on where they live. These radios, which now cost less that USD 25.00 will automatically turn themselves on and sound an alarm when severe weather is forecast for the area for which the radio has been programmed. Peripheral technology, such as flashing lights, can also be added.

Once a warning is received by a disabled individual, there is a need to ensure that individual has a good chance to take the appropriate action, for example, seek public shelter. There are technologies that are making this easier, too.

Audible remote signage is a way of informing individuals who are visually impaired of what they need to know about their environment. Particularly useful for safe evacuation of building, audible directional instructions can be transmitted by low power radio waves or infrared beams. The signal/instructions are then picked up by a small receiver carried by the individual (e.g., the exit is 25 steps south of the front desk, or simply stairway, restroom or elevator) act as signals when one approaches a stairway, restroom or elevator. Movement aids such as controlled descent devices for wheelchair users can also prove useful.

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[5] Emergency Procedures for Employees with Disabilities in Office Occupancies. Published by the U.S. National Institute of Standards and Technology and the National Task Force on Life Safet.

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Though technologies like those discussed above are proving to be effective, and in many cases truly indispensable aids to the early warning process, they alone cannot solve the problem. Few technologies override the value of human intervention in certain settings.

In an informative publication called Emergency Procedures for Employees with Disabilities in Office Occupancies, the National Institute of Standards and Technology and the National Task Force on Life Safety and People with Disabilities offer some observations and recommendations for providers of spontaneous assistance in early warning (and response). Many of them are common sense. All of them are important.

2 Assisting Individuals who are Visually Impaired or Blind

- Announce your presence; speak out when entering the work area.
- Speak naturally and directly to the individual and NOT through a third party.
- Do not shout.
- Offer assistance but let the person explain what help is needed.
- Describe the action to be taken in advance.
- Let the individual grasp your arm or shoulder lightly for guidance. He/she may choose to walk slightly behind you to gauge your body reactions to obstacles; be sure to mention stairs, doorways, narrow passages, etc.
- If leading several individuals with visual impairments at the same time, ask them to hold hands.
- You should ensure that after exiting the building that individuals with impaired vision are not abandoned but are led to a place of safety, where a colleague(s) should remain with them until the emergency is over.

3 Assisting Persons who are Deaf or Hard of Hearing

- Inside buildings, flick the lights when entering the work area to get the person's attention.
- Establish eye contact with the individual, even if an interpreter is present.
- Face the light, do not cover or turn your face away, and never chew gum.
- Use facial expressions/hand gestures as visual cues.
- Check to see if you have been understood and repeat if necessary.
- Do not allow others to interrupt while conveying the emergency information.
- Offer pencil and paper. Write slowly and let the individual read as you write. Written communication may be especially important if you are unable to understand the individual's speech.
- Be patient. The individual may have difficulty comprehending the urgency of your message.
- Provide the individual with a flashlight for signaling their location in the event that they are separated from the rescuing team or buddy and to facilitate lip-reading in the dark.

4 Assisting Individuals with Learning Disabilities

Persons with learning disabilities may have difficulty recognizing or being motivated to act in an emergency by untrained rescuers. They may also have difficulty in responding to instructions which involve more than a small number of simple actions. Some suggestions for assisting such persons include:

- Visual perception of written instructions or signs may be confused.
- Sense of direction may be limited, requiring someone to accompany them.
- Directions or information may need to be broken down into simple steps. Be patient.
- When assisting persons with learning disabilities simple signals and/or symbols should be used.
- A person's ability to understand speech is often more developed than his/her own vocabulary. Do not talk about a person to others in front of him/her.
- The individual should be treated as an adult who happens to have a cognitive or learning disability. Do not talk down to them or treat them as children.

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CHAPTER 2.6

Bringing Early Warning to the People: Electronic Technology: The Role of the Internet

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Most natural hazards are intricately tied to global developments, whether they be climatically-based or influenced, as is the case with storms, floods, wildland fires and droughts; geophysically-based, as is the case with earthquakes, tsunamis and volcanic eruptions, or biologically-based, as is the case with human, exotic plant and animal diseases.

Similarly, in the case of technological hazards, their consequences can often be felt throughout the world, and even impact upon countries that are thousands of kilometres away from the source of the incident. The scope of these hazards varies considerably, ranging from water and air pollution, the re-entry of space debris, nuclear accidents and dangerous chemical releases to structural, utility and networking failures.

Research has shown that a close interrelationship exists among hazards identified at local, national and international levels and that failure to heed interdependencies can seriously limit knowledge about potential hazard impacts and jeopardise effective response to them, especially warnings. Furthermore, given that the impact of hazard occurrences spreads across economic, social and political boundaries, the adequacy of the cumulative response is greatly influenced by the degree to which proactive or mitigative, as well as reactive action can be effectively integrated and optimised.

Therefore, it is important that those who are responsible for disaster mitigation, preparedness and response be given access to the widest range of information pertaining to such hazards and their effects. Once such information has been collected, critically analysed and evaluated, it is equally important that they be given access to the most effective means through which to communicate results to colleagues, policy makers, practitioners and most importantly, when warnings must be issued, to the public and emergency responders. Communication and the exchange of information, therefore, become the basis of progress towards the goal of reducing the effects of hazards and disasters in all societies.

Consequently, it is prudent for all concerned with disaster reduction to examine the benefits of establishing networks of interconnected local, regional, national and international information systems related to hazards and associated risk reduction processes.

The emerging development of new electronic networks, such as the Internet, provides a timely and revolutionary option for rapid, automic and increasingly near global dissemination of early warning and preparedness information, and for integrating and coordinating information activities across disciplines and across national and international jurisdictions. Numerous individuals and organisations have been developing Internet services for delivery of near and real-time hazard data.

Clearly, the advent of the Internet provides both opportunity and challenges to the international community in determining how best to harness its potential for dissemination of warnings while minimising the problems associated with a new and open communication technology. Among the major challenges to overcome are the abilities of organisations and regions to scale and organise their networks appropriately in order to ensure that the right type of infor-

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mation reaches the right organisations at the right time and in a form that is relevant and meaningful.

In this regard, it is important to recognise that national, regional and local communities have different needs, priorities, capabilities and expertise, jurisdiction, financial resources and perceptions of risk. Especially at the community level, it is also important to recognise the relative values of traditional systems in addition to the benefits of more contemporary technologies, as well as to ensure that each type can be adapted and integrated when appropriate.

The Internet now provides open access to an extremely wide range of hazard related information products and services. For example, many national meteorological services already provide Internet access to their public weather services and, in some instances, to more specialised ones such as marine and aviation forecasts and warnings. In addition, a very large number of university groups, private sector companies and individuals also make weather information available on the Internet.

In some instances, this information is extremely detailed including not only forecasts and warnings, but also satellites and radar imagery, hourly weather observations, storm tracking and climatic data. A review of Internet sites and applications reveals that warning information concerning a number of hazard-types is now emerging. Some of the most prominent are in the areas of meteorology and hydrology, vulcanology, wildland fires and tsunamis.

The spread of the Internet world-wide and the scope of services offered have been truly remarkable. Only four years ago, I was demonstrating its application to disaster reduction at the Yokohama World Conference on Disaster Reduction. For many delegates, this was their first glimpse of this new technology. At that time, having an electronic mail account was considered novel, and using Gopher, a text-based browser to connect to information sources around the world was considered truly revolutionary.

The following year, 1995, new projects using world wide web servers and browsers to organise and display graphical and text information began to emerge and expanded to include new multi-media applications, including audio and video capabilities. Many participants at this conference now make extensive use of these facilities to communicate with colleagues and the public.

The following brief list of examples is offered to highlight how some organisations are making warning or warning-related information available over the Internet. While the list is not intended to be all-inclusive, it does serve to highlight the diversity of approaches and information available.

Meteorological/Hydrological

FEMA Tropical Storm Watch
http://www.fema.gov/fema/trop.htm

Interactive Weather Information Network
http://iwin.nws.noaa.gov/iwin/graphicsversion/main.html

U.S. National Hurricane Center
http://www.nhc.noaa.gov/

WeatherNet
http://cirrus.sprl.umich.edu/wxnet/

National Drought Mitigation Centre
http://enso.unl.edu/ndmc/watch/watch.htm

Tsunami

West Coast & Alaska Tsunami Warning Center
http://wcatwc.gov/

Wildland Fire

Canadian Wildland Fire Information System
Canadian Wildland Fire Network
http://www.nofc.forestry.ca/fire/cwfis/

Volcanoes

Volcano World
http://volcano.und.nodak.edu/vwdocs/current_volcs/current.html

Alaska Volcano Observatory
http://www.avo.alaska.edu/

Cascades Volcano Observatory
http://vulcan.wr.usgs.gov/home.html

Hawaiian Volcano Observatory
http://wwwhvo.wr.usgs.gov/observatory/

Total Ozone Mapping Spectrometer
http://jwocky.gsfc.nasa.gov/eptoms/ep.html l

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Food

Food and Agricultural Organizational – Global Information and Early Warning System
http://www.fao.org/WAICENT/faoinfo/economic/giews/english/giewse.htm

Human Diseases

World Health Organization – Surveillance and Epidemic Response
http://www.who.int/emc/surveill/index.html

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III Aspects of Disaster Management, Emergency and Social Respone with Respect to Early Warnings

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CHAPTER 3.1

Systems and Problems of Early Warning in Germany

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German disaster experts currently state, that a central warning and alert system for the territory of the FRG does not exist. This means, that the registration of emergencies and disasters, the information and warning of the population and a comprehensive and effective exchange of scientific information as a vital part of disaster prevention cannot be provided by federal, regional or local authorities.

In the former FRG (before the reunification) a warning network consisting of more than 65 000 electric and about 600 electronic power sirens, combined with a central steering and set off, was primarily focused on a military threat and first strike by Warshaw Pact forces.
The former GDR (as part of this communist military alliance) provided more than 22 000 sirens against air raid and bomb attacks. After the reunification of both German states in 1990, the Federal Republic of Germany decided on a restructuration and modernisation of the warning service. The aim: Quick and adequate warning and information for the public.
The department responsible for these affairs is the Ministry of the Interior.

In 1996, the "Warning Service" was completely dissolved. The 11 sheltered warning agencies in addition to 40 others and complementary measuring and warning posts, operated by 330 civil servants and approx. 1 800 volunteers, were reduced to 8 warning agencies, one of them in the former GDR.

The sirens were reduced or handed over to other civil authorities, especially those communities, responsible for fire prevention and fire control respectively the local warning and information of the residents.

The reason for the above mentioned changes was the ability of this former "siren-warning-system" not only to warn and inform about military threats and defence situations. It could be also used regionally to warn of natural and technical disasters, fires, accidents with dangerous goods etc. Regional and local authorities such as counties and municipalities represent the responsible warning level by law and technical opportunities. The consequence of the "federal retreat" was the dismantling of more than 40 000 sirens and the loss of federal control of a functional nation-wide warning system.

A new system was to incorporate the use of radios to warn, inform and instruct the population by oral announcements.

The agreement between federal, state, county and community levels was based on the common and mutual commitment to use technical components for covering a territory-wide Radio/Warning-information-system (WARI) by principal support of the broadcasting stations.

The effectiveness and success of this system depends mainly on the readiness of the population to buy (on their own expense) a radio with an integrated warning component, like an alarm-clock, and the ability to understand the warning signals.

Negotiations with the broadcasting stations were completed with positive results, however, the information by the federal/state governments respectively. the canvassing of the public is still on a very low level (5–10%). Besides, industrial producers do not reproach low prized technical equipment.

And if an innovative engineer presents an invention – a brand-new environmental warning radio with an integrated warning component (alarm-clock) –, as happened in August 1998, the responsible federal CD-Agency (Bundesamt für Zivilschutz) refuses and denies the existence of any economical market in Europe.

Instead of a dialogue with the industry the agency refers to a research order from 23/01/

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1998 which was initiated by the Federal Republic together with the 16 states (Länder).

The aims are to develop an integrative alert, warning and information system, to describe the technical assumptions, to analyse existing techniques (like RDS) and the possibility of their inclusion.

This research study is currently in work (my critical comment: 8 years after the reunification).

Finally it must be said:

Unfortunately the WARI project was never realised, so that an automatic nation-wide warning system seems to be a utopian and visionary plan – not because of technical but due to political and monetary barriers.

The present status of warning:

1. The federal state covers ":dangers of aerial warfare" and "potential military threat." To fulfil those tasks the FRG provides three military Airforce-operation centres (sheltered).
   The civil defence organisation is linked by liaison units which are integrated and implemented in the military structure. Military perceptions and recognitions are used for the warning and information of the population.
2. Measurement for environmental protection and pollution is the responsibility of the Federal Ministry for Nuclear and Environmental Affairs and is based on a network of 2150 measuring posts, operated automatically and combined in a data bank system within the Federal Agency for Radiation Protection. It can be used to measure environmental activity (IMIS) and nuclear-specific contamination.
   This offers the ability to register nuclear, air raid and environmental threats to the whole territory, but excludes an early warning system for each type of natural and technical disasters.
3. The federal states are responsible for tackling other kinds of disasters such as natural or technical disasters. Activities for disaster prevention and mitigation respectively. disaster protection and intervention are in the political and administrative responsibility of various departments within federal, federal state or local government authorities.
   For example: the most important level for disaster management is the county or county-free-city. There are more than 510 authorities within 16 states in Germany: How to combine these independent authorities with very different political and economical resources?
   And – it has to be emphasised again – for peacetime disasters the federal states (Bundesländer) are the only responsible authorities with an independent legislation outside of any federal influence and the possibility to take care for standardisation and harmonisation of different acts.
   It shows, that Germany knows the deficit – "the gap" – but at present there are no plans to compensate it.
4. The fragmentary components of an early warning system aimed and accepted as recognising disaster and warning instrument for the safety of the population when disaster strikes are not connected and at present uncoordinated.
   Therefore the federal CD-Agency underlines the necessity of a cooperation between feder-

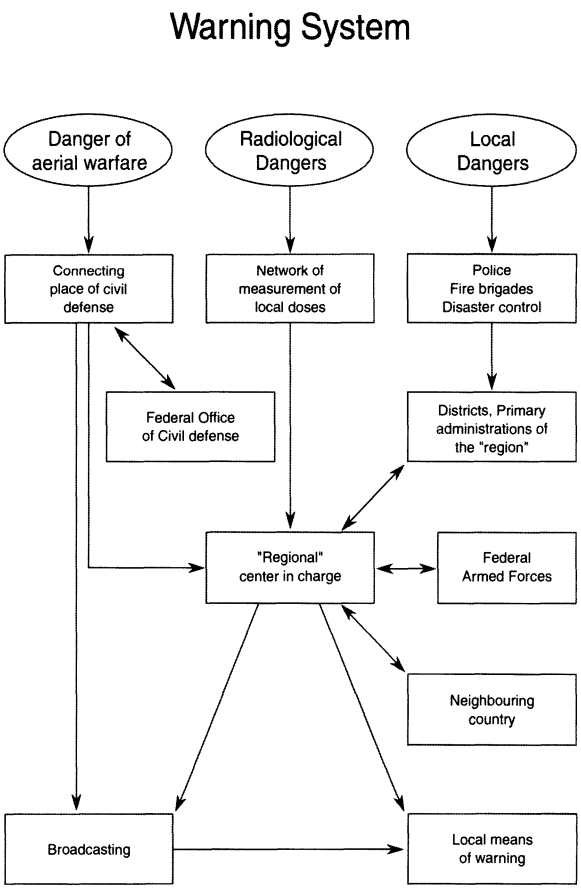


Fig. 1. Warning System

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al, state and broadcasting services. In autumn 1998 a working group with members of all different institutions and services will start negotiations for a solution of this problem. Possible solutions are presented on a poster which is published by the German IDNDR-Committee and the German Permanent Conference for Disaster Prevention and Disaster Protection Ständige Konferenz für Katastrophenvorsorge und Katastrophenschutz).

At the end of my presentation I will conclude with a more private and sceptical outlook for a reliable and in time working early warning system:

At present the responsible authorities for peacetime emergencies – the 16 states (Bundesländer) – are (under the pressure of political assumptions and economical difficulties) not able to develop a mutual, interactive and bordercrossing warning and alert system accepted by the public.

Indeed the occurrence in July/August 1998 – the "Oder-flood-disaster" – is evidence, that a nation-wide early warning system must be part of a common warning and forecasting system of all disaster prone countries – for emergencies and disasters never respect borders and national interests.

Perhaps the European approach and the monetarian and economical unification of 15 member nations and several other aspirants to become members (besides the NATO-extension) are a hopeful signal for a common together in safety and peace.

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CHAPTER 3.2

Benefits of Early Warning from the Viewpoint of the Insurance Industry

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Abstract

Losses from natural disasters have increased dramatically since the sixties. Consequently, loss prevention measures are becoming increasingly important reducing as a means of minimizing the loss burden from such events, particularly in the insurance sector. At the same time, methods of forecast, prediction, early warning and alert have become more sophisticated, more viable and more reliable, at least for some types of hazard. However, the applicability of event forecasts/predictions and early warnings differs according to the type of hazard and the lead time available to carry them out. While there are many well-functioning operational warning systems for hydro-meteorological events, it is still difficult to warn of geological hazards. The success of warning systems for hydro-meteorological events has been observed particularly with respect to tropical cyclones (Hugo/South Carolina 1989), storm surges (North Sea 1995) and floods (Odra 1997). Here, modern methods of detection, observation, evaluation and communication methods, e.g. by satellite, provide a good basis for warning a threatened region of an imminent extreme event. The experience with volcanic eruption predictions is mixed. Successful evacuation (Pinatubo 1992, Rabaul 1994, Montserrat 1996) does not necessarily result in lower insured losses. To anticipate the onset of an earthquake remains the biggest challenge of all. The opportunities for loss reduction on the basis of real-time early warning systems (such as shutting off energy supply and critical facilities as already implemented at some locations in California, Mexico and Taiwan) are promising but still need to be tested during severe events.

1 Introduction

No populated area in the world is immune to the impacts of natural events. However, the range of vulnerability to these hazards is very wide. Some societies (communities, states, regions) have learnt to live with natural hazards. They are prepared. Others are sometimes completely taken by surprise when a nearby volcano erupts, a windstorm sweeps over the land, an earthquake strikes or a river or the sea rises to a level that local residents have never experienced before. In this context three aspects are very important: (1) the dramatic increase in the population of the world and of some regions, which creates the necessity to settle in areas that are dangerous; (2) the movement of refugees (political, social and other) to environments with which they are not familiar; (3) the increase in mobility and the desire of people to live in areas that have a beautiful natural environment and a favorable climate, in spite of their being exposed to natural hazards. All these factors bring people into areas whose natural features they do not know. They are not aware of what can happen and they have no idea how to behave if nature strikes. This is one of the underlying reasons why natural ca-

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tastrophes are becoming more and more frequent and severe.

Early warning systems are much more than just technical devices and the accuracy of the warning message. They must be adapted to a region's specific social, religious and political character. Knowledge of an impending extreme event alone may not be sufficient to reduce losses of life and property. People must believe in the benefits of a warning and must know what to do. If they are evacuated, their concern about leaving their belongings behind must be eased. Religious attitudes (e.g. fatalism) and political aspects (e.g. credibility of authorities) are other factors to be considered when setting up a warning system. These factors often make it very difficult – if not impossible – to transfer a well-functioning and proven warning system from one region to another. Acceptance is crucial for any such system. Disaster insurance is an important component of a full-scale mitigation system. Not only does it reduce (or even eliminate) the risk of being ruined, it also – by means of appropriately structured premiums and deductibles – gives incentives to take prevention and preparedness measures.

2 Great Natural Disasters

The development of "Great Natural Disasters" over the past four decades or so shows a marked increase in losses (Fig. 1) both in terms of economic and insured losses. In this context, "Great Natural Disasters" are defined as events that distinctly overtax the ability of a region to help itself, making interregional and international assistance necessary. This is usually the case when thousands of people are killed, hundreds of thousands are made homeless or when a country suffers substantial economic losses (depending on the economic circumstances generally prevailing in that country). A comparison between the sixties and the decade 1989–1998 shows that economic losses increased by a factor of 9.0, while the insured losses increased by a factor of 15.3 (Table 1, inflation is already taken into account). The number of such great events has also increased, by a factor of 3.3.

Earthquake is the main cause of fatalities and injuries. Seven of the ten deadliest disasters during the past 30 years (Table 2) were caused by earthquakes and their secondary effects. In earlier years, floods and in particular tidal waves were responsible for a much larger

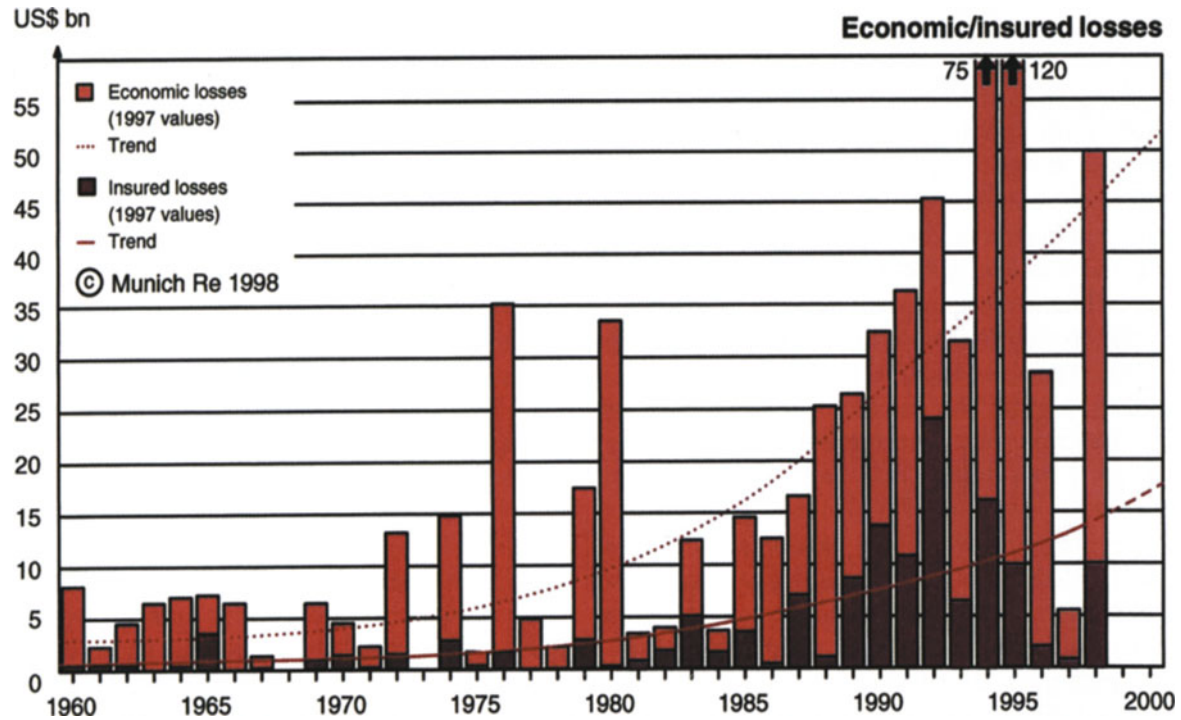


Fig. 1. Economic and insured losses of "Great Natural Disasters" (after Munich Re, 1998)

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Table 1. "Great Natural Disasters" 1960–1998, comparison of decades after 1960 (after Munich Re, 1998); (losses in US$ bn, 1997 values)

	Decade 60–69	Decade 70–79	Decade 80–89	Decade 89–98	Factor 80s:60s	Factor last 10:60s
Number	16	29	70	54	4.4	3.3
Economic losses	50.4	96.9	153.8	451.4	3.1	9.0
Insured losses	6.7	11.3	31.0	102.3	4.6	15.3

Table 2. The 10 deadliest natural disasters during the past 30 years (not including droughts)

Rank	Year	Event	Country	Death toll
1	1970	Storm surge	Bangladesh	300 000
2	1976	Earthquake	China	290 000
3	1991	Storm surge	Bangladesh	140 000
4	1970	Earthquake, landslide, tsunami	Peru	67 000
5	1970	Earthquake	China	55 000
6	1990	Earthquake	Iran	40 000
7	1988	Earthquake	Armenia	25 000
8	1985	Volcanic eruption	Colombia	23 000
9	1976	Earthquake	Guatemala	22 000
10	1978	Earthquake	Iran	20 000

Table 3. The 10 costliest natural disasters during the past 30 years (original numbers, inflation is not accounted for)

Rank	Year	Event	Country	Economic losses [US$ bn]	Percent insured (%)
1	1995	Earthquake (Great Hanshin)	Japan	100	3
2	1994	Earthquake (Northridge)	USA	44	28
3	1992	Hurricane Andrew	USA	27	63
4	1996	Floods	China	24	2
5	1993	Flood (Mississippi)	USA	16	6
6	1990	Winter storms	Europe	15	68
7	1995	Floods	North Korea	15	0
8	1988	Earthquake	Armenia	14	0
9	1993	Floods	China	11	<1
	1993	Storms, floods	Japan	11	14

number of deaths. This has changed significantly, a development that clearly can be attributed to improved forecast and communication techniques for flood hazards.

If we look at the losses, we see a different picture (Table 3). Although the table is led by two earthquakes and a storm, floods are, in economic terms, the number one cause of losses from natural events due to their much higher frequency. This tendency is displayed not only by "Great Disasters" but also by the total annual amount of losses from the many small and medium-sized events. On average, floods cause as much damage as all other destructive natural events together. Additionally, one should bear in mind that the amount of money societies all over the world spend on flood control (sea dikes, levees, reservoirs, etc.) is many times greater than the amount they spend on protection against other impacts of nature.

3 The Loss Reduction Triangle

As far as insured losses are concerned, the third major event type, windstorm in all its various forms, dominates the statistics (Table 4). Among the top ten insurance catastrophes, seven belong to the category of "Storm". In this

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Table 4. The 10 costliest natural disasters for the insurance industry in the past 30 years (original numbers, inflation is not accounted for)

Rank	Year	Event	Country	Insured losses [US$ bn]
1	1992	Hurricane Andrew	USA	17.0
2	1994	Earthquake (Northridge)	USA	12.5
3	1990	Winter storms	Europe	10.2
4	1991	Typhoon Mireille	Japan	5.2
5	1989	Hurricane Hugo	Caribbean, USA	4.5
6	1998	Hurricane Georges	Caribbean, USA	3.3
7	1987	Winter storm	Western Europe	3.1
8	1995	Earthquake (Great Hanshin)	Japan	3.0
9	1995	Hurricane Opal	USA	2.1
10	1991	Wildfire (Oakland Fire)	USA	1.8
...	...	...	...	...
19	1993	Flood (Mississippi)	USA	1.0

list, the costliest flood ever incurred by the insurance industry, the "Great Flood of 1993" along the Mississippi, ranks 19. The reason for the shift from "Flood" to "Storm" is the much higher insurance density for the latter.

Most local insurance markets are unable to sustain billion dollar catastrophes without the assistance of the international insurance industry. Even in strong markets such as the United States, great events leave their traces. For example, Hurricane Andrew wiped out 13 primary insurance companies in South Florida in 1992. The burden from claims far exceeded the capacity of these companies. In order to protect themselves from bankruptcy, insurance companies buy reinsurance cover. Thus, the financial risk is distributed worldwide.

A reinsurance rate of more than 95% is typical in developing countries. In developed countries, reinsurance rates range between 50 and 90%, depending on the strength of the primary insurance companies in the region.

The increase in losses from natural events over the past decades is a direct function of the number of people who – must or wish to – settle in disaster-prone areas and a function of the increasing values they possess. On the average, people today own more things than ever before and what they own is more expensive and more susceptible to disturbances (water, groundshaking, smoke, frost, etc.). Especially electric and electronic machines, appliances and other devices are highly vulnerable to humidity, abnormal temperatures, pollution, shaking and overvoltage. Examples of high-vulnerability items are automated traffic systems, lifeline systems (electricity, gas, water), just-in-time production, clean-air rooms, etc.

An important aspect is the "feeling of security" many people have knowing there are sound building codes, reliable warning systems and well-designed protection structures. For example, people along water courses rely on improved and sometimes sophisticated flood control systems consisting of reservoirs, retention basins and levees, which make sure that floods with a high frequency (once every few years on average) do not cause any problems. The greater this safety is, the more values are accumulated behind the levees in the flood plains. People ignore the fact that they live in areas endangered by floods and, after actually experiencing a flood, often "forget" their proneness in a surprisingly short time, a flood they have actually experienced and so that after a period of raised awareness they return to a position of indifference or ignorance.

Disaster preparedness, disaster prevention and loss reduction require an integrated approach, in which different components of a society have to be involved. Three of them exert the biggest influence: (1) the public authorities (state, provincial, local governments and their agencies), (2) the endangered/affected individuals, companies, etc. and (3) the insurance industry (Fig. 2). Only combined efforts that include – among other things – initiatives, activities, awareness, preparedness, appropriate response to an event by the three groups are capable of minimizing the total cost and preventing and mitigating the impacts of natural disasters.

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Fig. 2. The loss reduction triangle

Public authorities are responsible for the basic needs a larger part of the community not of individuals but of the community at large. The state's responsibilities include structural and non-structural protection measures, preparedness measures, relief services, reconstruction, land-use planning, etc. One of the key tasks of each government or administration is establishing early warning systems for all natural events that may affect the state's territory.

Given the basic level of protection provided by the state, the affected people can minimize their own material losses most effectively by taking appropriate measures to protect buildings and particularly their interior and contents from being damaged by a natural event. Structural measures provide continuous protection, non-structural measures help people to cope more effectively with the event. Preparedness starts with using resistant structures, continues with having temporary strengthening devices available and ends with storing emergency equipment.

The purpose of insurance is to protect the insureds from excessive losses that threaten their living or business conditions substantially. Insurance is not meant – though often used – to compensate relatively minor damages. One very important contribution the insurance industry can make towards loss reduction is to raise the willingness of home and business owners to defend their property against damage due to natural events. With adequately structured premiums and deductibles insurance has a powerful means of motivating the insureds to take measures aimed at loss reduction.

Preparedness and emergency actions require an awareness of the threat by the people concerned and their willingness to minimize losses. The incentive for the latter may be dampened or encouraged by various boundary conditions that are closely related to the state's warning and protection systems as well as to the financial assistance provided either by the state or by insurance in the case of loss. This makes it clear how intertwined the contributions of the three components of the loss reduction triangle are and how crucial it is to have a well-balanced preparedness system.

4 Effects of Early Warning

In former centuries floods were the number one cause of deaths from natural disasters. With the exception of storm surges this is not so anymore. Nowadays geological disasters (earthquakes, volcanic eruptions, landslides) pose the deadliest threat. In addition to having an extremely sudden onset, major geological events are difficult or even impossible to predict, and in most cases there is no time left for issuing a warning. Well-observed and well-instrumented volcanoes may be seen as an exception; predicting their eruption is quite feasible. Hydrological events almost always build up relatively slowly. It takes several hours or several days (sometimes even weeks) before disaster conditions are reached, and even the few minutes given by an approaching flash flood may be enough for many people to leave the scene and save their lives.

As far as property is concerned early warning should be considered under two different aspects: the long-term "hazard preparedness" and the short-term "event warning." While the first aspect mainly concerns general structural or organizational measures, the latter requires quick reaction and specific actions.

Floods and Storms

For no other type of natural disaster have early warning methods become more operational (?), more reliable and hence more effective than for meteorological and hydrological disasters. In 1970 and 1991 two storm surges in Bangladesh claimed the lives of 300 000 and 140 000 people, respectively (Table 2). In 1994 a storm surge that ran up to a height comparable to the one in 1991

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left only 200 people dead. This reduction in the number of victims was mainly a consequence of improved early warning methods based on better storm forecast models together with the availability of elevated shelters that allowed people on low land to flee the flood waters.

On January 10, 1995 Hamburg (Germany) experienced the second highest storm surge water level ever. It was 32 cm higher than in 1962, when Germany suffered its severest flood disaster in recent history. Given the severity of the 1995 event, the consequences were minor. After 1962 most dikes had been raised and improved and a storm surge forecast center had been established. The highly developed forecast system for Hamburg prevented large losses: harbor gates were closed and endangered items brought to a safe place. While buildings and their contents are not insurable against storm surge damage in Germany, the values of insured goods in harbors can reach enormous amounts.

Operational forecast systems for river floods have been installed in many countries of the world. Hydrologic-hydraulic models combined with rainfall forecasting make it possible to estimate the maximum stages and the times when they will be reached. The lead times enable people and authorities to react to the anticipated flood wave by flooding retention areas, erecting flood walls, placing sandbags, bringing sensitive movable items to safe place, alerting relief services, preparing emergency measures, etc. Given the technical possibilities and the awareness of the people concerned, early warning is the key that opens up vast opportunities to reduce losses. However, if any of these three components is not sufficiently developed, the remaining two cannot do the job.

In contrast to storm surges and river floods, flash floods, with their sudden onset and the erratic distribution of their location, are still a problem for forecasters. Basically, the only solution can be a rainfall forecast and an immediate assessment of precipitation volumes in the respective catchment be the solution. Once the flood wave has started to rise, there is usually too little time to give any warning. Sometimes, particularly in the case of mountain rivers where debris flow events are frequent, automatic devices (e.g. gauges or wires spanning the river) can set off alarm sirens. Such an automatic system is installed, for example, at Mount Sakurajima in Japan, which produces lahars quite regularly; low-tech wire-alerts are found in Central American countries.

The flooding along the Odra river in 1997 is a good example to illustrate the difference between flash flood and river flood. In many upper catchments in the Czech Republic the waters came so quickly that there was no time to issue a warning. The lower regions along the border between Germany and Poland could be alerted several days in advance and so were able to prepare for the coming flood. In this region a catastrophe was averted thanks to enormous human effort and a large input of material resources.

Every summer, hurricanes develop in the Caribbean and sweep over its island states, the Central American isthmus and the east and southeast coasts of the United States. Satellites already discover them in their forming stage and track their paths while checking their maximum wind speeds, which sometimes exceed 250 km/h. The anticipated track of the storms can be computed with sophisticated simulation models and warnings can be issued. In the time before landfall (up to several days) people are able to fortify their buildings, leave their homes or replenish their stocks of food, emergency items and other goods.

In 1989 Hurricane Hugo clearly demonstrated how effective prevention after a warning can be (Nigg 1992). The two U.S. cities of Charleston, SC, and Charlotte, NC, were hit within the space of four hours by similarly strong winds. However, Charleston, where Hugo made landfall, was prepared, whereas Charlotte, 300 km inland, was caught by surprise. Immediately after the eye of the hurricane had passed Charlotte, 98% of the population were without power. Charleston's "hardened" lifeline system also suffered major damage but the consequences were much less severe. All its utility services were restored within 18 days, the first case whereas in Charlotte some areas suffered from power outage for up to six weeks.

Earthquakes and volcanoes

Potential applications of early warning systems for earthquakes were summarized by Harben (1991). Basically, applications consist of shutting down critical facilities in the widest sense, ranging from disk drives on computers to criti-

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cal components in industrial plants and in energy distribution networks. Furthermore, emergency generators can be started and alarm plans in general can be activated before the event strikes. Trains and elevators can be stopped. One specific example which deserves mentioning is opening fire station doors so that fire engines are not caught inside. Almost all of these options have direct relevance to the insurance business in that insured losses may be prevented or reduced as a result. Regarding different lines of insurance the biggest reduction potential lies in commercial and industrial insurance, more than in personal lines where normal dwellings and households are covered. Losses stemming from the interruption of production or business in particular can be reduced significantly by ad-hoc measures even immediately before an event.

Practical observations are lacking so far, as early warning systems are still in their infancy. The only operating systems are the ones for the Japanese railways, for some high-tech facilities in California and for Mexico City. The Mexican system had its first real test in the M 7.3 earthquake of 1995. The system worked successfully, but the losses in this event were too small to allow any conclusions to be drawn on the system's actual loss reduction capabilities in large events like the 1985 earthquake. A warning system is being developed for Taipei (Taiwan), and proposals have been made for Bucharest (Romania), Istanbul (Turkey) and California. The options available for response depend on the lead time, which is a function of the distance between the focus and the affected site. It ranges from 17 to 75 seconds for the mentioned systems.

We may sum up by saying that early warning have has definite applications in terms of loss reduction from which earthquake insurers can benefit. It must be realized, however, that it will always be no more than a minor supplement to long-term loss reduction measures based on seismic macro- and microzoning and mid-term forecasts with a lead time from several years to decades. Short-term earthquake prediction as such will not be viable in the foreseeable future, but its blessings for insurance would be arguable anyway. A discussion of this complex issue goes beyond the scope of this contribution.

In contrast, there are numerous examples of success in connection with the early warning and prediction of volcanic eruptions. In general, the art of prediction is much more advanced in the field of volcanology than in the field of earthquakes, and the lead time is longer than that provided by the earthquake warning systems described above. This generally results in more opportunities for loss reduction. They start with evacuating people living in high-hazard zones before an imminent eruption. Recent cases in point are the evacuations on the islands of Montserrat and Rabaul (Papua New Guinea). The positive effect on life insurance is obvious but depends of course on the spread of such insurance in the affected areas. As far as material and business interruption losses are concerned, however, the opportunities for loss reduction and prevention are more restricted and depend heavily on the type of activity. For instance, the flow of lava streams can be influenced by the construction of barriers, and to some extent such barriers may also block off mudflows before they reach populated regions. On the other hand, protection against the consequences of pyroclastic flows and ashfalls is impossible. This is demonstrated clearly by the two examples just mentioned. Material damage was substantial in Rabaul as well as in Montserrat, whereas loss of life was minimized by evacuating the people. The only saving effect in terms of property insurance represented by was produced by the evacuated people taking their personal belongings with them.

5 Conclusions

Early warning is one of the key elements in preventing or at least reducing losses due to the impact of natural events. The main goals of early warning systems are: guaranteeing personal safety, preventing malfunctions in critical or important public and private facilities, making sure that infrastructure (such as lifelines) remains intact or can be restored quickly, providing the time needed to evacuate the people or to move them and sensitive items to a safe place, and protecting structures, building elements and equipment. Behind all these goals is – to a varying extent – the need to avert loss of life, minimize injuries, reduce property damage and shorten interruptions in public life, business and production processes.

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Loss reduction is favorable for the people and companies affected, the society as a whole and the insurance sector. General reduction measures almost always always reduce insured losses too, even though the percentage of these losses may vary over a wide range. Apart from the obvious direct savings generated by reimburse damages the smaller claims burden, insurance companies profit from early warning in other ways too. Even before the event strikes they have a chance to put together and dispatch disaster management teams that can go to the disaster scene and rapidly assess and evaluate the damage. Their experience forms the basis for a better understanding of the various kinds of structural failure that may occur and therefore for better preparedness. Furthermore, they improve the quality of risk assessment and establish a basis for an appropriate adjustment of the insurance conditions geared to the specific local structural risks. Finally, early loss regulation is very important for those hit by a disaster. The money for reconstruction and the replacement of lost items is most valuable when it is available as soon as possible after the disaster, while the psychological effect of "someone being there to help" can be immense and – in some cases – literally vital.

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CHAPTER 3.3

Natural Risks in Albania and the Role of Related Warning Systems

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1 Introduction

Organised Albanian research into natural risks in general began rather late, in the 60s, and has addressed particular aspects of this notion, including extreme phenomena of natural disasters and extraordinary events, such as floods, snow avalanches and earthquakes, and deals with causes, scale of action and their consequences in socio-economic life. Especially in the last years, during some scientific projects and in the Second National Conference of Geography (Shkoder 1995) a wealth of material was gathered in order to identify such phenomena and natural risks in Albania. This represents a marked contribution towards applied geography, due to its socio-economic importance. In this paper, we attempt to estimate the most visible effects of some of the natural risks more common in Albania, such (as degradation of land, glacial overflow, avalanches, earthquakes, drought and fires), and assess their effects on the environment and socio-economic life. This paper also deals with the efforts undertaken to prevent or diminish their consequences.

2 Categories of Natural Risks

The geotectonic and climatic position of Albania as a Mediterranean country have created a very interesting, sensitive, morpho-bioclimatic equilibrium, which is often accompanied by sudden disasters with visible effects. Because of the occurrence and intensity of natural hazards in the Albanian geospace, despite being a small territory, it appears to be one of the most threatened regions in Europe. Included in the group of geomorphologic risks, which damages the albanian natural environment, is degradation of land. This phenomenon primarily constitutes erosion, slope processes (such as slides, contusions, solifluction etc.). Their wide extent, intensity and diversity is related to the great extent of soft formations, such as shales and molasses, which occupy 58.4% of the territory. At the same time, 65% of arable land is on slopes with declivities of over 20°. Here, the aggressive climate is obvious. Irregular precipitation (with 1–24 hour intensity) is quite often related to long periods of land degradation, which is considered the main environmental risk, even as a national disaster. It has been calculated that the annual erosion is equal to a thickness of 0.5 m over 26 thousand ha, and constitutes 3.6% of arable land. Consequently, every year, about 60 million ton stiff granules while Albania has a surface of 28748 km^2. In Mallakastra, Krrabe, Cermenike, Tomorrice and Frasher, etc., fluvial erosion has reached a critical point and the corroding intensity in Albania is up to 100 to 1000 times greater than in many European countries. Besides the natural causes, these processes have been stimulated by cultivating land with a low resistance to erosion, as well as reducing green areas, such as bushes and forests. Because of the considerable declivity and energy of the slopes, there are many landslides, threatening parts of inhabited areas and different elements of the infrastructure. During the last 20 years, hundreds of landslides of different dimensions, depths, and origins with different consequences have become active.

Floods, caused by the maximal level of waters in the hydrographic network and pri-

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marily in rivers, have occurred frequently and with great environmental, economic and social consequences. The areas most threatened by floods are the lower parts of different rivers such as Drain, Bun, Matt, Seaman and Osumi, which correspond to the western low land. Thus, we can mention the southern part of the city of Shkodra, and the cities of Lezha and Berat. These floods are the result of intense precipitation, lasting hours or days. Worth mentioning are floods like those which took place in 1854, 1905, 1937, 1962–63, 1970–71, 1992 and 1995. In the period December–January 1962–1963, 70 000 ha of agricultural land were flooded. A consequence of the intense precipitation, which lasted some days, was that the volume of water delivered by the main rivers was 30 times higher than the perennial average. The Drin river reached a historical level (9 500 m^3/s) and thus flooded 15 000 ha of agricultural land, but bigger floods were caused by the Seman river (20 000 ha). An interesting fact to be mentioned is that flooding also occurred in 1995 even with little precipitation (about 100 mm over two days) and a thousand ha of agricultural land was damaged. This fact is best explained by the malfunction or destruction of the defensive barriers in channels or hydrophores rather than precipitation. Many floods are caused by highly inclined mountain streams; their steep beds are a result of poorly functional graded barriers, thus causing material damages, and damage to the infrastructure. Noteworthy are the very frequent flooding of the city Lezha due to the streams from the eastern part of this city and the city of Berat.

The geomorphologic and topographic conditions of our country, especially mountainous areas, are quite suitable for the birth of avalanches, as the slopes have considerable declivity. Under suitable meteorological conditions, avalanches occur more frequently when the slope declivity is 30°–40°, or even within tile interval of 20°–60°. Most frequently the avalanches occur on the slopes with northern and eastern exposure especially in the Alps and central mountainous regions.

A typical event took place in the winter of 1995, and had to do with the considerable amount of snowfall over a period of 60 days. The amount and thickness of snow had not been seen in the course of the last 30 or 40 years, and was accompanied by a very interesting phenomenon: lagging of the newly fallen snow upon the already existing lager. This provoked and caused snow avalanches, some of which brought about human and material losses, as for example the avalanche of Mali me Gropa or the one in Batra of Martanesh where 11 miners lost their lives. Interestingly, avalanches known to have caused great damage are observed to have occurred almost every 10 years, in 1933–34, 1941–42, 1953–54, 1963–64, etc.

Land reclamation and the exploration of mines and woods for decades in succession have increased the danger of artificial triggering of avalanches (glacial explosions), worsening in this way their negative consequences.

Albania lies in an area known for its particular seismic intensity, this due to the fact that the Balkan plate is present in between two large plates: the Euro-Asian plate to the north and the African plate to the south. For this reason, earthquakes represent a potential environmental danger in Albania. These are concentrated in particular areas, which according to the concept of plate tectonics, coincide with tectonically deformed areas, precisely within the areas of transversal and longitudinal faults. Worth mentioning are the transversal fault Shkoder-Peje, VIore-Elbasan-Diber-Peje-Shkoder and the longitudinal fault of considerable seismicity which lies along the Adriatic coast. For this reason, Shkodra, Elbasan, Korca and Delvina are regions of high seismicity. Of these earthquakes, the one of the 15th of April l979, which shook the coastal area of Albania-Mali i Zi, is estimated to be the strongest in Europe. The intensity was 9 MKS, and its magnitude 7.2.

The earthquake caused great damage, houses of thousands of inhabitants, mainly in the regions of Shkodra and Lezha, were destroyed, some people died, faults, landslides and pseudovolcanoes occurred.

Forest fires can be included in the group of natural hazards in Albania. These almost always only occur in summer, due to prolonged heat and dry weather. The main causes of fires are high temperatures, they do not directly produce them, they simply stimulate them. We make use of the term "stimulate" and not cause or produce, because in Albania, the highest temperatures do not exceed 43.9 °C.

It is true that 500 fires occur each year and that these burn 2–3 000 hectares of land. They frequently occur in the forests of Lura, Tuci

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Zeba, Martaneshi, Llogara in the mountains of Morava and Renci. This is an environmental danger which begs special attention, including ways to solve and avoid the problem.

3 Measures to be Taken and the Role of Warning Systems to Reduce the Effect of Natural Danger

Scientific studies have shown that, although the general global character of natural risks and their consequences are quite clear, it is impossible to foresee them, to predict the place and region where they will occur.

Furthermore, the differences in economic and social level of countries plays a role. In many countries, different small and large scale systems are set up and developed incorporating observation, telecommunication, data elaboration and cosmic technologies. In Albania, specialised institutions have also tried to set up and organise observing and warning systems, which primarily reduce and document the consequences of risks. We have to mention the fact that till now, attention was given to the documentation of disasters, to take preliminary measures to avoid them or to reduce risks in Albania.

In this respect we set up dams, carried out partial afforestation, and set up antiseismic buildings etc. Furthermore, many scientific studies offered valuable suggestions in this respect. All these measures contributed to the mitigation of serious environmental problems. The most successful achievements were those which are related to signals that identify areas marked by erosion intensity, and local maps compiled to identify index values (plant-erosion correlation). The latter will contribute to the future monitoring of erosion phenomena. Concerning land slide, indications used as a form of warning system worth mentioning are:

- general chaotic slope, its escalation to the opposite direction of the slope
- existence of wet surfaces resembling marshes which constantly change position
- trees and other objects which deviated from their vertical position
- degraded vegetation and earth cover lacking in profile: earth-profile thickness is much smaller because of the formation process commencing late

Concerning other natural dangers such as earthquakes, floods, and avalanches, it is possible to identify the areas they appear most intensely, and their potential, as well so as to compile specific maps, and to suggest projects and proposals to take measures and directly interfere when possible and when funds are available.

We must, however, mention the fact that we still lack warning systems and prognosis systems, the systems in existence are not effective or suitable.

Given the danger and the variety of possible risks, their extent and occurrence under conditions of densely populated areas, Albanian scientists have the task of using the abundant and diverse natural resources to preserve our natural and cultural heritage.

Opinions of our colleagues from countries rich in experience about the efficacy of EWS in the reduction of material danger, as well as the conclusions of this Conference, will undoubtedly contribute to the deepening of our knowledge in these fields, and to the effective application in our country.

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CHAPTER 3.4

Interaction and Cooperation Between Russia and NIS in the Area of Preventing Emergency Situations of Technogenic and Natural Character

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In comparison with previous centuries the development of the technogenic sphere progressed significantly during the 20th century. This led, however to two antipodal consequences in industrially developed countries, and all over the world.

- On the one hand outstanding results were achieved in electronic, atomic, space, aeronautic, power and chemical technology, in biology, gene engineering, confronting humanity with new boundaries in many spheres of activity.
- On the other hand previously unknown potential and real menaces to man, to objects, created by him, to local and global surroundings, not only during war, but also during times of peace were created.

Principally during the last decade these threats to mankind were caused as a result of the largest technogenic catastrophes: nuclear (USSR, USA), chemical (India, Italy, USA, Mexico, USSR), space and aeronautic (USA, Russia), above-water and submarine (USSR, USA, Estonia, England). The analysis and examination of numerous data (measured by thousands and dozens of thousands in the most developed countries) allow for a classification of technogenic accidents and catastrophes. Global, national, regional, local and object catastrophes have been distinguished based on the scale of covered countries and territories, on the number of victims and injured people and on economic and ecological damage (Table 1).

Potential hazard that may lead to similar catastrophes in the technogenic sphere include objects of the nuclear, chemical, metallurgical and rock-processing industry, unique engineering constructions (of platinum, trestles, oil- and gas-storages), transport systems (aerospace, above-water and submarine, above-ground), carrying dangerous cargoes and arterial gas- and oil-pipelines. Furthermore dangerous objects of defense such as aerospace and aircraft systems with nuclear and conventional warheads, atomic submarines and above-ground vessels, large stores of conventional and chemical weapon must also be included in potential hazard domains.

Accidents and catastrophes with the above indicated objects can be initiated by dangerous natural phenomena, such as earthquakes, hurricanes, storms. Technogenic accidents and catastrophes themselves can be accompanied by radioactive and chemical injuries and pollutions, caused by explosions, fires, or downfalls. Types and parameters such catastrophes vary within a very broad spectrum.

To ensure the technogenic safety on the border of the 20th and 21st centuries it should first be noted that the world technogenic civil and defense sphere contain up to 10^3 objects of nuclear technology for peaceful and military purpose, more than 5×10^4 of nuclear ammunition, up to 8×10^4 tons of chemical mass-scale weapons, hundreds of thousands of tons of dangerously explosive and inflammable substances, aggressive poisonous stuffs, dozens of thousands of objects with high reserves of potential and kinetic energy and gas and fluid energy.

The probability of a worst case scenario included by one of the first three classes in peaceful times range from $(2–3)\times10^{-2}$ up to $(0.5–1)\times10^{-1}$1/year, and losses from 10^{11} to 10^9 dollars/catastrophe. Whereby the risks vary within the range of 10^4 dollars/year up to 10^{10} dollars/year.

When analyzing the security of the technogenic sphere, both the damages shown in, and batch production of corresponding potentially hazardous objects should be taken into consid-

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Table 1. Accidents and disasters

No.	Disaster type	Period	Losses USD	Human	Objects
1	Global	30–40 years	10^9–10^{10}	10^4–2×10^6	Nuclear, military, space
2	National	10–15 years	10^8–10^9	10^3–10^5	Nuclear, chemical, military
3	Regional	1–5 years	10^7–10^8	10^2–10^4	Chemical, energetical, transport
4	Local	1–6 month	10^6–10^7	10^1–10^3	Technical
5	Objective	1–30 days	10^5–10^6	10^0–10^2	Technical

eration. The greatest emergencies originate on unique objects – single and multi-series. The number of single-type atomic power coils composes 1–10 with their common number in exploitation 450–500, the number of single-type aerospace systems is generally from 3–5 up to 50–80. Middle-series potentially dangerous objects are numbered by hundreds and thousands, and large-series – by dozens and hundred thousands (automobiles, agricultural machines, machine-tools). According to Table 1 integral economic risks defined by the multiplication of single risks with the number of objects, turn out to be comparable both for global, and for object catastrophes.

Thus, damages from single catastrophes of global and object scale differ by 8–10 orders, their risks – by 4–6 orders, and integral damages – by 1–3 orders approximately.

The attained level of security measures for potentially dangerous objects is of absolute important significance both for our country and for all other industrially developed countries. With respect to object and local accidents for large-series technical systems, in which hazardous failures originate under normal conditions of exploitation, the level of design substantiation of security and reliability makes up 10–100%. Whereby national and international rates of design, production and exploitation have great significance, as well as vast and durable experience in ensuring safe operation of these systems.

Dangerous and catastrophic destructions of large- and middle-series technical systems under normal exploitation are already forecast in essentially lower measures – from 1 up to 10%. Preliminary quantitative analysis of major emergencies gives successful outcomes in 0.1–1.0% of cases. Concrete technogenic catastrophes of regional and national character gain their reflection in calculations and forecasts not more than in 0.001–0.1%. Global catastrophes, as a rule, are not predicted at all.

Figure 2 gives the data on probabilities and risks of technogenic accidents and catastrophes on objects with exclusively high hazard potential. In this case the differences in the levels of required and acceptable (in national and international scales) risks, on the one hand, and the level of actualized risks, on the other, achieves two and more orders. Along with this it is known that the rise in the level of protection of objects against accidents and catastrophes on one hand requires vast efforts in the scientific and technical sphere and essential costs comparable with 10–20% of the costs of the project.

All these requirements call for a national and international level of new fundamental and applied scientific tasks:

- mathematical theory of catastrophes and probabilistic theory of risks;
- physics, chemistry and mechanics of emergency and catastrophes;
- theories of rigid, functional and combined standby protection of objects, operators and staff;
- theory of control and forecast (with application of space, aerial and ground systems) of scenarios and consequences of technogenic catastrophes;
- scientific methods, technologies and methods of elimination of the consequences of the extraordinary situations of technogenic character.

When analyzing the safety of a complex technical systems, three principal kinds of emergencies are stated: design, above-design and hypothetical. Basic parameters include local tensions σ and deformations ε, numbers of cycles N, temperature t and time τ of exploitation. Depending on the type of potentially dangerous objects these parameters vary within an extremely wide spectrum ($10^0 \le N \le 0^{12}$, $-270\,^\circ\mathrm{C} \le t \le 10\,000\,^\circ\mathrm{C}$, 100 sec $\le \tau \le 80$ years). This leads to the fact that designed emergencies, as a rule, are based on re-

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search on the accumulation of failures within the framework of the classic theory of the resistance of materials, theories of elasticity, plasticity and creeping. In this case calculated and experimentally defined tensions and deformations represent the limit of elasticity. In transition to above-designed accidents non-linear regularities of deforming and destructions are analyzed whereby the tensions are far less informative parameters, than deformations. Damages caused by vibrations and fatigue are translated into damages from low-cyclic fatigue. Still larger growth of σ and ε gives rise to a transition to hypothetical accidents and catastrophes. In this case the theoretical basis of the analysis of such situations becomes the non-linear mechanics of destruction. One of the parameters of such an approach to the quantitative analysis of the development of an emergency can be computative-experimental substantiation of safety.

The present decade of struggle against natural calamities in the USSR, Russia and CIS states practically coincided with the decade of the implementation of changes in socio-political, economic and scientific spheres. The analysis of the occurence of emergencies of technogenic character in our states showed that a correlation exists between technogenic emergencies and socioeconomic processes in Russia and CIS. At the moments of most socio-political changes in 1992–1993 (1996) an abrupt increase in the number of emergencies can be seen.

All this makes it necessary for our states to take into account the necessity for the prevention of emergencies. In this case the international experience regarding the solution of emergency problems must be applied allowing, however, for peculiarities of our states – a high level of economic cooperation, energetic links, scientific and technical collaboration, changes in the structure of state control and state supervision.

These peculiarities made it necessary to develop collaboration with former Soviet republics.

This is aggravated by the fact that the largest natural and technogenic accidents and catastrophes in their global ecological, economic and social consequences have no political, national and geographical borders.

At present total losses due to natural and technogenic accidents and catastrophes both in Russia and in CIS countries (Commonwealth of Independent States) are increasing and have reached hundreds of milliards roubles and tens of thousands of casualties.

This is confirmed by the following research data of the SAFETY Federal Research Program of Russia (SAFETY–Federal Research and Emergency Response Program): if the actual number of natural calamities within the past several years has not been high (1.4 times), the increase in technogenic accidents and catastrophes within the last 7 years has grown by 6 times and the rate of increase of the total number of these accidents and catastrophes has increased by 3.5 times faster than that of natural ones (Fig. 1).

In this regard risk-response measures for the protection of population, industrial areas and the environment within Russian and CIS territory under emergency or in case of ecological danger, should be given priority within the framework of agreed interstate programs of cooperation on problems of major hazards and catastrophes, as well as in the field of ecological safety.

Practical realisation of this task in Russia is performed within the framework of the National Program SAFETY with separate projects with CIS countries, and within the framework of an

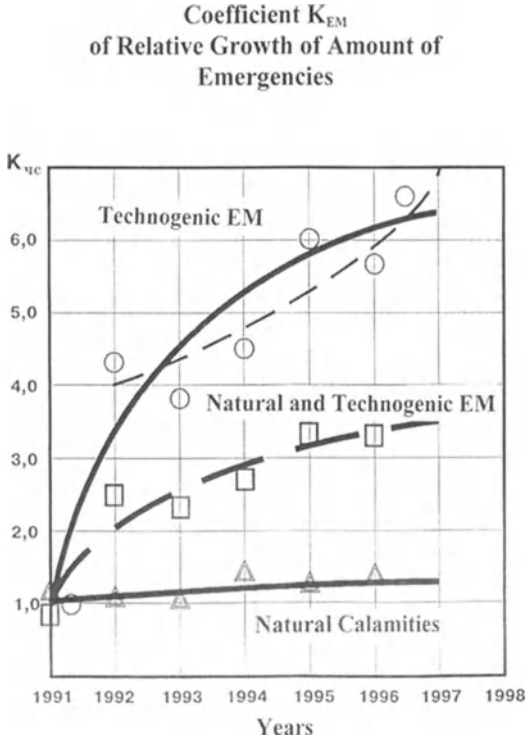


Fig. 1. Coefficient K_{EM} of Relative Growth of Amount of Emergencies

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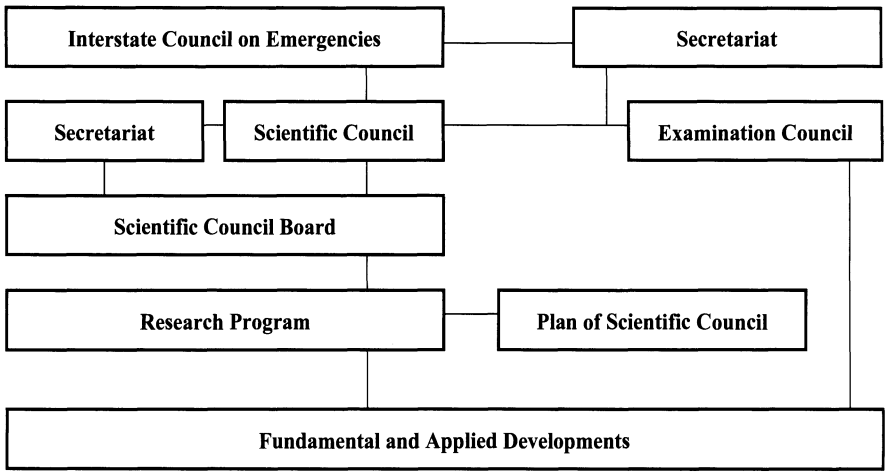


Fig. 2. Organizational Diagram of Interstate Collaboration

Agreement on Interaction in the Field of Prediction and Liquidation of Emergencies Consequences of Natural and Technogenic character (January 1993) which was concluded between CIS countries. In December 1994 a plan for joint fundamental and applied research for 1995–1997 was agreed and carried out within the framework of this Agreement. This plan has been approved at interstate level. The main coordinating body is the Interstate council on Emergencies with authorised representatives at CIS countries, Secretariat and Scientific Council (Fig. 2).

On the basis of the research results and the design for these years the design of the interstate program of joint research organizations of the states – participants of Agreement – for a period from 1998–2003 was elaborated.

The program was approved in July 1998 during an interstate meeting on emergencies. The program was developed by Russia, Republic of Belarus, Republic of Armenia, Georgia, Republic of Kazakhstan, Kyrgyzstan Republic, Moldova, Republic of Tajikistan, Republic of Uzbekistan, Turkmenistan and Ukraine.

The main objective of the mentioned joint programs is the coordination of efforts of all interested governmental and research organisations of CIS countries (Academies of Sciences, Ministries/Committees on emergencies and civil defence, ministries on environmental protection, on science and technology policy, etc.) for the development and adoption of a set of unified documents and regulations, research methods, systems and technical facilities on prediction, warning and quick-response measures to emergencies and ecological catastrophes taking into account possible transboundary transfer.

The organizational structure of the Interstate program and its main 3 scientific blocks are given in Fig. 3.

Main attention in the joint program is given to the creation of advanced developments on concepts and methodical bases of the safety theory, to the scientific bases of forecasting of emergencies and models of assessment and to the rise of the safety of complex technical systems (CTS).

The complex of indicated tasks envisages the development of methods and criteria for assessment of dangers and risks both in technogenic, and in natural-technogenic spheres.

So, the first block (Fig. 4) contains, in general, applied scientific developments carried out with the purpose of the creation and operation of common measures for CIS countries Interstate System of Prevention and Elimination of emergencies.

This system actually will increase the rate of stability of operations in the economic and social sphere in case of accidents, catastrophes, spontaneous and ecological calamities.

In particular, experience from the Ukraine automated system of modeling and control and protection of regions and on prevention and elimination of emergencies will be widely used.

Included in the second block are the following main directions presented in Fig. 5:

- development of methods and criteria for the assessment of dangers and risks both in technogenic, and in natural-technogenic spheres;
- the development of the integral methods of protection against natural-technogenic accidents and catastrophes;

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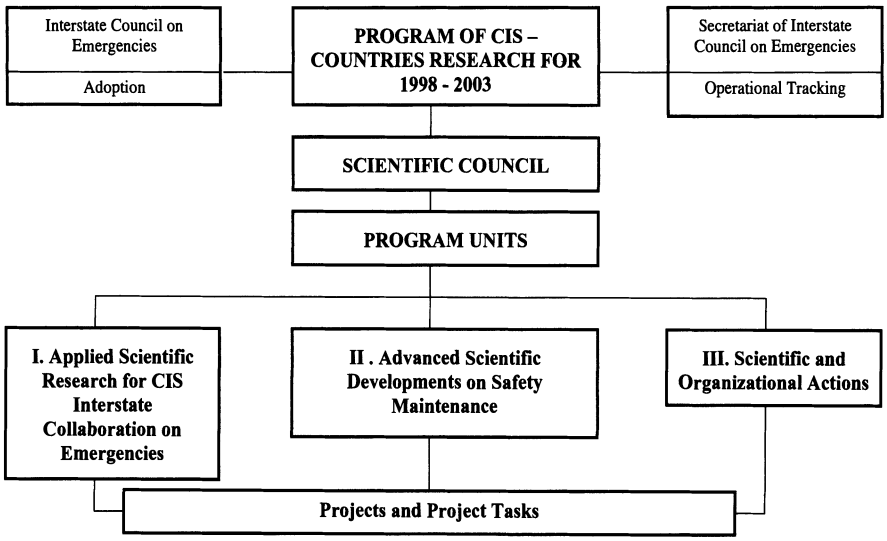


Fig. 3. Organizational structure of the Interstate program with its main 3 scientific blocks

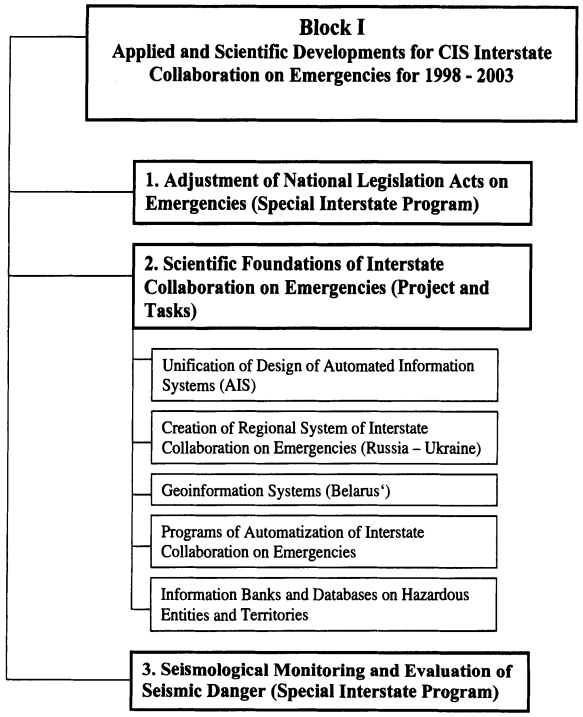


Fig. 4. The Interstate Program – Block I: Applied Scientific Developments for CIS Interstate Collaboration on Emergencies (1998–2003)

- the creation of initial normative basis for assessment of security and risk.

Specific methods of forecasting and estimates of consequences of emergencies, as well as a number of other applied and scientific directions will continue to be developed. A section on collaboration with international organizations on emergencies and civil defense is included.

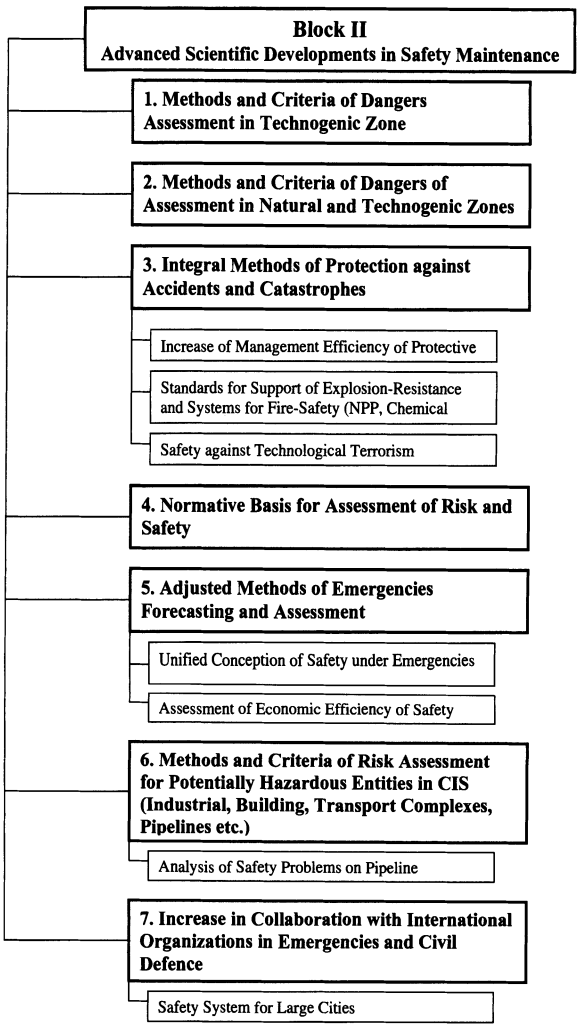


Fig. 5. The Interstate Program – Block II: Advanced Scientific Developments in Safety Maintenance (1998–2003)

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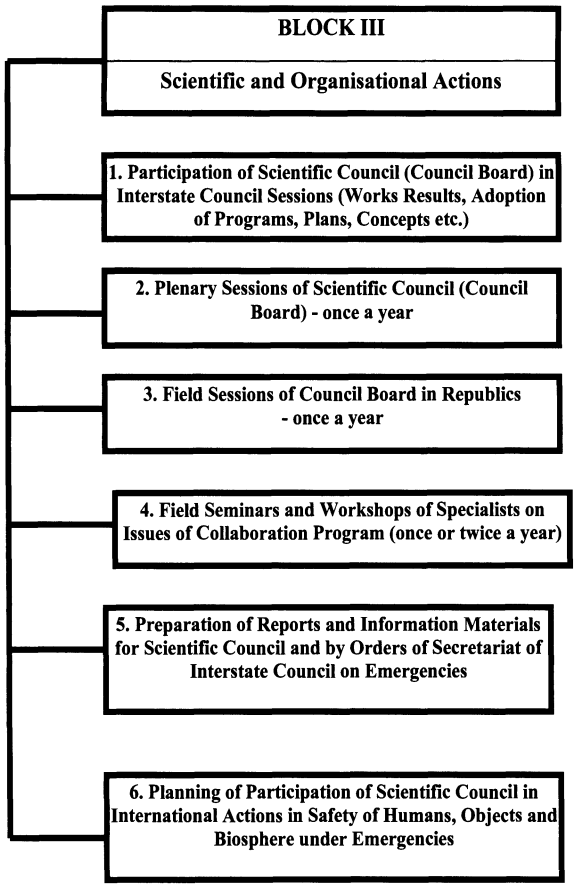


Fig. 6. The Interstate Program – Block III: Scientific and Organizational Actions

The third block of the Program composes scientific and organizational actions (Fig. 6).

Some examples of important joint scientific developments are considered briefly below:

1. With the purpose of the adjustment of legal and economic regulations for safety in CIS countries the Concept on adjustment of the legislation of the countries on issues of prevention and elimination of emergencies is developed and adopted.
2. An Interstate Scientific and Technical Program for the creation of a system of seismological monitoring of the territory of CIS countries is developed and adopted.
3. An atlas of 15 maps with dangers of natural and natural-technogenic processes on the territories of Russia in the scale 1:5 000 000 is compiled by the Institute of Geoecology of the Russian academy of sciences (IGE RAS). For example, natural dangers – map schemes of seismic hazard and dangers of floods were developed. The key to the solution of problems is the development of the general scale of dangers and unification of all natural and techno-natural processes and the compilation of unified legend.
4. In Russia on the basis of the scientific developments of the State Scientific and Technical Problem SAFETY a version of the concept of Federal Regulating Document on the bases of ensuring interstate safety is created.
5. Legislative and normative-legal basis of the operation of the Russian System of Prevention and Actions in Emergencies is formed, and the Concept on Further Development of the Russian System of Prevention and Actions in Emergencies is offered.
6. In the Ukraine the general approach to the building of single territorial-distributed automated system of modeling and control on prevention and elimination of emergencies is put forward.
7. In the Ukraine the concept on the formation of an information database on potentially dangerous and unfavorable territories over natural and technogenic factors is formulated and developed. On its basis the scheme of potential-dangerous and disadvantageous territories (zones) of natural and technogenic character is proposed.
8. In the Republic of Belarus the work on the development of methodologies for forecasting and an increase in the safety of complex technical systems, on the methods and facilities of reception and processing of aerospace information form the remote probe of earth etc. is progressing successfully.

Other republics have (Kazakhstan, Georgia, Kyrgyzstan, Uzbekistan et al.) advanced scientific and technical achievements in a number of certain areas.

The realisation of the program will allow for the creation of a common scientific-methodical basis on the fundamentals of the interstate scientific and technical policy in the field of research, adjustment and an increase of safety and assessment of risks in the natural-technogenic sphere with the purpose of prevention of large catastrophes and the reduction of their consequences on the territories of the CIS.

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CHAPTER 3.5

Gender, Age and Social Class in Psychological Work in Disaster Situations

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1 Introduction

The School of Psychology of the University of Costa Rica has been carrying out intervention in emergencies and disaster since 1989. Crisis situations at institutional, communal, group, family and individual levels have demonstrated that each person experiences and elaborates disaster situations differently, and that men, women, children and adolescents, and the elderly develop mechanisms that can facilitate or become obstacles for adequate reactions to these crisis.

In this work, we have learned to understand the way people make sense of their experience. In populations that have suffered floods, landslides or earthquakes, when they reconstruct their experience, the alert systems through which they were informed of the possible impact of the phenomenon become very important in that they are perceived as useful or, in other cases, insufficient for preparing the community and reacting properly to confront the situation. The response strategies organized by these communities also becomes an important source of lessons for identifying strengths and weaknesses in community organization and in the response of individuals and groups. This makes it easier to understand social factors affecting vulnerability that can be identified from the perception of risk, and transformed into useful tools for diminishing possible damage.

In a previous paper presented at this same conference Sáenz (1998) ascertains that in risk management one of the most important aspects to consider is the management of the vulnerability of persons or social groups facing eventual disaster situations. Within this vulnerability, the fact was stressed that there is an emphasis placed on the instrumentation, communication and development of detection of threats in the physical dimension (meteorology, seismology, volcanology, etc.) with less importance given to social vulnerability. A good part of this social vulnerability is related to inadequate perceptions that people may have regarding distinct events or the communication surrounding them. It is within this framework that we place the importance of early warning management, since if an adequate response to these warnings is not produced, the consequences of natural events can become authentic tragedies or disasters. Due to this, within the framework of risk management, it is necessary to take into account the perception that individuals and groups may have of these events, in consonance with their cultural patterns and their imaginary concerning nature, its events and possible disasters.

We have maintained, in synthesis, that social vulnerability will increase if there is not an adequate handling of early warnings, which can be more effective in their communication if they consider not only the characteristics of the sender of the message but also of the language used and the characteristics of the receptors (individuals and groups) of this message.

Based on the attention of emergencies and disasters that we have carried out in the School of Psychology of the University of Costa Rica since 1989, we have observed that in the population we have worked with it is assumed that disasters are only present in "major" events (earthquakes, severe flooding, major volcanic

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eruptions, etc.) ignoring that in a country such as ours risk is permanent in everyday life. Small "losses" (human, ecological, etc.) are not assimilated as part of the chain of consequences that disasters leave behind. Only when a "big event" arrives, risks, threat and losses are assumed as such (land slides in El Llano in San Marcos, flooding in Rivas, in Pérez Zeledón, earthquake in Limón, etc.).

Another serious problem lies in that there are no clear strategies in the country for working factors such as those we have described. The task of having a trained population, prepared and willing to diminish threats, and to acquire a different vision of what a disaster is, as part of everyday life, is still to be realized in our country. That is why we mention that social vulnerability is as present and as important as physical vulnerability.

We have carried out our work basically in rural communities, in which disasters of different magnitudes have occurred. Some of these have been of national proportions, such as the earthquake that hit Limón in 1991. We have to consider the small size of our country (51 000 km^2). This makes it hard to distinguish between local or national events. It must be mentioned, also, that we have a very important volcanic chain, a surprisingly large hydrographic network, permanent seismic activity, and coasts in both oceans.

Our interventions have allowed us to approximate psychosocial mechanisms that townspeople have developed to confront disasters. In this framework, it can be established that it is a population with a pronounced lack of knowledge concerning threats, vulnerability, and risks in the face of disasters, which at the same time, linked with other psychosocial factors, determine perceptions and reactions. We attempt, here, to make a projection of the implications of these situations in the reception of early warnings.

We will now offer a brief summary of how gender, age and social class influence the coping with disasters, we must note that these factors are interrelated.

2 Social Class and Community Organization

The communities we have worked with are mainly rural, with scarce economic resources, with houses built by the town-dwellers themselves, many times in terrain that is not fit for construction. Besides, some of the agricultural practices used have caused deforestation, and inadequate use of soils has contributed to vulnerable conditions. The economy tends to be of a subsistence level, with strong debts owed to banks (which makes recuperation after disasters even more difficult). There is strong dependence, in these conditions, on government and institutional support.

Many of these inhabitants are quite conscious of the risk situations that they face. However, they feel incapable of changing these conditions, due to their economic condition and lack of government support that could allow them to overcome their marginal condition. The community organization tends to lack preparation in the handling of disasters, and thus do not count with action plans upon receiving the alert. They lack knowledge of the characteristics of the event and of how to respond adequately (for example, where the most secure places are). The way communities responded to the announcement of Hurricane Caesar in 1996 were based on the knowledge that communities had of their surroundings and the changes detected in them. The decision to evacuate inhabitants stemmed from this local knowledge.

Upon remembering and construing these experiences with local leaders, these insist on the anxiety created by being responsible for decision making without counting with adequate information about what was going to happen. God is credited with what worked, but they blame themselves (and the emergency commissions) for the lack of organization and preparation for disasters.

If: "Alarm systems are useful for protecting people that are in danger due to an imminent disaster, and they are characterized by alerting and providing information so that the people know how to protect themselves" (Sorensen 1996), in the cases we have worked with, both of these functions face obstacles. Communities tend to not have adequate information concerning threats and risks that they face. When the alert of Hurricane Caesar was presented in 1996, the inhabitants could not know how this would affect the community, and they did not count with an organization for warning of the emergency that could produce an organized, effective response. If the community responded to the indications of their leaders it was due to

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the fact that they were well known figures that provide trust and credibility. The deaths of people that did not attend the alerts were perceived by the leaders as "personal failures," because they thought they were not convincing enough because they did not count with information that would facilitate their neighbors comprehension of the gravity of the event.

It is important to note that the effects of an event persist for months or years in people's lives, depending on the type of impact and the experience these people have had with previous disasters. Our own experience leads us to believe that previous exposition to disasters makes people more aware and sensitive towards the possibility of new disasters, but does not instigate action leading to preparation for the event. Many individual and collective mechanisms act to minimize reaction: negation (loss of historical memory), devalorization of new information, and the coexistence of other sources of explanation such as myths, religious explanations, etc.

3 Gender

Many texts, referring not only to the topic of disasters, make the mistake of homologizing gender condition with women, exclusively. This has direct consequences for work carried out with persons and groups. If we adhere strictly to what gender theory advocates, this concept would refer to both men and women and their social determinants (Lagarde 1990, Salas 1996, Salas 1998).

The distribution of time, space and social relations tends to be different among men and women. In our rural context, women organize their everyday life in precarious conditions, developing communication networks that tend to be informal and closely-linked. There is a predominance of affective and subjective aspects. A more flexible and explicit handling of affects and feelings in part of this quotidian life, associated with models and socialization processes in which "existing for the sake of others" is the dominant theme, with an influence of religious magical thinking that adds new elements for everyday living.

Those men that we have worked with in rural areas tend to have a much stronger contact with public life, specially in what concerns productive labors outside of the home setting (specially agriculture). This contact with nature, source of their wellbeing, allows them to accumulate a more empirical knowledge of the causes and consequences of natural events, specially the recognition of inadequate use of soils and the danger that this represents.

Men, generally speaking, have a larger participation in community organization and dynamics, which links them with the exterior world in a different manner, though it cannot be underestimated that in these populations many women are involved in productive chores in a direct way. But when it is time to make decisions (as in emergencies, disasters, etc.) it is the men that prevail.

Women tend to develop greater activity related to health, education and care issues, responding precisely to that "existing for others sake," while men tend to become more involved in production and infrastructure. Men are more easily involved with local decisions in the face of disasters, and are incorporated more easily to tasks of construction or reparation of infrastructure.

For example, in the severe flooding that took place in the southern community of Rivas due to Hurricane Caesar in 1996, or in the large landslides in El Llano in San Marcos (that caused several deaths and much destruction), the alert given gave way to different mechanisms in men and women. In both communities the alert was given basically by men. The women's task was to give immediate response to evacuation and then take charge of reorganizing everyday life, fractured by disaster. Despite the immediate reaction from women in evacuating and saving their loved ones lives, concrete actions required men's approval. The complex system of dependence and submission to men that permeates their existence is also active in disaster situations.

In the alert phase or regarding the effects of disasters women connect more easily with the idea of saving lives, rather than properties or belongings. Expressing fear or similar sentiments is easier for women. Men are busy saving belongings and properties. After all, the masculine socialization stresses the roles of "protectors" and "providers;" they also have to maintain a "rational" position and not "lose control." Fear, anxiety or despair are not proper states for men.

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These variables have to be considered in community organization facing threats and vulnerability, not only upon confronting certain events, but permanently.

Any alert system, as sophisticated as it may be, must consider these types of variables, and not assume that all people will respond in the same way. To think that "all adults are equal" not taking into account gender differences can be a serious mistake.

4 Age

Our system of child-rearing, that responds to vertical and rigid socialization models, assumes that children always depend on adults. That is why in disaster situations not only do children not decide (which has, of course, often an objective base) but they are not informed, instructed and placed in what is happening. It is assumed that the child does not understand, forgetting that he listens, observes and perceives with perfect clarity what is happening or that at least he perceives that the basic aspects of his life are being altered. Many of the fears and anxieties produced are contained and handled by the mothers.

As a result of this, a child's reactions might become a nuisance and distraction for the "important tasks" that are urgently required; this makes things even more tense. In many occasions, in the family or in other community instances, children are underestimated in their possibility of contributing to the confrontation of the disaster situation.

Our experience tells us that, to the contrary, the child is an important social actor in risk management and that he often becomes an important reference for the design of emergency plans and the detection of threats. Some work we have developed in formal education structures has shown great sensitivity and susceptibility in what concerns protection of nature and sustainable development.

From this perspective, we consider that formal educational systems can play an important role as channels and transmitters of alert systems. This could even be incorporated as part of the curriculum, in an obligatory and systematic manner.

Adolescents require a special chapter, given the images of nuisance and uselessness that tend to be assigned socially to them, at least in our context. This occurs even when many of them are inserted in production systems or in formal education. On many occasions, they process very important information concerning threats to the community or region, but this knowledge is not recognized or validated. Their ambiguous situation with respect to the adult world is also reproduced in disaster situations, in which they tend to not be assumed as adults and, on the other hand, are not given the protection that is invested in children. This situation tends to be very complicated, for example, in Rivas they faced "labeling" due to their place in the community and in a changing world, with a definite urban influence, that invades the small rural population. The adolescents are easily placed in the pole of "evilness" (lazy, useless, prone to vices, etc.).

Nonetheless, in our experience we have observed their organizational capacity and their concern for others, seeking solutions for problems, and they can form a very important group for organized response to early alert warnings.

For their part, older adults are invalidated and placed in a role of even greater dependence and are excluded form decision making, not only those that concern the community, but also those that affect them directly. Traditional culture, that gave a predominant role to older adults in the processing of information and in decision making, has been changing to a scheme where the elderly are basically not taken into account. This occurs in these rural settings, and there are reasons to believe the trend would be even worse in urban areas.

5 Closing Comments

The basic proposal of this paper lies in what we consider a fundamental task for social sciences and their role in the attention and handling of disasters: to come to terms with a social world in which the differences between persons and groups mark diverse approaches to disaster and emergency situations.

This is particularly important in disaster situations and in risk management. Valuable and well-founded scientific information can fall into a vacuum if characteristics of its receptors are not considered. This paper has attempted to provide some elements in this regard.

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It is within this framework that we place the management of early warnings, since if an adequate response is not produced, the consequences of natural events could mean disasters or tragedies. In risk management it is necessary to include the perception of people and groups, according to their cultural patterns and social imageries, concerning nature, its phenomenons and possible disasters.

With respect to information concerning alerts and the responses by communities, it is necessary, as has been stated in this paper, to consider gender, age and social class in establishing preparation programs for disasters, seeking an active role for individuals and groups.

The problem is that in Costa Rica we lack clear strategies for working on these factors. The task of counting with a well-prepared, organized population, willing to diminish threats, and acquiring a different perspective on disasters as part of everyday life has yet to be achieved. That is why we insist that social vulnerability, is just as important as physical vulnerability.

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CHAPTER 3.6

Psychological Interventions in Disaster Situations

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Introduction

This paper attempts to portray part of the work that has been carried out in the last ten years by the School of Psychology of the University of Costa Rica relating to disaster and emergency situations. This work, which has taken place in communities, with families, groups and individual attention, has responded to the call of the National Emergency Commission and has been strengthened by the reflection and proposals of a group of professionals and students that have been involved in this experience. A large part of this effort has pursued in close coordination with local emergency committees that exist in different locations in our country.

Much of the work has involved rural populations. While it is true that events that have affected our country have hit different areas, the tasks carried out by our School of Psychology have mainly involved this rural population. We have also integrated, in these experiences, professors and students from other disciplines, such as social work, geology, civil engineering, geography, nursing public health.

We feel the need, derived from these experiences that have emphasized emergency attention, of analyzing paradigmatic transformations in the organization of knowledge and the actions involved in the handling of disaster situations.

Alert systems and their subsequent responses should be understood within the framework of the administration of disasters, which can facilitate or become an obstacle for the participation of citizens for the reduction of risks. This paper is part of a major effort that seeks to engage the question of socio-cultural factors in disaster policies and early warning systems, and that supposes that if social and personal or subjective factors are overlooked vulnerability will rise significantly.

The Attention of Disaster and Emergency Situations in Costa Rica

Even though our country has engaged, especially in the late sixties and early seventies, in important efforts that seek to organize and consolidate an agile and dynamic structure that can respond quickly and effectively to disaster and emergency situations, much of the effort realized centers around the handling of the emergency or the event, paying little attention to other crucial phases of risk situations.

Costa Rica, due to its geological, geographic and climatic conditions, in a country with a high exposure to natural phenomena, that with increasing frequency turn into emergencies some of them of great proportions (see map).

According to Lavell (1996b), our country presents an "emergency handling system," a model that has been oriented fundamentally towards the phases of preparation and response to emergencies and disasters.

This model is influenced by a vision of disasters as dangerous natural phenomena, difficult to prevent and control, and thus, compares the disaster to extreme natural physical, technological or anthropogenic phenomena and conceives the tasks of reduction and detection of threats.

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Following this model, scientific studies should focus physical threats, their prediction and prognosis.

Based on this perspective, and despite the condition of a small and underdeveloped country, Costa Rica has managed to receive international financial backing for top level scientific and technological research, and has developed infrastructure and highly qualified personnel in these fields. There are valuable scientific centers that produce information on physical threats: the Laboratory of Seismic Engineering in the University of Costa Rica, which develops techniques of antiseisimic construction, the Research Center on Housing and Construction of the Technological Institute of Costa Rica, two seismic and volcanological networks (University of Costa Rica–National University), the Central American School of Geology, the National Meteorological Institute, etc. This has possibilitated a monitoring system and early warning system that attempts to prepare the population for pertinent and preventive actions.

All this becomes particularly relevant if we take into account that the characteristics of the event mark the difference in the early warning. This is a basic idea for this paper, since we have such a variety of natural threats confronting our country.

In Costa Rica, as in other parts of the world, the most significant advances in die production of knowledge regarding disaster situations has stemmed from the so-called natural sciences. Social sciences, including psychology, have had little participation (Cardona 1993). This has tended to vary in the last decade, but in a slow arid difficult manner, at least in our context. Work in Psychology and other social sciences is incipient.

There has been little work produced regarding the psychosocial factors that influence the perspective on disasters developed by communities, and their behavior and organization in these situations. In our experience in emergency situations, it becomes clear that despite all the scientific and technical information that is disseminated regarding physical threats, in significant sectors of our population myths, diverse beliefs and magical thinking (for instance disasters conceived as punishment or as actions of divine entities) have a marked influence on how the scientific information is received and processed, and how people behave in response to it. For example, there is a religious myth in Costa Rica, stressing the protection provided the country by the national religious figure: the Virgin of Los Angeles. In 1988, when Hurricane Joan, that was expected to strike at costarrican territory, suddenly "changed course," destroying Bluefields, in Nicaragua, this was interpreted by a significant portion of the population as a "miracle" carried out by the protective virgin.

Cultural aspects that influence the perception of risk should be understood and worked in the early warning systems. Cardona (cited in Jiménez 1997, p. 7) states that:

> an early warning system takes into account the characteristics of the phenomenon that acts and cultural factors characteristic of the zone. Part of these cultural aspects are the manners in which the inhabitants perceive and how they confront the phenomenon in question.

The belief that natural forces are uncontrollable and that the only thing left to do is to wait for events to occur is reinforced by people being excluded from participation in the management of disaster situations. They have been placed in the role of receptors, in a manner such that scientific information is not linked with their everyday experience and is perceived as being "complex information" that is incomprehensible.

There is little knowledge of the procedures with which conclusions were reached and this impedes trust. Besides, people are told about predictions that point to probabilities and uncertainty while their necessities are very certain. For example, in the town of Rivas, in the southern part of the country hit by floods in 1996. When told by experts about the geological conditions of a zone prone to periodic flooding, townspeople replied that since a major flood had just happened, it would take many years for a new event to occur, and thus they could pursue their everyday life as if they did not live in a high-risk zone.

In this framework, not only do people tend to be placed exclusively as receptors of information, but they also do not consider themselves part of the network of institutions or organisms that manage disasters. There is a double exclusion in this process.

There is another nodal issue involved: the elaboration, transmission and diffusion of all this information is carried out in a vertical model of relationships in which many have to

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assume subordinated positions. The experiences that we have developed indicate that there is distrust towards institutions, based on the distance existing between the populations and these institutions, and that it is necessary to bring these universes or cosmovisions closer together: the so-called dialogue between "ways of knowing" and "ignorance" (on both sides). For example, in the community of El Llano, in San Marcos (northeast of San José, the capital), upon the non-specific alert that Hurricane Caesar (1996) would affect the zone, alert given by mass media, a series of "previous knowledge" was activated in the community. Changes were monitored concerning rainfall: "it rains differently," rivers widened their bed, and mountains "seemed to be moving and could come down" (with water absorption levels becoming saturated). This helped the alert to function, and many people were evacuated, by the townspeople themselves.

Wilches-Chaux (1998) suggests that,

> if the external agents are able to engage in dialogues of "ways of knowing" and ignorances with members of the communities, and can through this dialogue unveil the particularities of each process, identify the elements that provide the community with a sense of purpose and pertinence that characterizes a concrete situation, the contributions of science and technology will be applied with greater possibility of success in the benefit of the community.

Early Warning and Psychological Work

To rethink the possible contribution of Psychology in this field, it is important to remember that early warning is an intrinsic part of disaster management, and as such it is not exempt from how disasters are understood and managed in general. In the so-called physicalist model of disaster management, even in developed countries, there has been an emphasis on the detection of physical threats, tendency which still dominates in many places. Later on, the need to consider the vulnerability was included, though with an accent, once more, on physical aspects. In other words, in the domains of threats and of vulnerability there has been a sort of dominant "technocratism," centered on the physical-technical aspects of disaster situations.

Let us consider, briefly, the concept of vulnerability. This is understood as weakness or "incapacity to resist" or "incapacity to recuperate from" threats. When a disaster occurs it does not depend exclusively on the threats themselves but also on multiple factors present in the localities that can be recognized as vulnerabilities, in this manner we can refer to "global vulnerabilities." In this paper, we will stress two of these factors (they are interrelated):

- Social factors: relationships, behaviors, forms of organizing that can place communities in risk.
- Ideological and cultural factors: ideas, beliefs and values that are useful for interpreting natures phenomenons and their relationship with society, conditioning thc capacity of reacting to risks.

Within the alert and from social vulnerability, it is imperative to explore how perception of the risk and its derivations is taking place. It is obvious that social sciences would have a major task in this regard. In this way, it is necessary to access a series of psychosocial factors that are present in the lives of individual persons and social groups.

One of these, that we insinuated a few lines back, concerns the belief of disasters as consequences of dangerous natural phenomenons difficult to prevent and control. If this is linked to myths and magical religious consciousness present in the way in which many people explain disasters, the facts "present themselves to man as provoked by strange forces, uncontrollable, that strike. This fatalist vision inhibits action and conduces towards resignation and conformity." (Romero & Maskrey, 1993, p. 1).

Another factor, related to the one just mentioned, is that which concerns explanations such as divine punishment of sins, as proofs that God imposes or as forces, malignant, or strange spirits that lurk in the depths of the planet. This type of reasoning or explanation "transfers" the causes of disasters to supernatural levels that cannot be engaged. Besides, natural phenomena perceived as dangerous or difficult to prevent and control are reinforced with the difficulty in access and comprehension of people towards scientific and technical studies.

The primary source of access to this information is through mass media, with the danger of fostering alarmism, with contradictory infor-

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mation that reinforces doubt, mistrust and uncertainty. An example is the prediction of an earthquake in Nicoya (northern part of the country) with contradictory reports from the two seismological networks of two universities, with an inadequate handling by the media. For Bermdez (1993, p. 13): "Sensationalism in mass media is evident in the images or photographs used in title pages and accompanying texts." Mass media play an important role in how people interpret and define their behavior confronting natural phenomena.

In this manner, mass media reinforced the belief that disasters are unexpected events, associated to large scale events, such as, in the example above, the "great earthquake of Nicoya."

Despite efforts by different organisms and institutions in establishing a more direct relationship with populations in risk, the problem lies in the fact that the contact with scientists is not inserted in everyday practices of these populations. Besides, in many occasions, the language in which messages are presented makes comprehension by the people targeted very difficult, and present probabilities of occurrence of events in populations that due to their concrete life conditions emphasize the necessary priorities of here and now. This makes them feel they do not have real conditions for risk managing and that they do not count with the political and economic substrate for acting on vulnerability.

For these populations, that the occurrence of an event is a possible fact, does not make it a probable one: so that it is not necessary to prepare for its occurrence.

The evaluation and monitoring of natural threats carried out by scientists, that let them know how these behave and change, is not linked in many occasions with the knowledge that these populations have of their surroundings, their identification of these threats and their transformations. This situation fosters the confrontation of two "ways of knowing" that are dissociated: at the same time this dissociation influences the perception of risk and the decisions made during early warnings.

On the other hand, the historical memory that populations have of disasters, that permits their understanding of the possibility or probability of occurrence of events, together with their knowledge of their surroundings, is rarely used to accomplish a link between scientific information and quotidian knowledge or practice. For this reason, when populations are reached, they become passive receptors of external knowledge.

The need arises, then, of working on what Wilches-Chaux has called the dialogue of knowledge and ignorances:

> the dialogue between the truth of the scientist and the truth of the community The mutual acknowledgment of the scope and limitations of each truth till reaching a shared interpretation of reality (though not necessarily the only interpretation of reality).

This author appeals to the concept of "social imaginary" conceiving it as "a group of images, that is of ideas through which we represent the world." (Wilches-Chaux, 1996, p. 83). These do not belong exclusively to the order of the objective world to where the subjective aspects are essential in interpretations.

The diversity of images present in those populations with which we have worked give account of heterogeneous representations that exist with respect to disasters, in populations and in the persons or institutions encharged of their management. This diversity of images and ideas is traduced in attitudes, of relationship affects, communication processes and social practices, and in actions to confront situations that should be traduced in such a way that they become useful tools in the reduction of disasters.

The risk management strategy proposed by the Network of Social Studies in the Prevention of Disasters in Latin America is of vital importance for programs and projects for risk reduction that are based on the social imaginary that communities poses concerning threats, vulnerabilities and risks. Understanding and analyzing is of great importance for understanding behavior and motivation of populations at risk.

Oftentimes communities have views on the state organisms and non governmental organizations encharged of disasters in which they filter not only the information that these provide, but also the answers that they consider these instances expect from them. People become wary because they perceive that these organizations do not give due attention to their needs or that they intervene imposing criteria.

State organisms and other external social actors also have stereotypes or preconceived images concerning what communities should

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know and how they should act on specific situations. This is an obstacle for coordinating and establishing linkage between the external agents and the communities.

Regarding this matter, Wilches-Chaux (1996) points out the effects of this problem in the handling of disasters:

1. Institutional plans are often based on lack of knowledge about the particularities of populations.
2. Generic answers are applied to diverse situations, with different characteristics and needs.
3. Scientific, technical and administrative recommendations are not sustainable, and lack political social and cultural meaning for the communities.
4. Real processes of participation and appropriation of the problem by communities is not accomplished. That is why early warning systems should take into account the phenomenon that is occurring and its characteristics and also, cultural and social factors of the zone in which it occurs.

Wilches-Chaux has proposed that

> populations can be more receptive towards strategies that satisfy their stronger needs and can be introduced with ease in the technological world, that toward exotic strategies that have no evident connection with their more immediate needs (1998, p. 87).

The task that has to be solved is then the link between the knowledge of the natural physical world with the subjective world that is present in all human endeavors. We believe that an inadequate management of these subjective components (affects, sentiments, values, etc.) becomes another element of social vulnerability, that should be understood in any strategy involving individual or collective actors.

In Costa Rica, there are difficulties in the manner in which valuable scientific information is transmitted to the population, in the way it is traduced to everyday language. The population reacts with incredulity (satire, jokes) or with indifference or negation.

We must then add social vulnerability to the physical vulnerability of our country increased by incredulity concerning scientific information or inadequate treatment of this information generally centered on the event and its physical threat.

If the population only considers major events as disasters, ignoring "lesser" but insidious social vulnerability can only be increased. This has an important impact on the response of populations facing early alert warnings as part of the general handling of disaster situations in the country.

Facing this panorama, there is an urgent need to increment the resources of individuals and groups in the adequate and "sensible" handling of the information received. From this angle of analysis no system of detection or alert for sophisticated and modern that it may be, will be effective if it does not count with an adequate transmission of its information and an adequate and pertinent response by the population. In our country, this aspect has been historically ignored.

It is clear that in disaster situations social traumatism is in inverse proportion to the level of organization and preparation that the community has. For a community to be duly organized it requires receiving and processing information in the best way possible it is a challenge for the social sciences to do this in a short term basis.

Challenges for Psychology and Other Social Sciences

We must add to the above that in a rather paradoxical way, populations either tend to refract the message that the expert provides or to leave everything in his hands. Either way communities do not assume an active role in the management of threats and vulnerability and in direct action concerning disaster situations, leaving everything in the hands of experts.

From our work in communities we have observed these diverse reactions that people have regarding to alert or early warning and we have seen the mechanisms that groups and persons utilize to manage these different situations.

We believe that the main task of the social scientist consist in working on this situation, proposing mechanisms and actions that can counteract the trends we have noted. For this, a positive dialogue must be engaged with the physical sciences, fostering a common action aimed at improving the life conditions of our people. We must create a more fluent and opportune knowledge.

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However, as psychologists we know that this, as in all fields of human action, knowledge is not only cognitive. Information by itself is not enough. Individuals and groups possess a series of subjective or affective components that impede or allow for the incorporation of new knowledge. In potential or real disaster situations these components are even more important, and they can then not be ignored. In risk management we must seek and promote a strategy that considers all people as actors in different levels.

We must seek a process of popular education and participative research that strengthens local and regional factors for the purpose of risk reduction, working on the analysis of beliefs concerning disasters and the interrelations of scientific knowledge, magical conscience, resignation and conformism. People must have access, then, to the identification, analysis and action concerning risk scenarios in a system in which the local, the regional and the national interact. All social actors must be incorporated from the scientist to the townspeople, each with their own knowledge and ignorance. The social imaginary that has been historically construed concerning disasters and their causes is another challenging field of work for social sciences.

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IV Early Warning Systems for Hydrometeorological Hazards

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CHAPTER 4.1

The Role of the WMO World Weather Watch System in Mitigating Hydro-Meteorological Disasters

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1 The WWW System of WMO

1.1 Historical Development

The development of basic infrastructures in support of operational meteorology dates back to the 18th century when the first observing network was established by monks which spread over several continents. When the World Meteorological Organisation (WMO) was founded as a specialised agency of the UN in 1950, global exchange of data was about to be organised on the understanding that weather is truly international, however, weather services were essentially focused on their national responsibilities.

This situation changed radically with the advent of jet air traffic which triggered the need to cover large parts of the globe with weather data and products needed for air navigation. At the same time, various other fields of meteorology stated requirements for international systems approaches, some of them out of long tradition, such as marine meteorology.

The launch of the first satellites added new dimensions to the observational infrastructure and stimulated the development of the World Weather Watch (WWW) concept in 1963 which later became the WWW Plan and Implementation Programme of WMO. This process is based on resolutions of the UN General Assembly and has since then become the centrepiece of the WMO activities on which operational meteorological services rely, same as many international programmes and research activities.

WWW has gone a long way from a loosely coordinated construction of various national components to an international system based on common standards and procedures.

WWW Milestones

1991	UN Resolution on the Peaceful Use of outer space
1963	WMO concept of WWW UN Resolution endorsing the WWW
1967	WWW Plan and Implementation Programme adopted by WMO Congress
1970s	Decade of Global Atmospheric Research Programmes (GARP) GATE (Tropical Experiment) MONEX (Monsoon Experiment) TOPEX (Tropical Ocean Experiment) ALPEX (Alpine Experiment) POLEX (Polar Experiment)
1978/79	First GARP Global Experiment (FGGE)

Cooperation in Research and Operations

1975	European Centre for Medium-Range Weather Forecasting (ECMWF)
1975	European Space Agency (ESA)
1976	Launch of METEOSAT 1
1972	Start of the Tropical Cyclone Programme
1978–84	The WWW Integrated System Study
1985	Composite Observing System North Atlantic (COSNA)

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1985 International Regional Centres
Africa: AGRHYMET, Niamey
ACMAD, Niamey
Drought Monitoring Centres
Asia: ASEAN MET Centre, Singapore
1986 The Tchernobyl Disaster
1986 EUMETSAT founded
1987 IAEA Convention on Early Notification And Warning of Nuclear Accidents
1988 Concept of Regional/Specialized MET Centres within the WWW
1989 Focus on Environmental Monitoring
1990 Expansion of the WWW Concept to serve all WMO Programmes
1997 The EUMETNET concept of networking European MET Services

1.2 Basic Programme Features of WWW

1.2.1 Integrated Systems Approach

WWW as a system has grown historically and therefore comprises a variety of technical solutions and standards. A matter of permanent concern is the different stages of development to be found in parts of the system. WMO has set minimum standards regarding operational procedures and capabilities which are implemented by Members as part of their commitment under the WMO Convention. Through its Commission for Basic Systems WMO acts regulatory with the primary aim to facilitate operational meteorology on all scales by maintaining appropriate standards, advise on cost/efficient ways of meeting the requirements for data and services and assisting Members in the implementation of the WWW operational components. Special emphasis is placed on the use of proven technology and systems compatibility.

Systems design and development became a major issue 15 years ago when the results of the global atmospheric experiments showed that the global observing system was lacking homogeneity, and the overall quality of the data was inadequate to meet the requirements of operational meteorology on all scales. In addition, the meteorological services found it increasingly difficult to cover the costs of data capture, particularly in the conventional system of surface and upper-air stations which is still the backbone of the WWW/GOS. Since then the WMO has invested substantial efforts in design reviews starting from the regional scale by identifying the gaps and deficiencies in data capture through a systematic performance monitoring carried out by designated monitoring centres. They provide regular feed-back to the services operating the network. This process aims at a steady harmonisation of the GOS while improving the cost/effectiveness of the system for which all National Meteorological and Hydro-meteorological Services (NMHS) spend a large part of their regular budget.

1.2.2 Involvement of all Members

The WMO/WWW has a strong driving force by the global nature of weather and climate which call for close international cooperation in maintaining the system through contributions by all Member states. At the same time there is a strong interest of all participants in getting data and products from the WWW system to satisfy their national requirements. This has led to a rather sophisticated inter-relationship between the NMSs which in fact excludes autonomy.

1.2.3 Standardisation of Techniques and Procedures

One of the basic requirements placed on the WWW is compatibility which stipulates the strict adherence to a set of rules and technical standards commonly agreed between all Members. Already the very first networks used calibrated standard equipment and generated data at standard observing times. Since then, the WWW has gone a long way in developing standards for data management, telecommunications, data processing and quality control which ensure the optimal inter-operability of all components on global, regional and national scales. One example is the agreement on meteorological codes which make the exchange of data and products independent of languages. Originally conceived as character codes using numbers and letters, the system of about 100 codes for various purposes is now converted into a universal binary code system specially designed for computer use.

1.2.4 Free Exchange of Data and Products

Although not explicitly mentioned in the WMO Convention, the principle of free and unrestricted exchange of WWW data and products constitutes the basis of all meteorological op-

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erations and research activities. This is particularly important in the area of disaster warning and mitigation. Recent trends of commercialisation have affected the data exchange policy of WMO Members and triggered the adoption of common rules for the exchange of data and products between Members safeguarding the international cooperation and ensuring the necessary data flow for all types of applications and research.

1.2.5 Multi-Purpose System

WWW was originally established to serve operational meteorology which includes applications for aeronautical, marine, agriculture and public weather services users with focus on safety of life and property. It soon became evident that the WWW infrastructures offered the potential of supporting other programmes under WMO sponsorship. This led to an expansion of the WWW scope and identified WWW as the basic programme of WMO providing infrastructural support to a variety of programmes. Notably, the telecommunications component (GTS) of the WWW has been used since years for non-meteorological purposes like the transmission of seismic data upon request by the UN Conference on Disarmament.

1.3 WWW Operational Components and Scales

1.3.1 The Global Observing System (GOS)

This component of the WWW has the longest history starting with systematic measurements of selected weather parameters supplemented by human observations at prescribed standard times in a network of fixed stations which is still the backbone of the GOS (Fig. 1) and which forms a reliable basis for diagnosis and forecast products and generates long time series needed for climate monitoring. Much emphasis is therefore placed on assuring the quality of observational data by application of sophisticated checks at various stages before incorporating them into a data base.

As human resources become more expensive, there is a marked trend towards automation in the GOS which is favoured by the developments in computer technology. At the same time the data yield even from the conventional stations is dramatically increased by more frequent observations offering the possibility to detect short-wave phenomena important for the very short range forecasts of mesoscale phenomena which are of particular interest for disaster mitigation.

What used to be a well defined but static network is now becoming an integrated system comprising all available data sources, e.g. by including mobile observing platforms (ships, buoys and aircraft), satellites and ground-based remote sensing devices (Radar, lightning detection, wind profilers etc.). Most of these compo-

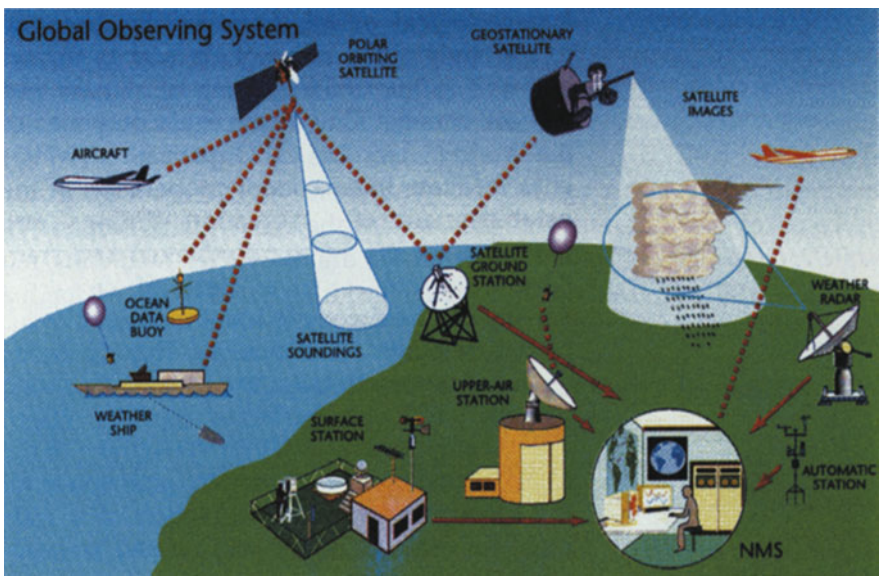


Fig. 1. The Global Observing System

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nents are introduced and tested in a research mode before they are integrated in the GOS. In this process it is essential to determine the optimum mix of components and technologies under technical, cost/efficiency and other criteria.

1.3.2 The Global Telecommunication System (GTS)

Timely availability of data and products is one of the basic preconditions for operational meteorology and hydrology. There is a close relationship between the invention of telegraphy and the establishment of NMHSs. The introduction of radio links/broadcasts, radio facsimile techniques, satellite communications/broadcasts, computer communications and switching techniques has influenced the evolution of operational meteorology. Many will recall that since morse coded radiocommunications the data transmission rates in the period of the last 20 years has increased by a factor 20000 and the communications infrastructure is now providing adequate coverage of the whole globe. As one of the power users of communications, the WWW GTS nowadays copes routinely with a data volume of around 100 MBytes per day for global exchange with much higher demands for specific purposes on an increasing number of links. WWW therefore has to maintain a position at the leading edge of communications developments.

Although the future of communication services looks very good, the GTS has to struggle with many problems and deficiencies, such as the differences in the available infrastructures and the varying levels of implementation on the regional and national scales. With the introduction of satellite communication services and automated message switching and data handling systems the NMHSs can now satisfy their data needs without running against insurmountable problems as they did only few years ago. At the same time the level of service has improved dramatically while the tariffs offer more bandwidth for a dollar, due to the deregulation of communications in most parts of the globe.

At present the GTS is still a dedicated network of multiple bilateral links between NMHSs operating in a store and forward mode. Regional Telecommunications Hubs (RTH) are responsible for the smooth data flow in the GTS as a free service to the NMHSs connected to them which includes the collection of basic data and the dissemination of data and products as agreed on a global and regional scale. The GTS also includes radio and satellite broadcast components which were established to satisfy regional requirements. These broadcasts are particularly useful for making available disaster warnings and related predictions to the authorities concerned.

1.3.3 The WWW Data Processing System (GDPS)

The term data processing in the WWW context includes a broad spectrum of operational functions aiming at the provision and presentation of output products for the users. In recognition of the fact that not every NMHS is in a position to generate the required output, the GDPS operates on the principle of shared responsibilities and close cooperation. By establishment of a three tier structure of centres with global, regional and national responsibility it is ensured that, within the WWW, each Member can benefit from the GDPS to the best of its ability. The output products of GDPS centres are listed as firm commitments in WMO publications which are updated regularly in accordance with requirements and evolving abilities of the centres.

There is a limited number of NMHSs who provide global analysis and forecast products on a routine basis. A much greater number of centres (35 RSMCs) generate regional and specialised products as a service to national centres who use them as a basis for national production. Many of the RSMCs are specialised on the provision of products for tropical cyclone warning, environmental emergency response (e.g. in the case of nuclear or chemical emergencies), and some other types of products.

Evidently, the development of computer power has a great influence on the progress in the GDPS (Fig.2) The quality of numerical weather prediction models has gradually eliminated the need for manual intervention on basic products thus leaving more human resources for forecast interpretation and taylor-ing. There is a marked trend towards automation in the pre- and postprocessing of data and products, and with the availability of high performance workstations there is now an opportunity for many NMHSs to develop their own capability in NWP on the basis of limited area

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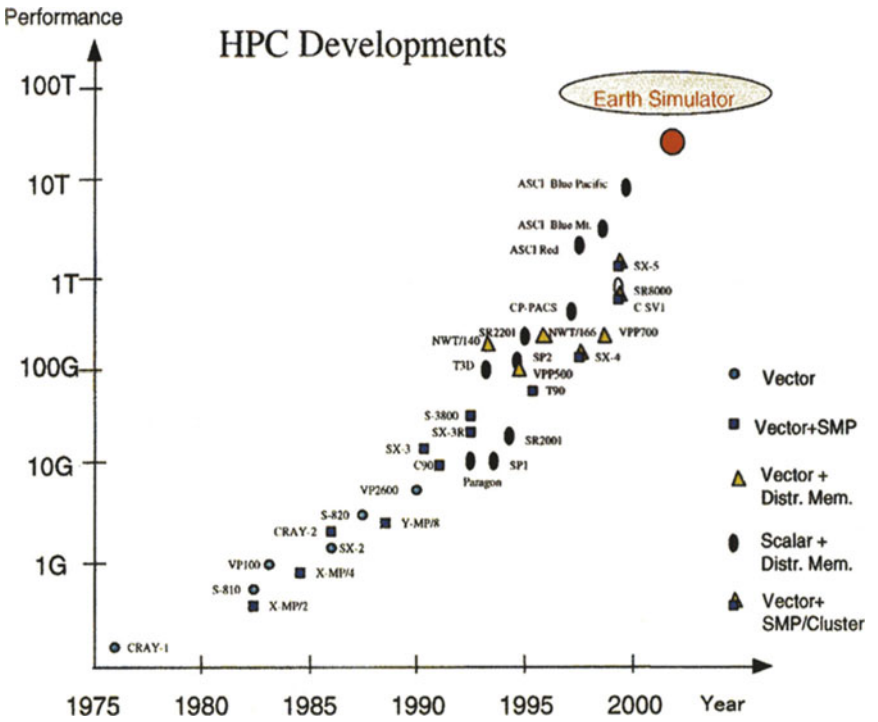


Fig. 2. Developments in High Performance Computing

models available from advanced centres in the WWW which are specially adapted to their national requirements. This trend is supported by scientific cooperation between the modellers on a multilateral or bilateral scale which includes the continuous verification of GDPS centre output under the WWW.

1.3.4 Data Management

Global data exchange places a strong requirement on the format and readability of data and products. One of the primary aims of data management was therefore to develop standard codes which make observational data language independent and easy to handle. In the beginning of WWW meteorological codes represented strings of characters/numbers focused on manual data handling. The broad based transition to computer use triggered a fundamental change to binary data representation which now dominates the exchange within the WWW system. This was a result of a consequent automation of data exchange on all levels. At the same time, the increasing requirements to exchange mass data (e.g. from satellites, radar, etc.) and large product fields depends on the use of computers in connection with increasing communications bandwidth.

Data management in the WWW system has a few other important components which call for strict standardisation. One is the concept of distributed data bases with data centres providing products and data on request for operations and research as a service which leaves the onerous task of setting up and maintaining global or regional data bases to a few designated centres. The quality of the data is assured by application of standard algorithms for quality assurance. Another important function is the regular monitoring of the availability and quality of the basic data. This is carried out by centres who take specific responsibility in regard to certain groups of data (e.g. upper-air data, sea surface observations, land surface data). These centres monitor the daily flow and quality of the data and initiate corrective measures in case of failure in direct contact with the operator of the data source.

1.4 WWW Implementation Support

In a system where each participant critically depends on the functions of the others and global coverage and homogeneity plays and important role, it is necessary to avoid discontinuities as much as possible. Differences in technology cannot be completely eliminated since

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they are a result of availability of resources and infrastructures. Since the inception of the WWW system, implementation support activities and technical assistance has been an ongoing process under which large sums of money have been spent and expert services have been made available by Members of WMO without much publicity. The main goal of the WWW implementation support activities is to guarantee all Members of WMO a minimum of performance and services which serves the interest of both developed and developing NMHSs. The UN Agenda 21 calls this capacity building describing a host of well planned projects aiming at improving national and regional systems as a contribution to the performance of global systems like the WWW.

1.5 WWW Design and System Development

Major parts of the budgets in all NMHSs (typically more than 60%) are regularly spent on the WWW infrastructure. In accordance with the joint responsibility of all Members for implementing and maintaining the WWW it is of critical importance to take a systems approach based on agreements reached on global standards and procedures. The design and further development of the WWW components is strictly based on stated requirements of the WMO programmes and is supported by scientific studies on the best mix of technologies, the impact of new components and their effect on daily operational activities.

In a world of financial constraints a systematic scientific approach to WWW is indispensable. The opportunities offered by the technical developments (e.g. computer performance, communications services, observing techniques) are balanced against increasing challenges from existing and new programmes in the area of climate monitoring, environment protection, emergency response and disaster mitigation, to mention only a few.

One important feature of the WWW programme is the expansion of the infrastructures of Members beyond their national boarders. System components of the WWW in the vast ocean areas and on aircraft platforms operated by Members as a voluntary contribution to the global system are now being placed under international funding and management schemes with contributions assessed in accordance with regulations applied in the UN system. Not surprisingly, these developments are starting in the European Union but will hopefully spread as a model to other regions of the globe.

2 What Makes WWW Unique?

Among the global systems WWW is unique as it is based on the Convention of WMO which includes the commitment of all Members to implement and maintain the WWW system operational on continuous basis.

- WWW infrastructures are providing permanent services at a high degree of serviceability.
- Continuity of standards and operations is a basic feature of WWW.
- Functionalities, workload and to some degree costs are shared between the participants.
- Data and products are exchanged between all NMHSs without principal restrictions and free of charge.
- Data are managed jointly in accordance with agreed standards and procedures.

While based on the UN General Assembly Resolution aimed at meteorological applications only, the WWW scope is expanding to provide support to other programmes. The WWW is now used as a model for and in support of operational systems for climate monitoring and oceanography.

3 The Use of WWW for Disaster Mitigation

3.1 The Tropical Cyclone Programme of WMO

Developments in meteorology show many examples where major evolutions were triggered by natural disasters. In 1970 it was the Bangladesh cyclone disaster which induced the adoption of a Resolution of the UN General Assembly inviting WMO to lay the grounds for the Tropical Cyclone Project which later became the Tropical Cyclone Programme of WMO (TCP; Fig. 3). The objective was to establish a regional, coordinated system for the mitigation of tropical cyclone disasters in cooperation with other organisations concerned.

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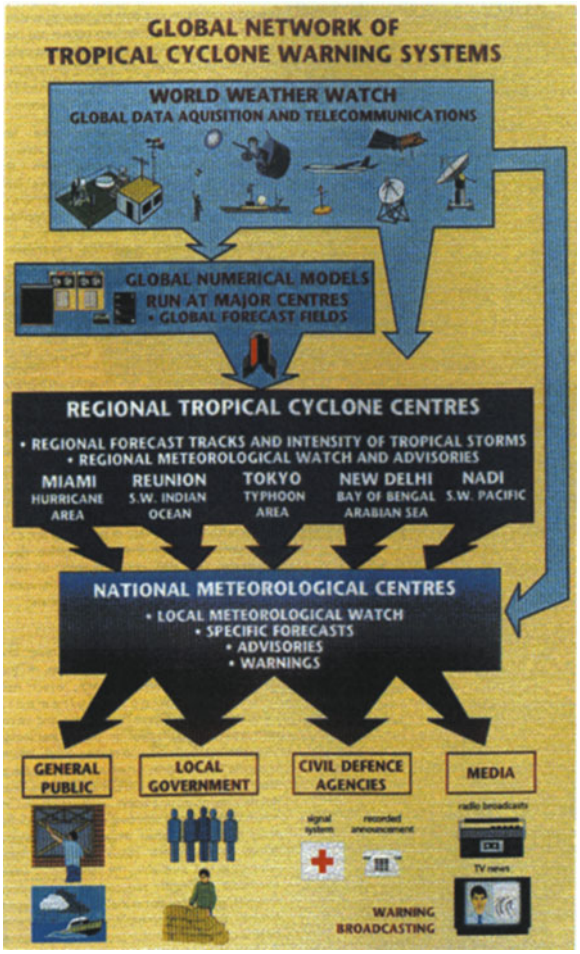


Fig. 3. The Tropical Cyclone Programme

This led to the establishment of five intergovernmental bodies in the regions suffering from tropical cyclones, i.e. the Typhoon Committee (Asia/Pacific), the Panel on Tropical Cyclones (Bay of Bengal/Arab Sea), the Regional Tropical Cyclone Committees (Africa and Pacific) and the Hurricane Committee (Central America and the Caribbean). These groups consequently developed an action plan comprising the main operational components of the TCP, namely

- Meteorological Component (TC Tracking and forecasting),
- Hydrological Component (TC flood forecasting and warnings),
- Disaster Prevention and Preparedness Component (in cooperation with the aid organisations).

The WWW system provides the basic operational infrastructure for the meteorological component of TCP. Under the concept of specialisation on products and services, Regional Specialised Centres were established to generate TCP products and warning services for each of the affected regions.

3.2 Environmental Emergency Response

In the aftermath of the Tchernobyl disaster, the WMO was one of the international organisations directly concerned with the lessons learned from this catastrophic event. Together with the International Atomic Energy Agency, the UN Environmental Programme, the World Health Organisation, the World Food and Agriculture Organisation and various other UN Agencies, WMO contributed to the formulation of the Conventions on Notification and Assistance in Case of Nuclear Accidents and Emergencies and drew up an operational plan for the assessment and mitigation of such disasters by using the WWW as a basic infrastructure to distribute notification messages and gather atmospheric and other environmental data necessary to feed atmospheric transport/dispersion/deposition models.

There was a joint effort to test and evaluate such models by conducting large scale experiments and evaluations of the quality of existing numerical simulation models on the basis of the Tchernobyl data set and later on data gathered from a measuring campaign using releases of tracer substances into the atmosphere. This served the intercomparison of prediction models and at the same time helped to establish operational arrangements for affective reactions on global, regional and national levels in case of the release of radionuklides into the atmosphere. The WWW system essentially provides its dedicated communications facilities, atmospheric data and appropriate numerical prediction model output. The latter is the responsibility of regional specialised centres under the WWW who have a demonstrated capability in providing relevant services and products to the decision makers and users. Such services are provided in accordance with the IAEA Conventions on Notification and Assistance to the competent authorities in each member country. Regular tests of the system components ensure functioning of the system.

An expansion of the simulation methodology and disaster warning system to other types of

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environmental emergencies follows logically from the system of nuclear warnings. This is enabled by the increasing possibility to simulate smaller scale atmospheric processes which are relevant for example in the case of major chemical emergencies.

3.3 External Uses of the WWW System

The WWW has been used in its observing/monitoring capabilities and data transport functions since many years by other UN programmes. Examples are the exchange of seismic data over the WWW GTS upon the request of the UN Conference on Disarmament, the exchange of oceanographic data under the agreement with the International Oceanographic Commission, the monitoring and exchange of climate and other environmental data under the Framework Convention on Climate Change etc.

The WWW system offers to these programmes a free ride provided the original purpose of WWW is not compromised and appropriate standards of data management and communications are observed.

4 The Future Development of the WWW

Recognising the fact that it is usually very costly to establish parallel infrastructures, the WWW system will have to serve many purposes in the future. One important precondition is that all users comply with the international standards adopted for the WWW.

The increasing requirements of various programmes served by the WWW imply that technical developments and opportunities are integrated as appropriate to ensure a functionality and performance at the leading edge of technology in areas like super computing, communications and data banks.

Along with the multi-user concept the interdisciplinary nature of research is strongly supported.

The ability of WMO Members to implement, maintain and operate the WWW as their contribution under the WMO Convention is clearly limited. Consequently, cooperative arrangements have been developed in an attempt to solve some of the problems in the WWW operational components. Up to now this was based on voluntary commitments by groups of Members to satisfy common interests, e.g. the establishment of an observing system on the North Atlantic. This only involved a minority of Members instead of the whole user community.

Consequently, there are attempts to establish a fair cost sharing arrangement by taking a network approach with a scheme of joint responsibilities for funding, management and operation of relevant WWW components. This approach is now being implemented by 17 West European NMHSs forming a network of services and activities which is called EUMETNET. The trend towards common ownership of systems like the WWW to which all Members contribute their share in accordance with agreed rules promises a way to solve some of the problems of WWW implementation and operation. At a time of dwindling national resources this is perhaps the best way of covering more successfully the specific requirements for the mitigation of natural disasters.

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CHAPTER 4.2

Meteorological and Hydrological Early Warning Systems

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1 Introduction

One of the most fundamental and widely accepted roles of governments through the ages has been to provide for the protection of their national communities from external threats to their safety, security and general way of life. The most serious threats have historically come from armed invasion and from the various forces of nature which imperil the safety of life and property and may lead to economic and social dislocation, famine and disease.

In many countries, the most frequent and pervasive threat derives from the wide range of meteorological and hydrological hazards, especially the immediate impacts and secondary effects of tropical cyclones, severe storms, floods, drought and fire. Governments have long accepted responsibility for national leadership in reducing the damage and loss of life from the full array of natural disasters of meteorological and hydrological origin and in assisting affected communities to recover from the social, economic and physical devastation left in their wake.

Over the past century, governments in an increasing number of countries have identified meteorological and hydrological warning systems as a vital element in their armaments against the burgeoning economic and social cost of natural disasters which have recently been estimated to exceed USD 200 billion annually in economic costs alone (United Nations 1998). The operation of such warning systems and the provision of warning services has historically been one of the highest priority functions of the National Meteorological and Hydrological Services (NMHSs) that now operate in more than 180 countries and, in many cases, the primary rationale for their existence.

Two features, one characteristic of the human response to disaster of all kinds and the other a particular attribute of natural hazards of meteorological origin, bestow a uniquely international dimension to the challenge of natural disaster reduction. The first stands in significant contrast to community complacence at the loss of life through armed conflict and

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chronic causes of death such as disease, malnutrition, traffic accidents and street crime and derives from the intensely humanitarian emotions evoked in even distant communities, especially now in the age of instant global news coverage, at the plight of those who fall victim to natural disaster; and the expectation of citizens everywhere that their governments will spring to the aid of foreign countries in disaster situations without significant regard to cost, convenience or prevailing political climate. The second is the overwhelming dependence of governmentsrsquo; capacity to predict and forewarn their own communities of impending meteorological and hydrological disasters on rapid access to essential information from beyond their national borders.

Achievement of the goals of natural disaster reduction is thus particularly dependent on, and characterised by, a commitment to international cooperation and to free exchange of information and expertise between countries which is far removed from the competitive disciplines of international trade in goods and services built into the charter of the World Trade Organization (WTO) and which finds particular expression in the internationally cooperative traditions and policies of the World Meteorological Organization (WMO). There is little doubt also that strengthened international cooperation in the application of modern meteorological and hydrological science and technology to global initiatives in natural disaster reduction will contribute significantly to national strategies for sustainable development and, ultimately, to the betterment of the lives of people of all nations.

This paper seeks to elaborate on the contribution of meteorological and hydrological warning systems, and the NMHSs which house them, to the goals of natural disaster reduction embraced and elaborated through the special decade-long effort of the UN (United Nations)-designated IDNDR (International Decade for Natural Disaster Reduction). It builds on the overall foundations of pre-Decade warning system strategy (e.g. Zillman 1985) and the progress achieved and challenges set during a series of mid-Decade reviews* in Yokohama, Surfers Paradise and elsewhere (World Conference on Natural Disaster Reduction 1994, Heathcote et al 1996). It draws particularly on the experience of the Commonwealth Bureau of Meteorology in providing a wide range of meteorological and hydrological warning services to all sectors of the Australian community over the past century.

2 Meteorological and Hydrological Hazards

Meteorological and hydrological hazards come in many forms and on many scales in time and space and are generally taken to include all those phenomena of the atmosphere, ocean and inland waters which, individually or in combination, pose a threat to the safety of life and property, the social and economic stability of communities and the quality of the natural and built environment.

Their detection, monitoring, understanding and prediction and the forewarning of their occurrence to potentially affected communities falls within the domain of the overlapping sciences of meteorology, oceanography and hydrology (Fig. 1). Within the Fig. 1 sub-domain of meteorological service provision, it is usual to distinguish between the provision of warning services for severe weather phenomena, air pollution events and climatic hazards such as drought (Fig. 2).

The most frequently identified hazards of meteorological and hydrological origin include the following, grouped somewhat arbitrarily according to whether they are manifest primarily in the atmosphere, ocean or inland waters:

- Severe weather phenomena
  - Blizzards and winter storms
  - Fire weather (forest fires, bush fires, grass fires)

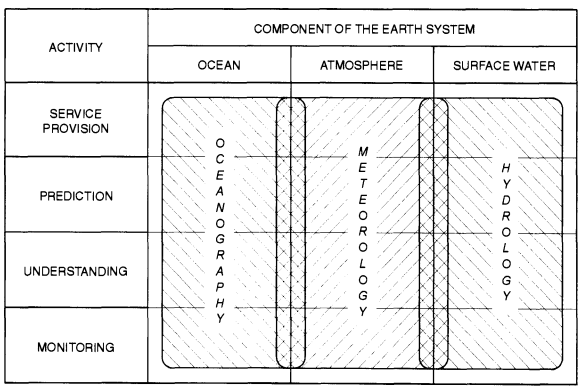


Fig. 1. The interrelated and overlapping sciences of meteorology, oceanography and hydrology which deal with the systematic monitoring (through observation), understanding (through research) and prediction (through modelling) of the behaviour of the fluid earth system and their useful application through the provision of a wide range of services to the community

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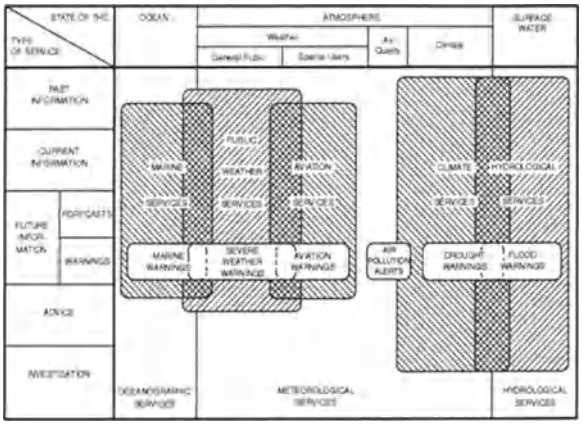


Fig. 2. A simplified taxonomy of meteorological, oceanographic and hydrological services including warning services for hazardous phenomena of meteorological and hydrological origin

- Gales
- Sandstorms and duststorms
- Severe thunderstorms (hail, lightning, squalls, damaging wind gusts)
- Snow (snowstorms, blowing snow, snow-squalls, whiteout)
- Tornadoes and waterspouts
- Tropical cyclones (including hurricanes and typhoons)
- Turbulence

- Other hazardous weather conditions
  - Cold snaps (cold waves, frosts, road, river and lake ice)
  - Fog and low cloud
  - Freezing rain, freezing drizzle and sleet
  - Heat waves
  - UV-B radiation exposure
- Air quality hazards
  - Acid rain
  - Radioactive fallout
  - Poisonous gas release
  - Smoke haze
  - Urban air pollution (brown haze, smog)
  - Volcanic ash
- Climatic hazards
  - Crop diseases
  - Drought
  - Pest invasions (grasshoppers, mice, etc.)
- Marine hazards
  - Currents (rips and other dangerous currents)
  - Icebergs
  - Sea ice (pack ice and fast ice)
  - Storm surge
  - Tsunami
  - Waves and swell
- Hydrological hazards
  - Algal outbreaks (low flow conditions)
  - Erosion and landslides
  - Flooding (including flash flooding)

As pointed out in a recent report of the IDNDR Working Group on Early Warning for Hydrometeorological Hazards including Drought (Kootval et al. 1998) and shown schematically in Fig. 3, the spatial and temporal scales of these hazards vary widely from short-lived, violent, phenomena of limited extent (e.g. tornadoes and severe thunderstorms) through larger systems (e.g. fronts, tropical cyclones and extra-tropical cyclones) which can subject whole countries or regions to strong winds, flood-producing rains, storm surges and coastal flooding or heavy snowfalls, blizzard conditions, freezing rain and extreme hot or cold temperatures for periods of several days. At the largest scale are widespread El Niño-related droughts which may affect huge sub-continental areas for months to years on end, causing famine and disease, mass migration, desertification and loss of animal populations along with increased risk of disastrous forest fires.

It is important to realise that many of these hazardous phenomena occur in combination or may be triggered one by the other. For example, flash floods may follow closely in the wake of severe storms and may, in turn, lead to landslides and erosion. Similarly, a number of meteorological and hydrological hazards may result indirectly from geophysical events or may be triggered by human activities – river flooding from a dam collapse as a result of seismic activity or overtopping due to inappropriate dam management practices; tsunamis generated by undersea earthquakes or bush fires triggered by the deliberate or unintentional action of humans as well as by natural processes such as lightning. Hunt (1994) has emphasised the distinction between primary and secondary events leading to natural disasters, with different forecasting and preparedness mechanisms often called into play to minimise the impact of the secondary hazard once the primary event has been anticipated or has occurred.

Most of these meteorological and hydrological hazards are, of course, restricted to particular geographical regions of the world. For example, tropical cyclones pose a significant threat only in the three major tropical cyclone basins shown in Fig. 4.

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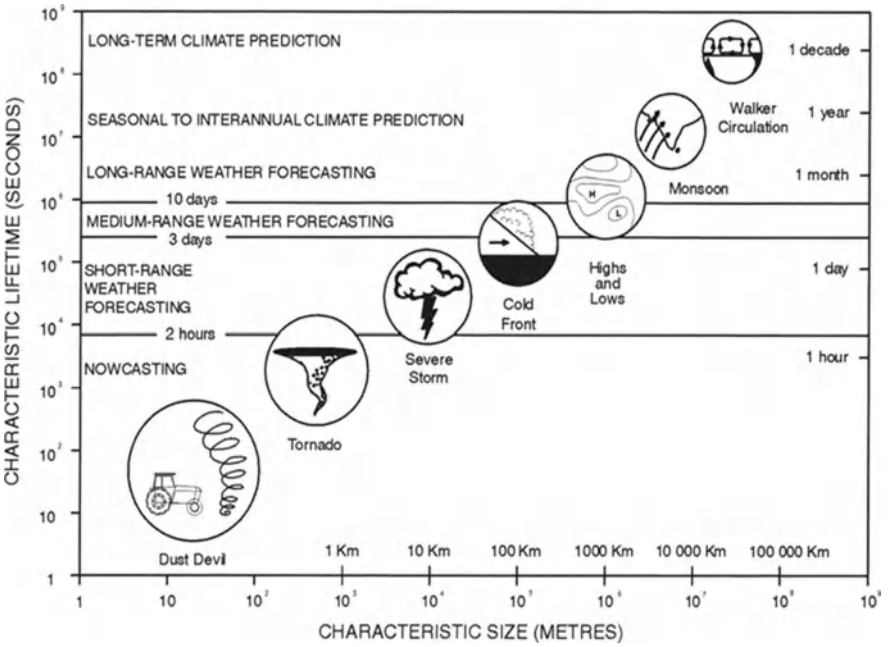


Fig. 3. The characteristic size and lifetimes of some typical atmospheric phenomena. The terminology used to describe weather and climate forecasting lead times is also shown

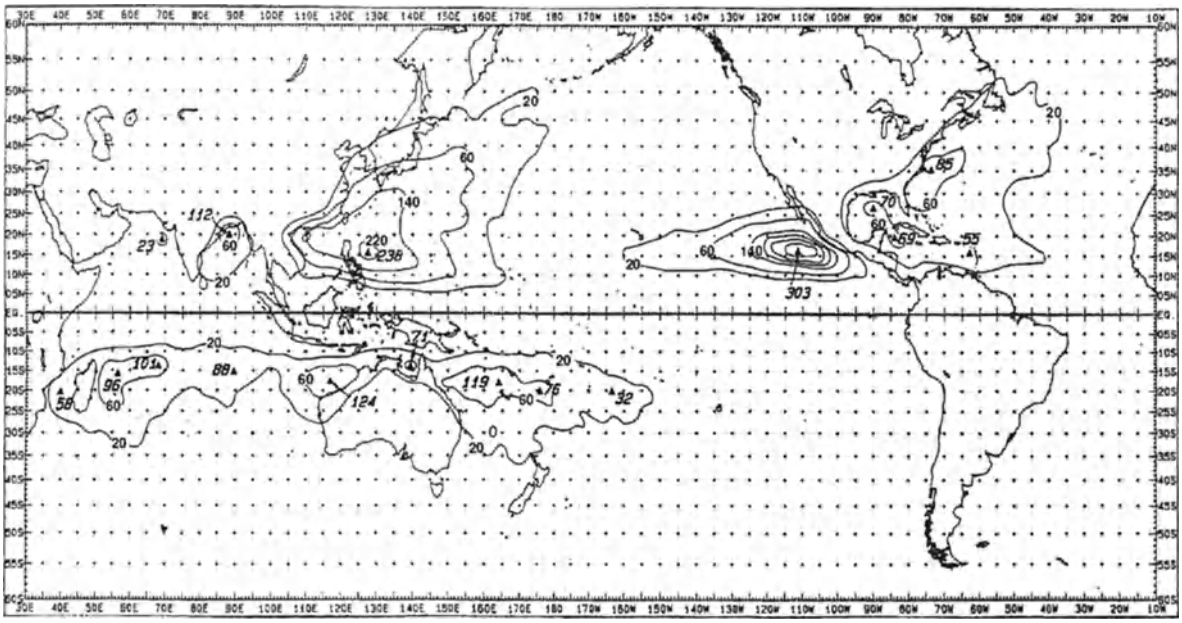


Fig. 4. The major tropical cyclone breeding grounds (Holland 1993). The isopleths show the frequency of cyclones per 100 years within 140 km of any point

3 The Role of National Meteorological and Hydrological Services

National Meteorological Services (NMSs) have long been regarded as an essential component of the basic national infrastructure of all countries with the twin responsibilities of collecting and safeguarding of the national climate record and of providing a wide range of meteorological services in support of the general safety and wellbeing of the community at large and the specific needs of major user groups such as agriculture, shipping and aviation. Given the strong dependence of surface hydrological processes on the timing, intensity and distribution of precipitation and on local and regional patterns of evaporation, some 50 or so NMSs also perform an extensive range of hydrological monitoring and forecasting functions. In most other countries, separate National Hydrological Services (NHSs) exist for this purpose. Together, the National Meteorological and Hydro-

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logical Services (NMHSs) of the world provide a wide range of scientifically based services to their national communities as well as to international shipping and aviation in formally designated areas of responsibility.

Most NMHSs carry out an essentially four-fold mission involving an integrated approach to:

- observing and monitoring the state of the atmosphere, ocean and inland waters;
- research aimed at understanding, modelling and predicting the behaviour of atmospheric and related processes and phenomena;
- the provision of information, forecast, warning and advisory services to the community at large and to specific user groups;
- fulfilment of their countries' obligations for international cooperation in data exchange and service provision under the Convention of the World Meteorological Organization.

The service role of the NMS is usually built around its public good responsibilities to provide essential weather, climate and related information to the community at large, and ordinarily involves separately identified:

- public weather services (including severe weather warning services to the general public, usually via the mass media);
- marine weather services (including warning of weather, wind, wave and ice conditions which might threaten safety of life at sea);
- aviation weather services (including warning of severe weather, turbulence, icing and other conditions which could threaten aviation safety);
- agrometeorological services (including warning of frost, hail, heavy rain, strong winds and other conditions damaging to agriculture);
- climate services (including warning of impending extended periods of drought or flood);
- environmental services (including air pollution alerts and warnings and the like);
- hydrological services (including flash flood warnings and flood warnings for major river systems).

The concept of operation of a typical NMS is shown schematically in Fig. 5. In most countries, the warning systems and services are integrated into the total public interest activities of the NMS. In some, however, separate warning centres exist within the individual National Meteorological Centres or Regional Service Offices or, alternatively, may operate in a physically self-standing mode such as in the case of the National Hurricane Center and the Storm

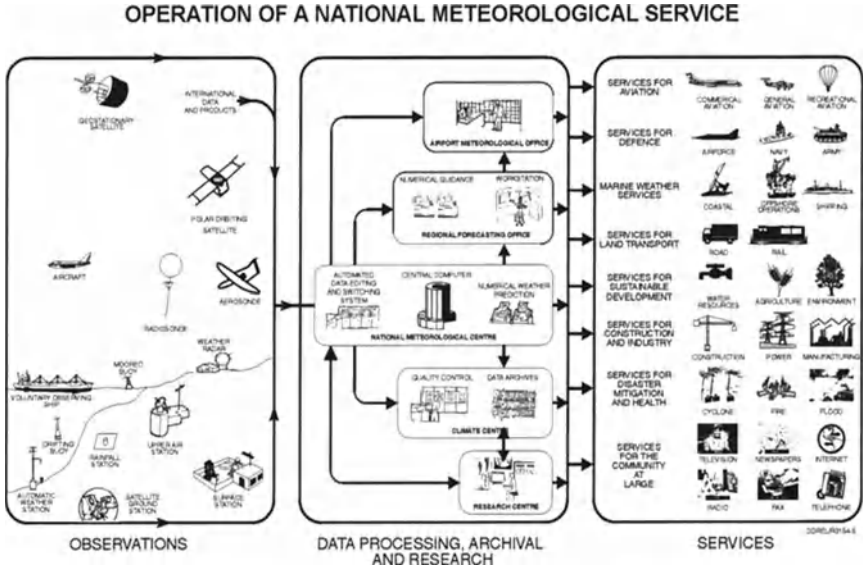


Fig. 5. The operation of a National Meteorological Service based on a series of observation networks and systems (left), data processing, archival and research facilities (centre) and service provision through a variety of delivery mechanisms to a wide range of users (right). Each of the Service Offices (centre panel) may issue warnings appropriate to its particular user community and/or region or, alternatively, separately located warning centres may be established for specific severe weather phenomena, purposes or regions

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Prediction Center which are part of the U.S. National Weather Service's National Centers for Environmental Prediction. The main rationale for the use of specific-purpose warning centres with nation-wide coverage relates to the rarity of severe events and the need for forecasters to cover a large area of responsibility (e.g. the entire continental U.S.) in order to maintain sufficient exposure to, and familiarity with, the monitoring and prediction of such events.

Before considering the detail of the design, implementation and operation of meteorological and hydrological warning systems within the NMHSs of individual countries, it is important to understand the extent of the international interdependence of the NMHSs of all countries and the role of international cooperation, through the framework of the WMO, in providing the foundation for effective warning services to national communities throughout the world.

4 The Role of the World Meteorological Organisations

The imperative of international cooperation in meteorology originated from the need for weather data from distant locations to help provide forewarning of approaching dangerous storms to ships at sea. From its modest beginnings under the auspices of the International Meteorological Organization (IMO) in 1873, the system of international cooperation in the collection and exchange of meteorological and related information in support of the safety, security and general welfare of the communities of all nations, has evolved into the extremely effective and highly efficient World Weather Watch (WWW) system of the intergovernmental World Meteorological Organization (WMO) which now operates as a specialised agency of the United Nations. The WWW provides a round-the-clock operational framework for cooperation between the NMSs of the world. It is unique in international affairs in its reliance on universal commitment to the common good and it is widely seen as the model of international cooperation within the United Nations system.

Modern geophysical science has convincingly demonstrated what was intuitively evident to meteorologists even a century ago; that, if we are to predict the behaviour of weather and climate forming processes and, in particular, the development of severe weather events more than a few days in advance, it will be essential to have access to data from the entire globe and from within the upper layers of the ocean as well as from the atmosphere itself. This is illustrated schematically in Fig. 6, which shows the domain from which, and the approximate density with which, data must be available in order to produce scientifically based prediction of the development and behaviour of individual synoptic scale weather systems such as extratropical cyclones and anticyclones for various notional forecast lead times. (Forecasting of

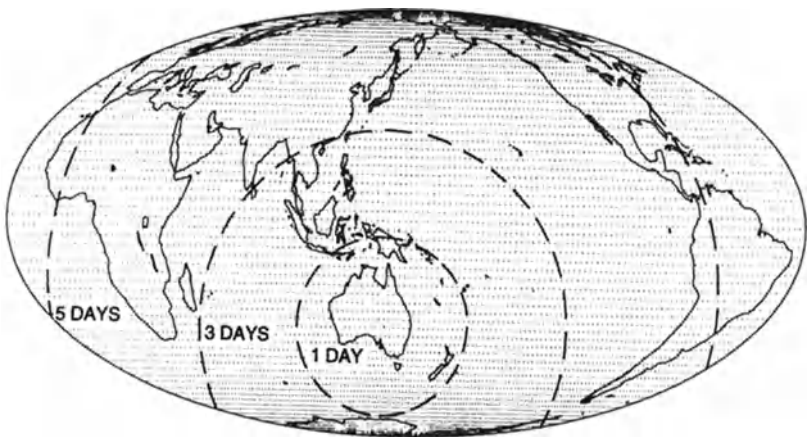


Fig. 6. The areas from which observational data must be available and the approximate density of observing points at which vertical profiles of wind, temperature, pressure and humidity are required in order to forecast general weather trends for southeast Australia for one to five days in advance using scientifically based numerical prediction models. In order to predict interannual fluctuations in climate patterns or the much longer-term effects of increased concentrations of greenhouse gases in the atmosphere, the models must be extended to include the full depth of both the atmosphere and the ocean

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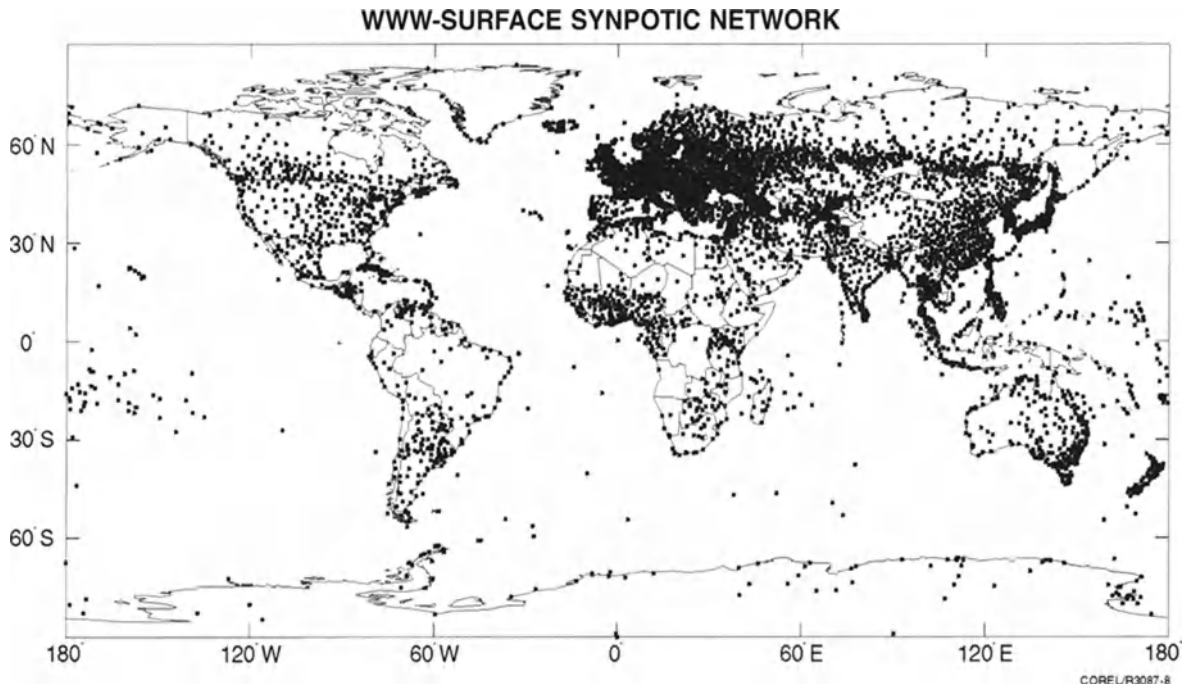


Fig. 7. The World Weather Watch as the core programme, of the World Meteorological Organization (WMO) on which depend a range of applications and services programmes including a number of warning services for the community at large, as well as for aviation, agriculture and marine users

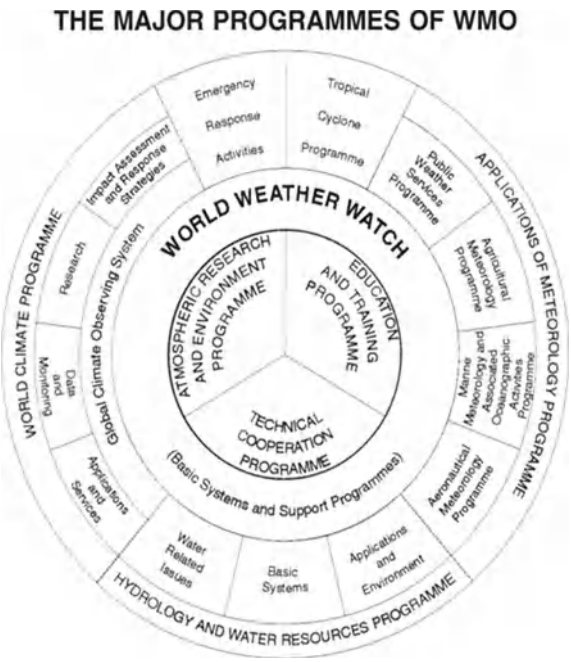


Fig. 8. The Regional Basic Synoptic Networks of surface observing stations of the WMO World Weather Watch

smaller scale phenomena such as individual severe storms and the like within the framework of the synoptic scale predictions requires much more detailed monitoring and modelling of the local region on generally shorter timescales.)

The World Meteorological Organization performs two vitally important functions that bear on the provision of warning services for essentially all meteorological and related hazards. It provides the international framework for standardisation, and operational exchange of the basic data necessary to run the physically-based atmospheric prediction models which support the full range of weather services, including warning services, in virtually all countries. It also provides the cooperative framework, through its various applications and services programmes such as its Public Weather Services Programme, its Tropical Cyclone Programme, its Emergency Response Activities Programme, its Hydrology and Water Resources Programme and its Aeronautical and Marine Meteorological and Associated Oceanographic Activities Programmes, for the exchange of expertise and experience in the design and operation of national warning systems and, where necessary, internationally coordinated arrangements for the delivery of warning services. It is important to note that, at the international level, aeronautical meteorological services (including aviation warning services) and marine services are provided in close collaboration with the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) and Intergovernmental Oceanographic Commission (IOC) of UNESCO, respectively.

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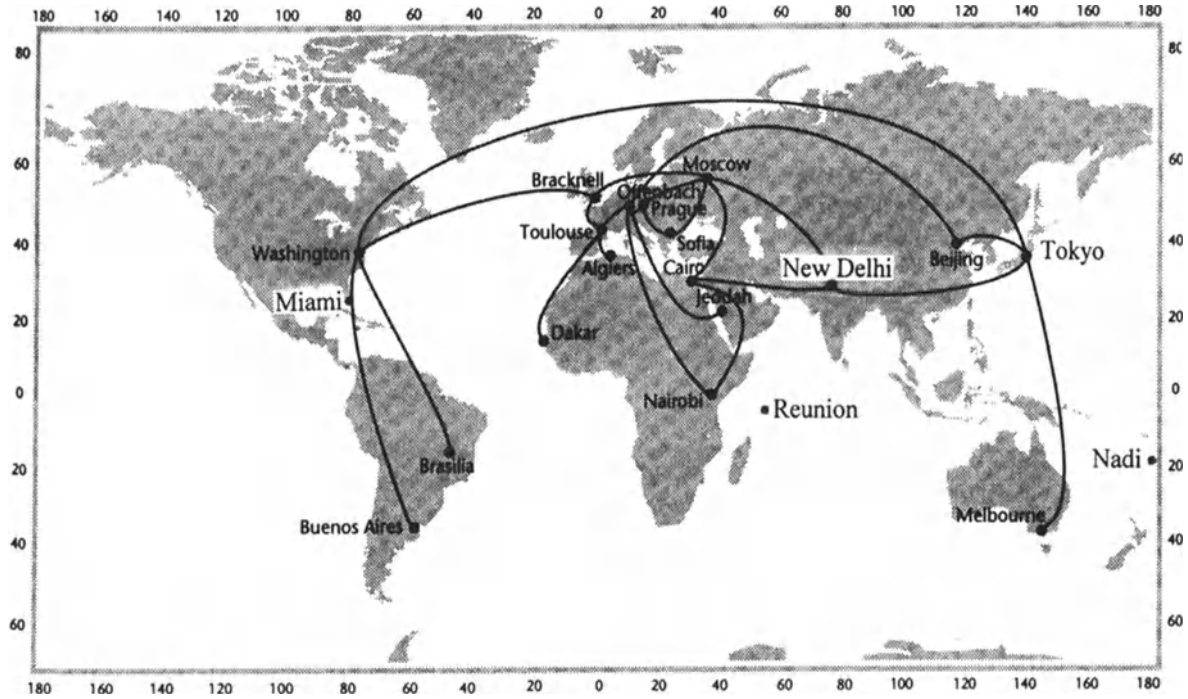


Fig. 9. The Main Telecommunication Network (solid lines) of the Global Telecommunications System (GTS) of the WMO World Weather Watch which links the network of World and Regional/Specialised Meteorological Centres including Regional Tropical Cyclone Centres at Miami, Reunion, Tokyo, New Delhi and Nadi

Figure 7 illustrates the role of the World Weather Watch as the core activity of the WMO made up of the various data collection, communication and processing facilities and systems of the individual WMO Member countries. Figure 8 shows, for example, the global distribution of surface observing stations included in the Regional Basic Synoptic Networks of the World Weather Watch and Fig. 9 shows the main dedicated telecommunication links which ensure that essential data are quickly collected and exchanged between the major processing centres including a network of Regional Specialised Meteorological Centres responsible for tropical cyclone warning over extensive regions of the global tropics.

5 Design and Implementation of Warning Systems

One of the important results of the IDNDR so far has been a substantially deeper insight than hitherto into the entire natural disaster phenomenon (e.g. United Nations 1997, 1998) and, in particular, the economic and social costs of natural disasters and the role that an effective warning system can play in all four phases of the disaster reduction process, viz:

- Mitigation or Prevention – long-term activities undertaken prior to impact aimed at reducing the risk of occurrence and/or effects of a disaster.
- Preparedness – pre-disaster activities intended to increase the effectiveness of emergency response during the disaster.
- Response – activities undertaken immediately prior to and during impact to protect lives and property.
- Recovery – post-disaster activities undertaken in order to return affected communities to a more normal condition.

This insight has, in turn, provided a more secure basis for the design and implementation of warning systems in those countries which do not have them, and for reconfiguration and refinement of existing systems in line with advances in relevant science, technology and warning system architecture (Jeggle 1997). Some of the key considerations involved in warning system design and implementation are summarised briefly below.

5.1 Goal of Early Warning

The overall goal of early warning is to provide information which enables and persuades peo-

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ple and organisations to take action that increases the safety of themselves and their property, and thereby reduces the deaths, injury and damage caused by the hazard concerned.

While this goal is easily stated, its attainment has proved more elusive than its importance would suggest that communities would accept. Indeed, post-hazard analysis of the performance of many forecasting and warning systems often reveals substantial failure of these systems when assessed against this goal. The reasons for failure are, of course, many and varied, and include the performance of the technological components used to detect and predict the hazard, the communication systems for disseminating information to affected areas, and the effectiveness of the response of the people and agencies in those areas.

In is particularly important to recognise that early warning systems are not created in isolation by a single agency, but require acceptance by all involved that, if the stated goal of early warning is to be reached with a satisfactory level of effectiveness and efficiency, there must be close cooperation and coordination amongst a large number of agencies and organisations throughout all stages in the development and operation of the system. It is essential to constantly eschew the tendency for components, particularly the technological components, to be treated separately, and for groups or individuals to mistake parts of the system for the whole.

5.2 Risk Assessment and Vulnerability Analysis

The Yokohama Strategy for a Safer World (The World Conference on Natural Disaster Reduction 1994) laid particular stress on the importance of risk assessment in the development of successful disaster reduction policies and measures. Risk assessment involves determination of the likelihood of occurrence of the various forms of natural hazards on the basis of observational records, and assessing their areal extent, intensity and duration (Kootval et al. 1998). Vulnerability analysis, in turn, includes mapping areas likely to be affected by particular hazards, such as areas which may be inundated by tropical cyclone storm surges or floods, and then determining the potential for loss of life and damage to property.

An effective warning system incorporates knowledge based on such risk assessment and vulnerability analysis. It is essential that those designing and operating the warning system, and those interpreting and applying its products, are fully sensitised to the likely severity and extent of the impacts of the forecast hazard against a comprehensive understanding of what has happened in the past and what current scientific assessments suggest may be possible or likely. It is important to note that changes in land use, population density and features of the built environment can lead to significant changes in vulnerability over time, and it is especially important to maintain up-to-date mapping of flood plains, foreshore developments, build-up of fuel on forest floors and the like.

5.3 Design of the Warning System

The detailed design of individual warning systems will reflect the particular features of the hazard phenomenon, the vulnerability of the region, the needs of the potentially affected communities, and so on. In general, however, the design of a warning system must provide for the following basic requirements:

- A sound scientific basis of understanding of the meteorological or hydrological phenomenon concerned including particularly the scientific basis for its predictability (e.g. Johns & Doswell 1992).
- Rapid access to global data streams in order to initialise forecast models for the short- to medium-range forecast process.
- Rapid access to regional data, including locally processed remotely sensed data, in order to initialise short-range regional models and mesoscale models to provide prior and during-the-event guidance on fine time and space scales, and also to provide monitoring of conditions during the event.
- Hardware and software to store and retrieve data, to analyse and display information, and to perform the extensive calculations required of today's Numerical Weather Prediction (NWP) models.
- Systems to automatically detect and alert forecasters to severe weather events. These include the algorithms to detect downbursts from radar data, or expert systems which can alert forecasters to the likelihood of severe weather events based on observational or forecast data.

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- Communications to provide information to emergency management authorities and other users with lead times that allow adequate response time for emergency managers to complete preparedness action.

5.4 The Role of Capacity Building

Whether for newly planned warning systems or in the progressive upgrading of existing systems, an important ingredient of success is a strong underpinning investment in national capacity building. Key target areas for capacity building include:

- Training in risk assessment, preparedness planning, approaches to improved coordination and the exercise and management of preparedness plans.
- Resources to acquire, install and maintain adequate technological monitoring and telecommunications systems. When technological systems fail for electronic or other reasons, it is essential that skilled personnel are immediately available to bring these systems back on line.
- Training of forecast staff to permanently improve predictive capacity, to make the most effective usage of the enhanced network access to data and to use effectively guidance from specialised centres and the latest forecast techniques.
- Enhancing media relations capability to promote better warning distribution. The encouragement of mutual understanding between scientists, media staff, political decision-makers and others can also contribute significantly to long term effectiveness of the warning system.
- Development of new warning delivery and access systems such as the Internet and digital electronic pagers. The latter offer exciting possibilities, especially for very short lead time warnings.

In the severe weather (fire weather, tropical cyclone and severe storm) and flood warning areas of responsibility of the Australian Bureau of Meteorology, the commitment of specialised and dedicated staff to an upgraded service following a significant funding increase by government in 1986 has led to sustained service improvements. A major advance has been the greater opportunity for real-time and non-real time liaison and training activities with emergency management authorities who are among the most important users of the warning service. Outposting of forecasters to emergency management control centres now occures routinely, and a much larger amount and wider range of information than previously disseminated is now communicated orally to emergency management authorities and the public. Much of this concerns alternative scenarios, confidence levels and the limitations of the science and technology used in the predictions. The practical impact of this additional information is enormous. Not only does it allow a more informed decision-making process, but it greatly enhances the user perception of the accuracy, reliability and integrity of the warning service.

5.5 Public Awareness and Understanding

The costs associated with the impacts of severe weather events can be significantly reduced given higher levels of community comprehension of, and preparedness for, these events. People are often extremely surprised when hit by a natural disaster, indicating a lack of awareness of the potential for such an event – many hazardous events are not frequent enough at any particular location to build reputations consonant with their dangerous potential, thus highlighting the need for *education as a surrogate for experience* (Keys 1996). Forecasters and emergency managers can take advantage of other professionals with the necessary skills for the educational task. A range of devices must be used for effective community education, which must be planned for strategic times when the community is most receptive, such as at the beginning of the annual tropical cyclone season. The effectiveness of community education is enhanced by partnerships between the responsible NMHS, local emergency management authorities and local Government (Senate Standing Committee on Industry, Science, Technology, Transport, Communications and Infrastructure 1994).

The psychology behind blockages in the communication process must be taken into account in the design of educational programmes. People often discard information which does not interest them, or which requires action, or demands changes to existing attitudes, habits

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and behaviours (e.g. warnings may well be received and registered, but ignored because the receiver believes the phenomenon is unlikely to strike him/her, or feels powerless to react effectively given the severity and scale of the forecast severe weather event).

Appropriate strategies for increasing public awareness of storm threats and creating a heightened understanding of what can be done to mitigate hazardous event impacts include:

- provision of educational material for schools;
- distribution of brochures and action guides;
- the holding of public meetings and commemorations of well-remembered events; and
- the mounting of media campaigns.

From an overall perspective, public awareness and understanding merits constant attention and substantial commitment of resources, as a very critical component of the success of an early warning system. Obvious barriers to increased public awareness and understanding of hazards and vulnerabilities include low levels of literacy and educational attainment. These are compounded, in some instances, by the dominance of technocratic perspectives among specialist early warning staff which can make communication with local populations difficult. The relative priority to be assigned to developing public awareness and understanding will, of course, vary with individual circumstances, such as the pre-existing knowledge levels among the population and the frequency of occurrence of hazardous events. One of the major challenges in implementing any effective early warning programme is motivating people to respond in an appropriate manner, since people under threat react in different ways.

Most NMHSs are well aware, from long experience, that communication is more than simple dissemination of forecasts and warnings, but is achieved only after the information has been received and understood. Consequently, effective early warning requires that the target population not only receives advance warning of hazards, but also understands the content of the warnings, believes the information received and knows how to react. This implies that well-designed early warning programmes must include a substantial public awareness component to ensure that the public understands, believes and knows how to respond in a warning situation.

5.6 Coordination with Emergency Management Authorities

A high degree of coordination must exist within the hazards community both before and during disasters and in the period following their occurrence. For maximum effectiveness, early warning systems must be designed in close coordination with organisations and humanitarian bodies responsible for response actions. This holds true at all levels – local, national and global. At local and national levels, coordination is usually achieved through committee structures orchestrated and supported by a municipal agency or lead department, and drawing upon the resources and expertise of other organizations and individuals. A key to success here is involvement of the local population, and strong support for the coordinator by the local political leadership. At the international level, a particularly important aspect of coordination is to ensure the reliable delivery of relevant early warnings of meteorological and hydrological hazards to United Nations and other relief and humanitarian organisations.

Maintaining communication and coordination can present a significant challenge, because the functions of early warning often cross several tiers of government (e.g. national, state, provincial or county and local). Inter-organisational coordination may sometimes be ineffective because of communication problems due to differing organisational structures, sub-cultures, expectations and even rivalries. Failure to fully understand the needs of disaster response agencies and officials leading to the provision of support based upon a perception of what is needed rather than upon actual identification of needs may be a particular problem. In addition, situations sometimes exist where long-established hazard warning systems have failed to adapt to changing requirements such as, for example, in the case of warning systems designed for a predominantly agricultural economy but now being used in a rapidly industrialising environment dominated by tourism.

Inadequate coordination leading to confusion with respect to flood warnings sometimes occurs between countries, between states within the same country, and even between different agencies within a state, due to differing conventions or poorly defined responsibilities. Different jurisdictional arrangements within coun-

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tries which share the same river system or climatic region can stand in the way of effective coordination.

The Australian Bureau of Meteorology experience tends to indicate that warning services perform best when arrangements are made for the risk information message to be delivered directly and personally to the user, for example as happens during severe weather events – bush fires, tropical cyclones, severe thunderstorms – and floods. This partly reflects the usefulness of the direct contact between the NMHS and the users, as well as the success of the "dedicated team" approach which allows for a better understanding of user requirements and concerns. Unfortunately such effective delivery is difficult to maintain due to constant pressure on just those resources – especially staff – which are most crucial to its success.

5.7 System Review and Improvement

To improve the quality of their forecasts and warnings, NMHSs need to constantly evaluate their procedures and performance. Verification is essential for eliminating model and forecaster biases and systematic errors, and for indicating priority areas where research, techniques development, training, improved observational quality and coverage and new technology are needed.

Verification has always been a difficult, tedious and labour-intensive task because of the variety of parameters contained in even a single weather forecast. A large amount of work is needed to compare each of these with actual observations and formulate some kind of index of accuracy which will serve as a satisfactory reporting measure and provide the necessary feedback for adjustment of the process if required. Automation has become accepted as the only feasible option. It is easy, however, to underestimate the technical difficulty in verifying all stages of the forecast and warning process, not just the accuracy of forecasting a small number of technical parameters which might be meteorologically very relevant but have only an indirect relationship to user needs. For example, measures of the accuracy of a series of forecasts of the location of the centre of a cyclone (e.g. Fig. 10), while of considerable importance in evaluating specific aspects of the forecast process, tells us little about the daylight hours of preparedness lead time provided to communities which ultimately experienced destructive winds from the cyclone.

Post-disaster assessments of such events are of particular value in improving the performance of early warning systems, providing important lessons regarding the dissemination of warnings, public awareness and the overall management of preparedness and response. These assessments can also provide useful inputs to hazard and vulnerability analyses, and contribute observational data which may assist in improving observing algorithms. Feedback from post-disaster assessments is an essential component of the learning process through which more effective early warning capability is developed.

Regular reviews of warning systems for hydrometeorological events are needed to ensure that they function as intended and to continue to improve their performance. These reviews should cover the technical and non-technical elements of the system and should, as far as possible, be undertaken within the framework of the total system concept.

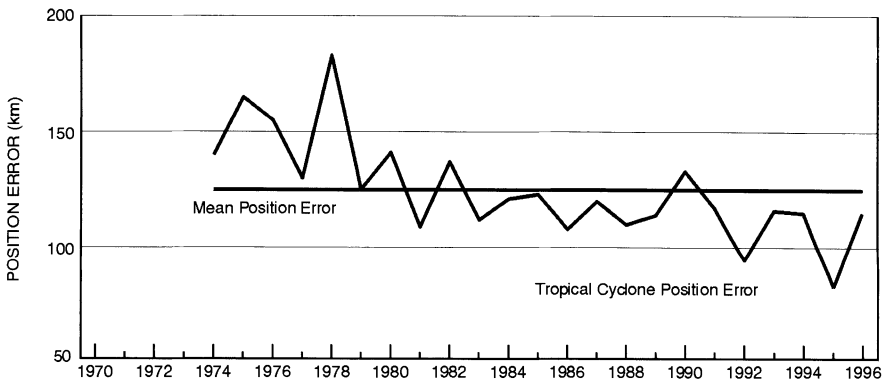


Fig. 10. Trends in average errors of 12-hour forecasts of the position of tropical cyclones in the Australian region

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Reviews should be held as soon as possible whenever the system has been tested operationally. This will normally be after the event, but may also be after a 'near-miss' and include reviews undertaken after any test-exercising of the system. These reviews should involve assessment of the performance of the different components against what might be considered "best practice" for each component.

Reviews should also be undertaken when technological or environmental changes occur. Technological changes will more commonly influence the prediction and possibly interpretation components as new data collection and analysis systems become available, and changes in communications technology need to be considered for their potential to improve the effectiveness of the warning dissemination. Examples of environmental changes include changes in catchment or river channel conditions following flood or other natural events, as well as artificial changes such as channel widening introduced as part of other flood plain management activities.

6 Operation of Warning Systems

While every warning system has its own unique character reflecting the nature of the individual hazard, the geographical region affected, the allocation of responsibilities amongst agencies and the available options for community response, it is possible to characterise the overall operation of a meteorological or hydrological warning system in terms of the following key elements shown schematically in Fig. 11:

- Data collection;
- Routine monitoring;
- Hazard detection (including detection of environmental conditions conducive to hazard genesis);
- Hazard prediction;
- Watch and warning formulation;
- Information dissemination;
- Community response and feedback;
- Post-disaster support.

6.1 Data Collection

The observational data base required to support the operation of meteorological and hydrological warning systems is essentially identical to that needed for provision of routine weather forecast services, albeit a number of special observing systems may be maintained routinely, or activated for short periods, to enable more detailed tracking and warning of individual hazardous phenomena. The essential elements of the total observing network include:

- Surface synoptic stations. These provide six hourly or more frequent observations of the standard meteorological parameters of temperature and dewpoint, rainfall, wind speed and direction, barometric pressure, present

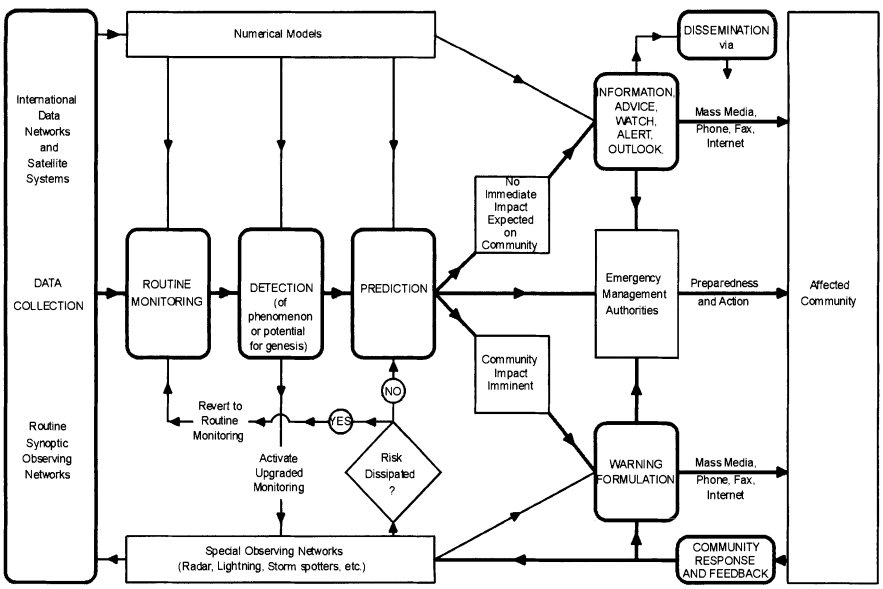


Fig. 11. The essential elements of an operational warning system for meteorological or hydrological hazards

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weather conditions, visibility and cloud information. Subsets of the total national networks together make up the Regional Basic Synoptic Networks of the World Weather Watch (Fig. 8). Ship and drifting and moored buoy observations are used to fill in the data gaps over the oceans, and much greater spatial detail is often available over land from networks of rainfall-only stations which may be operated by volunteers or may, alternatively, consist of automated data loggers providing rainfall intensity information with high temporal resolution.

- Upper air stations. Rawinsonde stations, most of whose data are freely exchanged internationally under the World Weather Watch, provide essential input of upper air wind, temperature and humidity information to numerical prediction models as well as providing direct support for detection of severe weather phenomena or identification of atmospheric conditions that may lead to their development.
- Vertical wind profilers. Vertical wind profiles have the particular advantage of providing continuous measurement of wind speed and direction in the troposphere and enabling detection of sudden changes in direction, the passage of mesoscale systems and the like.
- Environmental satellites. Over the past thirty years, meteorological satellite data have emerged as an essential and integral component of the observational data base for most meteorological and hydrological warning systems. Satellite data are particularly effective in enabling early detection of tropical cyclones, severe storms and flood-producing rain systems, and in tracking their development and movement. Satellite data are also important in monitoring the build-up of snow pack as a precursor to spring flooding, and in monitoring vegetation indices as an indication of the onset of drought. They play an especially significant role in support of the detection of volcanic eruptions as a basis for volcanic ash warnings for aircraft, and surface hot spots associated with bush fires originating from both natural and human causes. The main types of satellite data of importance for warning system operation include:
  - cloud amounts, patterns, types and heights;
  - surface temperature and tropospheric temperature profiles;
  - water vapour profiles;
  - cloud drift winds;
  - sea state.
- Radar. Conventional surface-based weather radar can detect rainfall at a range of up to about 250 km, and is an invaluable component of the integrated observing networks needed for support of warning services (e.g. Fig. 12). It is especially important for tropical cyclone, tornado and severe storm warning. Many NMHSs now operate Doppler radar networks which provide detailed measurement of wind fields determined from the radial movement of radar echoes, and which are particularly useful in identifying severe thunderstorm signatures associated with the development of tornadoes and other severe local storms.
- Lightning Detection. After falling into disuse for several decades, the early concept of "sferics" involving the location, through either direction-finding or time-of-arrival techniques, of the source of radio frequency emissions from lightning discharges is now becoming an important element of the severe weather observing system in many countries – both for routine monitoring and special warning support purposes.
- Adaptive Observing Systems. In a disaster or impending disaster situation, there is usually an urgent need for extra observations in key



Fig. 12. The Australian wind finding and weather watch radar network used in support of tropical cyclone, severe storm, flood and other warning services

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locations, over and above those available from the routine observing networks. These can be provided by a number of means, most of which are in operation in one or more countries around the world. They include:

- Storm spotters. Several countries operate special networks of volunteer storm spotters for severe thunderstorm detection and tracking and other special-purpose observers for particular dangerous weather phenomena such as tropical cyclones.
- Extra observations from network stations. In severe storm or flood/fire/cyclone situations, additional radiosonde flights from upper air observing stations are often necessary to help define crucial features of the overall synoptic situation.
- Portable Automatic Weather Stations (AWS). Emergency deployable AWSs are an important tool for monitoring conditions in and around fires.
- Portable Atmospheric Profilers. The positioning of portable atmospheric profilers near, or ahead of, severe weather events is now practised, in particular, in the U.S.
- Upper air temperatures and winds measured by commercial aircraft (AMDAR and ACARS).
- Aerosonde. The Aerosonde, a primarily Australian development, is a miniature robotic aircraft for long-range environmental monitoring. It has been developed specifically for meteorological and environmental reconnaissance over oceanic and remote areas, for which its economy will allow routine operations on a much wider scale than has been affordable in the past. It has the potential to fill gaps in the global upper-air sounding network, and to conduct systematic surveillance of tropical cyclones and other severe weather phenomena.
- Aerial reconnaissance. The use of piloted instrumented aircraft to probe severe phenomena like hurricanes has a long history in the U.S., but is an expensive option.
- Dropsondes. Special radiosondes can be dropped from aircraft to obtain atmospheric profiles in and around severe weather events.
- Rapid scan satellite imagery. Increasingly, geostationary satellites can be expected to provide 5–15 minute imagery updates over limited scanning areas.

6.2 Routine Monitoring

The routine monitoring of environmental conditions for signs of potentially dangerous phenomena or early indication of their likely genesis is normally undertaken by NMHSs as an integral part of their ongoing round-the-clock weather watch and routine service provision. The process involves continuous scanning of all incoming observational information (surface and upper air observations, satellite imagery, radar, etc.) and of the output of operational numerical analysis systems and numerical prediction models.

The responsibility for routine monitoring may reside with the senior forecaster on shift in an integrated National Meteorological Centre, Regional Meteorological Centre or River Forecasting Centre as is the case in most countries where the warning function is fully integrated with the routine service role. Alternatively, it may constitute the full-time responsibility of the operations supervisor of self-standing special-purpose warning centres such as exist in some countries for hurricanes, severe storms, tsunamis and the like.

6.3 Hazard Detection

Once a hazardous phenomenon has been detected during the routine monitoring phase, or numerical prediction models or other indicators suggest the likelihood of its genesis in the near future, it is usual to move into an enhanced monitoring mode. This will normally involve activation of additional observing systems and/or additional analysis models or aids in order to provide forecasters with the maximum possible information base for prediction of the future development and movement of the threatening severe weather event.

If the additional information from special observing networks and more detailed models suggests that the potentially hazardous phenomenon has decayed, or the prospects of its further development are reduced to the point where the risk has dissipated, the forecast office or warning centre will revert to routine monitoring mode. If, on the other hand, the phenomenon remains active or appears to be intensifying, the focus swings to the prediction, using numerical model and other techniques, of its future development and track.

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6.4 Hazard Prediction

Forecasting offices and warning centres in both developed and developing countries normally have access to a number of numerical prediction models and forecasting aids including the output of World and Regional Specialised Meteorological Centres of the WMO World Weather Watch.

Once in full operational mode, the warning centre will usually draw in extra staff support where available, and advise emergency management authorities of the need to prepare for response to the impact of the forecast event.

6.5 Watch and Warning Formulation

Although both terminology and operational practices vary widely between countries and according to the nature of the hazard involved, one of the key decisions to be made in the light of the predicted behaviour of the hazard relates to the urgency of the need for communication of the requirement for emergency preparedness action. Because of the still significant limitations in prediction skill for most severe weather phenomena, it is not usually seen as appropriate to issue public *warnings* until the threat to affected communities is reasonably imminent. It is particularly important to minimise the social and other costs resulting from unwarranted preparedness action (e.g. evacuation of offshore facilities, port closure, etc.) for a threat which may not eventuate. But it is equally important to avoid *underwarning* by saying nothing until the threat is so imminent that there is inadequate time for necessary preparedness action. Many countries thus employ the concept of a "watch," "alert" or "advice" stage, preliminary to their issue of warnings, except in situations where the lead times are extremely short. This applies particularly to severe storms where the public may be notified of areas under severe storm or tornado *watch* several hours in advance with actual *warnings* only issued with lead times of minutes up to an hour or so once there is a high level of confidence that the threat will materialise in a form which will impact directly on an identifiable sector of the community.

It is particularly important to the effectiveness of the warning system that the formulation of the warning information be done in a way that enables the recipients to act as quickly as possible, and take whatever preparedness action is appropriate under the circumstances. This means that the wording of the warnings is crucial to the effectiveness of the service. Experience has shown that, when composing warnings, it is important that:

- the heading stand alone and stand out;
- the components of the message be clearly defined;
- the message be simple;
- it personalise the event, the consequences and the actions required ("People are warned that..");
- information which allows people to confirm an impending event for themselves be included;
- special care be taken with warnings for extraordinary events;
- the most important information be placed first;
- allowance be made for shortening of the message by broadcasters;
- location references be made relative to well-known places;
- plain language be used (e.g. a.m. and p.m. not 24-hour clock);
- a statement of recommended action be included; and
- a sympathetic but arresting tone be used.

Experience has also shown that people have more confidence in warnings issued by fellow residents who are also at risk and that they will evacuate more rapidly for local community leaders than for government officials. An important factor is the value of the historical knowledge of community residents in interpreting and responding to flood or other warnings.

6.6 Information Dissemination

A reliable dissemination system is a vital component of any effective warning system. Local officials and the public must first hear or see hazard warning information before they are in any position to take avoidance action.

Effective dissemination requires more than the simple transmission of warning messages. The UK Flood Hazard Research Centre has observed that the design and operation of warn-

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ing systems has often in the past been dominated by technological considerations and overall effectiveness sometimes diminished by inadequate attention to the dissemination stage. The performance of warning systems is often assessed using technical parameters with aspects important to end users, such as reductions in damage, increased personal security and increased satisfaction, not being evaluated. Those undertaking technical evaluations can often demonstrate that their systems are working effectively when research with end users demonstrates that this may not be the case. Since early warning systems are only as good as their weakest link, successful hazard detection and prediction are largely wasted if warnings are not disseminated swiftly and communicated effectively to the people at risk.

Warning dissemination systems are generally well-developed and fairly resilient in developed countries but this is not the case in many developing nations. In the latter, the main barriers to improvement are cost, technological capacity and access to maintenance and replacement services. In Africa, for example, many countries use HF (High Frequency) communications systems which can suffer from atmospheric interference, and are difficult and expensive to maintain with, among other problems, many trained technicians being recruited by other organisations who can pay higher salaries than the NMHSs. Clearly, achievement of overall improvement in early warning capacity requires that local and national communications systems be capable of providing rapid, reliable and consistent dissemination of warnings to threatened populations. This will require substantial capacity building efforts within a number of developing countries directed towards installation of reliable and robust telecommunications networks and training local personnel to operate and maintain them.

As a general principle, the use of multiple warning modes usually increases warning effectiveness, although not all modes are equally useful in all circumstances. The choice of mode will depend firstly on what is available, but will be guided also by the available warning lead time, the rate at which hazardous conditions are changing and whether the need is for a general warning or more specific dissemination. Both general and specific modes of dissemination should be seen as complementary, with the specific warnings serving to reinforce the more general warnings typically available early in the development of the hazardous event. Some of the most important dissemination modes include the following:

- General
  - Radio flashes: break-ins with community announcements or interviews with forecasting or emergency service staff.
  - Television: crawlers (messages drawn across the screen) or announcements during news or programme breaks.
  - Scheduled news bulletins: these may take longer to go to air.
  - Notice boards: community or tourist information boards in town centres.
  - Newspapers: local or regional.
- Specific (all potentially rapid)
  - Recorded telephone messages.
  - Telephone calls (and telephone trees or cascades where each person contacted then calls others) with the information.
  - Digital electronic pagers and mobile telephones.
  - PC alert cards triggered by satellite transmitted warnings.
  - Fax and telex: especially for business and institutions.
  - Computer linkages: as with fax.
  - Internet email delivery or access to NMHS web sites.
  - Two-way radio: CB (Citizens Band) radio, or "packet" radio.
  - Loud hailers, public address systems or sirens: mobile as with police or fire vehicles, or fixed.
  - Doorknocking.
  - Community or ethnic leaders: use of key individuals to access their network.

General warnings are often inadequate by themselves since many people will not receive the warning message immediately, or may only hear part of it. Furthermore, there is no way of knowing who has heard the message, let alone understood and believed it. Specific warnings can overcome these disadvantages since they are usually more persuasive, as the message can be delivered personally and provide direct opportunity to assess the credibility of the source, as well as meeting the need for confirmatory information. The broadcast media of course offer benefits because they provide a free channel

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of communication and are, in many cases, the only rapid way of reaching large and diverse audiences. It is also important to consider the extent to which different modes can complement each other. For example, some of the more general delivery modes such as sirens or alarms, sometimes favoured in circumstances where warning times are very short, have been shown to be relatively ineffective unless accompanied by clear voice instructions. The final choice of mode depends on what has to be achieved in a given time. This, in turn, depends on the severity of the hazardous conditions, available warning time and target audience, the resources available and the required response.

Whatever the official channels, "unofficial" warnings are often disseminated in parallel through informal networks. It is important to recognise that this practice will persist, and to find ways of integrating these informal systems so as to maintain a single credible source of information. The informal system can be very effective in serving the need for confirmation and it is important to prevent a situation where the two systems (official and unofficial) are seen to be competing or in conflict. Dissemination of warnings through these external agents and facilities must, however, be carefully coordinated to ensure timeliness, accuracy and consistency. Experience confirms that there must be a *single official issuing authority* for warnings to minimise public confusion.

A close working relationship with the media must always receive a high priority in provision of warning of meteorological and hydrological hazards since the distribution of warning messages is, in most countries, largely through media broadcasts. In the most effective warning systems, considerable importance is attached to embracing the media's assistance in raising awareness, increasing knowledge of warning procedures and appropriate mitigation and response actions and for dissemination of warnings.

A recent compounding difficulty is that the pressures for commercialisation of weather services in a number of countries appear to be inhibiting the exchange of important information, such as satellite images, which can be particularly effective in raising public awareness. Rivalries concerning on-air dissemination of warning information between professional media presenters and NMHS staff, or between NMHS staff and private meteorologists employed by TV and radio stations, have also been identified as sometimes posing obstacles to the achievement of effective public interest partnerships with media outlets. Clearly, these concerns need to be constantly addressed where they exist. In some countries and regions where international television weather broadcasts are received, international coordination is also required to ensure consistency of internationally broadcast information with locally issued warnings.

Early warning is still inadequate for most of the world's peoples, due, in part, to inadequate telecommunications capabilities. Even where communications systems are well developed, they must be continuously reviewed to keep pace with technological developments. In many countries, reliance on overhead telephone and power lines and other exposed components such as satellite antennas leaves communications vulnerable to failure during high winds, ice storms and floods. Consequently, backup communications capability is essential for reliable delivery of warnings during severe conditions. In extreme circumstances, all international telecommunications may be lost, as happened in Mauritius during cyclone Hollanda in 1994. In some countries, including Australia, radio and TV broadcasting is, increasingly, being networked (or centralised). This makes it more difficult to place specific local warnings on local radio and TV. In many instances, other local warning systems such as sirens, loudspeakers, a specific telephone ring or even door to door visits must be used to alert the population, and these community-based approaches to dissemination can be highly effective in some circumstances.

6.7 Community Response and Feedback

Prompt and detailed feedback from the affected community is an essential element of the effectiveness of meteorological and hydrological warning systems. It is especially important that those formulating advices and warnings be quickly informed of developments which depart from the earlier forecast conditions, both to enable their prompt updating and to avoid the erosion of community confidence in the latest warning information being received through the media.

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6.8 Post-disaster Support

It is especially important in any natural disaster event that the warning system continue to operate effectively after the forecast phenomenon (severe storm, hurricane, flood, etc.) has struck, in order to provide maximum possible weather information support and reassurance to those engaged in relief activities.

7 Warning Systems for Individual Hazards

Although most NMHSs endeavour to provide at least a general level of warning service in respect of all of the individual hazards experienced in the country concerned, several services now operate quite sophisticated specific warning systems for such individually important natural hazards as:

- Tropical cyclones
- Severe storms
- Floods
- Fire weather
- Air pollution
- Drought

By way of illustration of the current scope and stage of development of warning systems around the world, some particular features of each of these are summarised briefly below, with particular examples drawn from the Australian experience.

7.1 Tropical Cyclones

Tropical cyclones pose a significant threat to populations in the North Atlantic/Caribbean basin, through the tropical Pacific including northeast Australia, China, Japan, the Philippines and many small island nations and the Indian Ocean including India, Bangladesh, Mauritius, Mozambique and northwest Australia (Fig. 4). The main threat from tropical cyclones comes from their extreme wind speeds, from storm surges associated with landfall and from flooding from intense rainfall.

The WMO has designated Regional Specialised Meteorological Centres (RSMCs) for tropical cyclone forecasting in the key ocean basins, as identified in Fig. 9. These support and complement the domestic roles of the various national centres providing cyclone/hurricane/typhoon warnings for the countries concerned.

During the cyclone season, all centres responsible for tropical cyclone forecasting and warning maintain essentially round-the-clock weather watch over their area of responsibility. The synoptic conditions that are most conducive to cyclone development vary slightly with regional circumstances, but the broadscale precursors identified by Gray (1975) remain the key indicators: sea surface temperatures above 26 °C, a moist tropical atmosphere, broad-scale convection, low-level inflow with upper outflow and weak vertical wind shear.

When a cyclone is about to enter a Tropical Cyclone Warning Centre (TCWC) area of responsibility, either as an intensifying incipient disturbance or as an established system with winds in excess of 34 knots, the warning centre is generally expected to give that communities are likely to be affected up to 48 hours notice of the onset of gales. For shipping, High Seas Forecasts are issued, for aviation SIGMETS and other advices are issued, and for coastal communities watches and warnings are issued according to national practice.

In Australia, *tropical cyclone watches* are issued if a cyclone or potential cyclone exists and there are strong indications that winds above gale force will affect coastal or island communities *within 24 to 48 hours*. The message contains a brief estimate of the cyclone's location, intensity, severity category and movement, and identifies the likely coastal area to be affected. Watch messages are renewed every six hours. Tropical cyclone *warnings* are issued as soon as gales or stronger winds are expected to affect coastal or island communities *within 24 hours*. They identify the communities being threatened and contain the cyclone's name, its location, intensity and movement. Forecasts of heavy rainfall, flooding and abnormally high tide are included when necessary. Cyclone warnings are issued every three hours, or even every hour when the cyclone is under radar surveillance close to the coast.

Emergency management personnel and certain private interests (e.g. tourism operators) are often interested in special types of tailored information. An example is the tropical cyclone strike probability forecast (Fig. 13). Based on the current cyclone position and forecasts and the history of errors in past forecasts, the inte-

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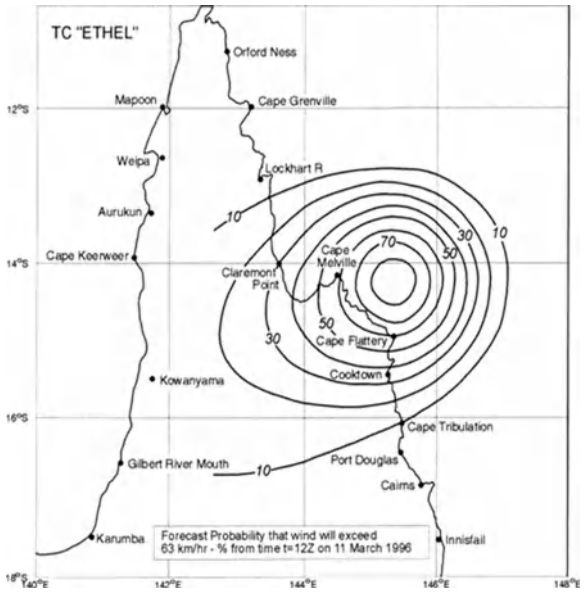


Fig. 13. An example of a tropical cyclone strike probability map for the north Queensland coast (Australia). The isopleths indicate the distribution of percentage probabilities that the wind will exceed 63 km/h (34 knots) in the next 12 hours

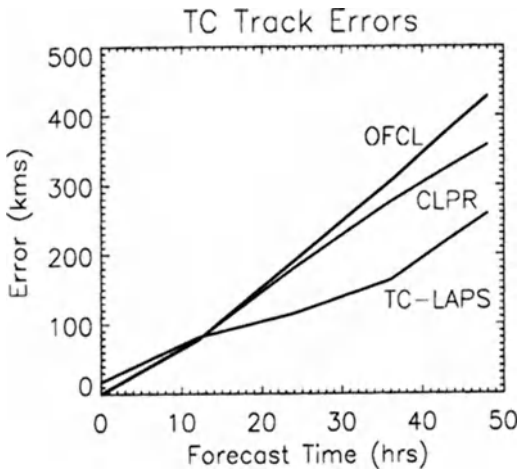


Fig. 14. Comparison of the ability of various techniques used in the Australian Region to forecast the position of tropical cyclones up to 48 hours ahead. The error vs. Forecast time graphs are averaged for 17 recent tropical cyclones observed near Australia. TC-LAPS (Tropical Cyclone – Limited Area Prediction System) shows significantly superior forecast skill over the official forecasts (OFCL) and the climatology-persistence (CLPR) approach

grated probability of the site of interest being affected by winds above a user-specified wind speed threshold is calculated. Recipients receive a map of their region containing the current and forecast cyclone track, together with contoured grid point values of their nominated strike probability. The provision of a series of these graphical products is better than a single site forecast, since it enables users to gain an overview of the evolving situation which may be important in critical decision-making.

The greatest threat to coastal communities from tropical cyclones arises from inundation by storm surges driven by on-shore winds and low atmospheric pressure. Since evacuation can be very expensive and cause major social disruption, it is especially important that TCWCs avoid overwarning and provide as specific information as possible on the likely range of inundation levels resulting from a forecast storm surge.

In the off-season, some TCWCs are able to concentrate on research, system development, liaison with key users and media, review of warning procedures and community education. Research into tropical cyclones by TCWCs and other major centres is mainly concerned with development of tools for predicting tropical cyclone movement and evolution. For example, the Australian Bureau of Meteorology Research Centre has developed an operational tropical domain prediction model (0.25° latitude gridsize) which is initiated whenever a named tropical cyclone is in the region. The new scheme has shown impressive improvement relative to current systems and will be implemented operationally in the 1998/99 summer season (Fig. 14).

7.2 Severe Storms

The term "severe storm" normally refers to deep moist convective events (usually thunderstorms) which produce damaging weather such as destructive winds, damaging hail, tornadoes, heavy rain conducive to flash-flooding, or a combination of these phenomena.

The severe storm is potentially the most violent and destructive, albeit localised, meteorological phenomenon confronting the forecaster. In Australia, severe storms produce a higher average annual damage cost than tropical cyclones and bush fires combined (Joy 1991). Nevertheless, because severe storms usually affect small areas, community awareness varies widely from place to place and time to time. This is a problem for the warning service, because the effectiveness of warnings depends on the recipients' readiness to take protective action.

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The greatest impediments to improved severe storm warning accuracy and leadtime are the relatively small size and short life cycle of the thunderstorm. Areas at risk of severe storms can be identified with confidence up to six-hours in advance, provided the important atmospheric characteristics are known in sufficient detail. Ideally, the distributions of temperature, humidity and instability and the wind patterns in both the horizontal and vertical would be measured every thirty minutes at a horizontal resolution of 50 km or less. Such a network would be prohibitively expensive, but several new remote-sensing technologies have the potential to provide forecasters with data which are much closer to the ideal than has been possible in the past. When storms have developed and forecasting becomes "nowcasting," other new or improving technologies can provide the finer "net" needed to catch storm data.

Storm spotter networks (e.g. Bureau of Meteorology 1995) can be of considerable assistance in severe storm nowcasting. The unique ability of such spotters to accurately monitor what is happening at the ground provides a valuable alerting and verification role for severe storms.

The short lifetimes of storms mean that rapid data analysis and warning preparation are more important to severe storm warning than to any other forecasting task. Again, new systems and techniques have the ability to assimilate and interpret the huge volumes of data produced by modern observing systems and to expedite the production of warnings in the variety of sophisticated formats required by end-users. The most significant of these systems/techniques are integrated forecaster workstations, artificial intelligence decision support software tools and sophisticated three-dimensional reflectivity radar and Doppler radar displays.

The philosophy behind severe storm warning services recognises that it is not possible to predict the exact location or intensity of storms before they develop, but that it is possible to detect and locate atmospheric conditions likely to produce severe storms up to 6–12 hours ahead, to an accuracy of about 200 km. Since thunderstorms have relatively short lifetimes of as little as 60 minutes, warnings issued after storms have developed cannot provide lengthy leadtimes. Although such short-term warnings are essential, they cannot be fully effective unless a more general preliminary alert is issued, advising that warnings are likely to be issued later.

Ideally then, the severe storm warning service needs (at least) a two-tiered structure, with watches/advises issued for district-sized areas about six hours ahead of storm development, followed by very specific warnings for storms in progress providing about thirty minutes leadtime. A prerequisite for the warning phase, however, is weather-watch radar, and this is not available everywhere. Further, monitoring and predicting individual storm cells is labour-intensive and time-consuming, unless automatic systems are in place. It is therefore impossible for most NMHSs to provide a refined warning service everywhere. It is, however, possible to provide more generalised watch/advice service using synoptic and satellite data over a much larger area, particularly in non-tropical regions. Watches/advises and warnings are usually in the form of textual messages distributed for the general public through existing radio and television media. However, graphical products utilising appropriate visualisation and GIS software, are increasingly being provided for delivery by television as well as access through the Web and fax.

The core of a severe storm warning service is the warning phase. Even though the short lifetimes of thunderstorms make it difficult or impossible to provide leadtimes of more than sixty minutes, this amount of warning can be extremely important. People can take basic precautions like putting cars under cover, returning small boats to shore, ensuring children are in safe locations, etc. Industries can secure potentially dangerous or vulnerable equipment or abort sensitive operations. Emergency management agencies can prepare their staff, ensuring a quick response when damage does occur, so minimising subsequent damage from rain.

Rapid developments in communication media mean that many new opportunities are becoming available for broadening and improving the presentation and delivery of severe storm warning information. Technologies and distribution media which will assume greater importance for severe storm warning in the near future are: alerting of appropriately-targeted users of digital pagers and mobile telephones; e-mail; ability to target particular geographical areas

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using GPS technology; generation of automatic phone calls to recite warnings, liquid crystal display on suitable FM digital radio receivers of text messages transmitted on sub-carrier FM frequency bands; and PC alert cards triggered by satellite-transmitted warnings.

7.3 Floods

Flooding poses a significant threat to the safety of life and property in many regions of the world. Flooding of major rivers following sustained heavy rainfall is a relatively common event in Australia and many other countries. Over flat topography, warnings for this type of flooding usually have relatively long leadtimes. Flooding can occur more quickly in mountainous regions resulting in potentially more damage and greater risk to life and property. Flash-flooding resulting from intense rainfall, usually associated with thunderstorms, poses the greatest risks, especially in association with overflow of drainage systems in urban areas. The latter forms of flooding are the most difficult to provide warnings for because of their rapid development and frequently isolated nature.

A major challenge to successful operation of flood warning systems comes from the fact that the responsibility for the different components of the system is often shared among different agencies, often from different levels of government. This gives rise to problems of an administrative nature concerned with jurisdictional boundaries, and the different organisational cultures and priorities of the various agencies. In developing the total flood warning system, it is important that the roles of the various agencies be clearly identified for each component of the total system and that flood warning is tightly integrated into other programmes such as broader flood plain management programmes as well as formalised emergency management arrangements. Of particular importance is the need to ensure that flood response agencies and the community are educated about flooding and have input to system design, and that each agency accepts some ownership of the system.

The flood prediction system must be driven by a clear understanding of the information required by the response agencies and the community, in order to most effectively reduce the impact of the flood. For example, this specification could be expressed as a forecast of the river reaching or exceeding a particular level 'x', to a defined accuracy and with a warning lead time ('y' hours from 'nowrsquo;), where 'x' is the level at which certain actions (evacuation, sandbagging, etc.) need to have been taken, and where 'y' allows sufficient time for the particular action to be completed.

Flood prediction requirements clearly vary from location to location, depending on the nature of the flood hazard. These requirements also differ at each stage in the development of a flood at a particular location. For example, prior to the occurrence of the rainfall that leads to the flooding, early but uncertain forecasts based mainly on meteorological forecasts can be very useful in making the initial preparations for flooding. Such forecasts have a higher probability of being flawed but, provided this uncertainty is appreciated by the target groups, they can provide valuable lead time and improve the overall quality of the flood response. In the case of flash flooding, these meteorologically-based forecasts may be all that can be usefully provided. As the event develops, and more observed hydrometeorological data becomes available, forecast accuracy can improve but a balance must be struck between accuracy and the available lead time for response actions to take place.

Flood prediction is concerned with the vertical extent of flooding at a particular location. To be more useful, however, these predictions must be interpreted in terms of the likely *areal spread* of the flood waters and their potential impact. This interpretation is vital for warning recipients to be able to determine what the prediction will mean to them and so better guide their response. There are two approaches that can be taken: the first based on the gradual establishment, from past floods or other available information, of what can be termed as 'flood intelligence;' the other a more technologically-based solution using the power of hydraulic modelling coupled with a geographic information system (GIS). While the development of flood intelligence systems using computer based approaches will grow in the future, as will the application of GIS to flood hazard impact analysis, problems relating to resources and the availability of appropriately skilled personnel in response agencies will mean that the simpler manually based approaches will be the more likely starting point in many applications.

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The roles of NMHSs in warning the public and specialised users of *flash-flooding* vary regionally, but such warnings usually take the form of generalised warnings of flashflood associated with the onset or imminent onset of heavy rainfall, or observation-based provision of area-specific warnings.

7.4 Fire Weather

While fire may be a natural part of many ecosystems and have important applications in land management, it also has the potential, under certain meteorological conditions, to spread rapidly out of control and lead to natural disasters of catastrophic proportions. In many parts of the world, wildfires pose a severe threat to life and property, lead to community disruption and damage to the environment. Effective advance warning of conditions conducive to fire outbreak is extremely important to the prospects of fire control and can, in certain circumstances, lead to precautionary action which completely averts the conflagration.

To monitor and predict the threat of wildfire requires realtime operational systems for measuring or estimating the condition of vegetative fuels and for observing and forecasting the weather. It also requires an understanding of the way fuel and weather conditions interact to produce the threat of wildfire.

The usual approach of fire weather warning authorities is to combine a number of fuel and weather parameters in a calculation that arrives at a single index value indicative of fire danger. Such a single index cannot, however, take account of all potentially relevant factors and, in practice, other factors are subjectively taken into account as necessary.

The role and modus operandi of fire weather warning systems maintained by NMHSs varies from country to country according to the magnitude of the wildfire risk and the distribution of responsibilities amongst related fire and land management agencies. In Australia, the Bureau of Meteorology has a statutory responsibility to issue warnings of weather conditions likely to endanger life or property, including weather conditions likely to give rise to bush fires. In meeting this responsibility, fire danger ratings based on daily fire weather forecasts are conveyed to the general community in association with public weather forecasts. Above a particular threshold rating, fire weather warnings are issued. This assists the community, including fire and land management agencies, the police and emergency services, to adjust their preparation and response strategies according to the level of threat. When major fires do occur, large contingents of people and equipment are involved in suppression operations and are potentially at risk. Detailed short term forecasts for specific locations are provided in these circumstances, and a weather forecaster may be outposted to the fire agencies' headquarters to assist by interpreting and elaborating on the forecasts.

A further important component of fire weather information is accurate, timely and representative weather and fuel observations. There have been many major advances in this area. Expanding networks of Automatic Weather Stations (AWS) in many countries allow more observations to be obtained from remote locations such as fire prone parks and forest areas, with higher reliability and temporal resolution in this data. Other useful systems include portable AWS, drifting buoys, lightning detection networks, and satellite remote sensing of grass curing state, and detection of hot spots, smoke plumes and fire scarred areas. Other relevant systems in development include atmospheric profilers and the aerosonde.

Operational forecast and warning systems are increasingly supported by numerical weather prediction model output. Mesoscale models provide useful guidance for short term detailed forecasts, while longer term global models combined with statistical downscaling can provide outlooks of fire weather elements (temperature, relative humidity, wind speed and others) for several days ahead.

7.5 Air Pollution

While not all NMHSs have a role in air quality monitoring, growing concern over air pollution has prompted increasing government attention to the need for effective forewarning of conditions that will lead to potentially dangerous levels of pollution. In Australia, responsibility for managing air quality, through the regulation of emissions, resides with state-based environment protection agencies. However, the Australian

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Bureau of Meteorology has within its Act the function of: "*the forecasting of weather and of the state of the atmosphere*," with the "state of the atmosphere" being interpreted to include specification of concentrations and movement of pollutants (cf. Fig. 2).

The development of sophisticated high resolution mesoscale numerical models (less than ten km grid spacing) by NMHSs such as the Australian Bureau of Meteorology has enabled the prediction of future distributions of atmospheric pollutants. The output from such numerical models can be used to drive coupled photochemical airshed models to generate regular forecasts out to 24 hours of hourly air quality for major urban centres. These forecasts can include ground-level concentrations of photochemical smog (ozone), fine particle matter, carbon monoxide, oxides of nitrogen, sulphur dioxide and toxic organic compounds such as benzene. Forecasts from such systems can help people at risk, such as asthmatics, to plan their daily activities. They will also enable evaluation of the benefits of pollution control strategies, such as reduced or more efficient motor vehicle use and estimation of the long-term health effects. Such a coupled model system is currently being developed in Australia for operational use.

In response to emergencies involving the uncontrolled release of gases containing radioactive components the WMO put in place a system of RSMCs (at Bracknell, Toulouse, Montreal, Washington, Tokyo and Melbourne) capable of providing trajectory forecasts of such releases at short-notice. The trajectory forecast capability of these centres enables them to predict the movement and dispersion of contaminants such as volcanic ash, radio-active clouds, airborne particles from soil erosion, foot and mouth disease vectors, rye grass pollen, wildfire smoke and smoke from fuel reduction burns (Fig. 15). Recent examples include the use of this capability for forecasting southeast Asian smoke conditions and the clouds of volcanic ash impinging on high-level air routes.

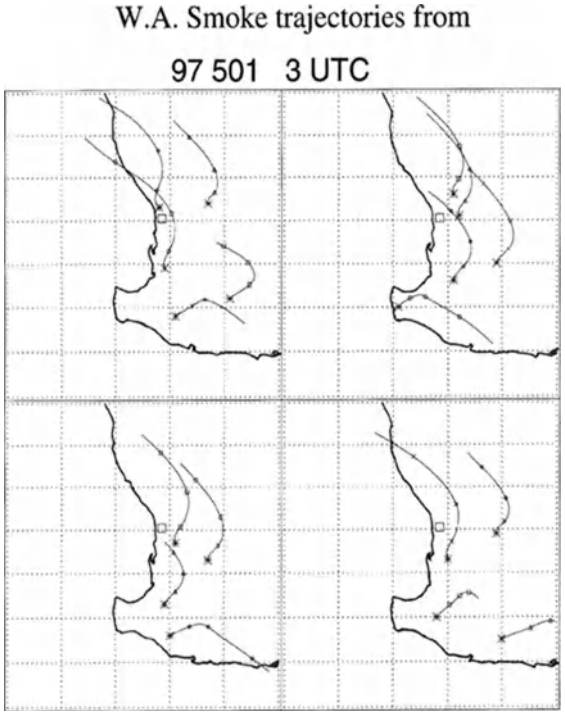


Fig. 15. Sample numerical model predictions of trajectories of smoke from controlled fuel reduction burns in southwest Western Australia

7.6 Drought

Climate variability, in itself, may be viewed as a natural hazard and its extremes – especially prolonged drought – as natural disasters. It must be recognised, however, that drought conditions reflect the result of a complex interaction of factors and cannot be considered to be purely meteorologically or hydrologically driven. Other important influences include economic conditions, poor land use and water management practices, long term soil degradation and human impacts resulting from population expansion beyond the natural system's carrying capacity.

While its inevitable recurrence with the ebb and flow of influences such as the El Niño and Southern Oscillation phenomena makes drought a more "predictable" event in individual areas, and thus more amenable to risk management policies and practices, its large areal extent and extended duration can make extreme drought a natural disaster of national proportions. Recent remarkable progress in understanding the behaviour of the atmosphere-ocean climate system and development of a prediction capability on seasonal to interannual and longer time scales (Zillman 1997), makes the prospect of usefully reliable drought warning systems a reality.

Ongoing monitoring of the components of the hydrological cycle, along with the application of developing seasonal and inter-annual predictive capability, assists in preparedness and response by providing an indication of the development

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or likely persistence of drought. Meteorological and hydrological monitoring and prediction programmes and related scientific advice enable governments to assess drought extent and trends and to plan short-term recovery actions and longer term preventive or adaptive measures. This includes early warning information which identifies geographical areas where food security crises are likely to arise, and the causes and likely severity of these crises, and extends to other information types including meteorological data and weather forecasts. Such information guides decisions about food imports and exports and also substantiates appeals to donors for food assistance and relief.

The Australian Drought Watch Service (Zillman 1998), analyses rainfall totals recorded over the entire country (mainly by an extensive network of volunteer observers) at the end of each month. Rainfall deficiencies are classified as follows:

- A severe rainfall deficiency exists when the rainfall for a period of three months or more falls within the lowest 5% (below the 5th percentile) of recorded rainfalls for the location and period in question.
- A serious rainfall deficiency exists when the rainfall for a period of three months or more falls within the next lowest 5% (between the 5th and 10th percentiles) of recorded rainfalls for the location and period in question.

Once an area is defined as experiencing serious or severe rainfall deficiencies according to the above criteria, it is considered as continuing to experience rainfall deficiencies until:

- The rainfall of the past month already amounts to average or better (i.e. above the third decile) for the three-month period commencing that month.
- Rainfall for the past three months is above average for that period (i.e. above the seventh decile).

Allowance is made for seasonal conditions in regions where there is a marked dry season. A Drought Watch Statement and associated maps are issued each month to interested authorities

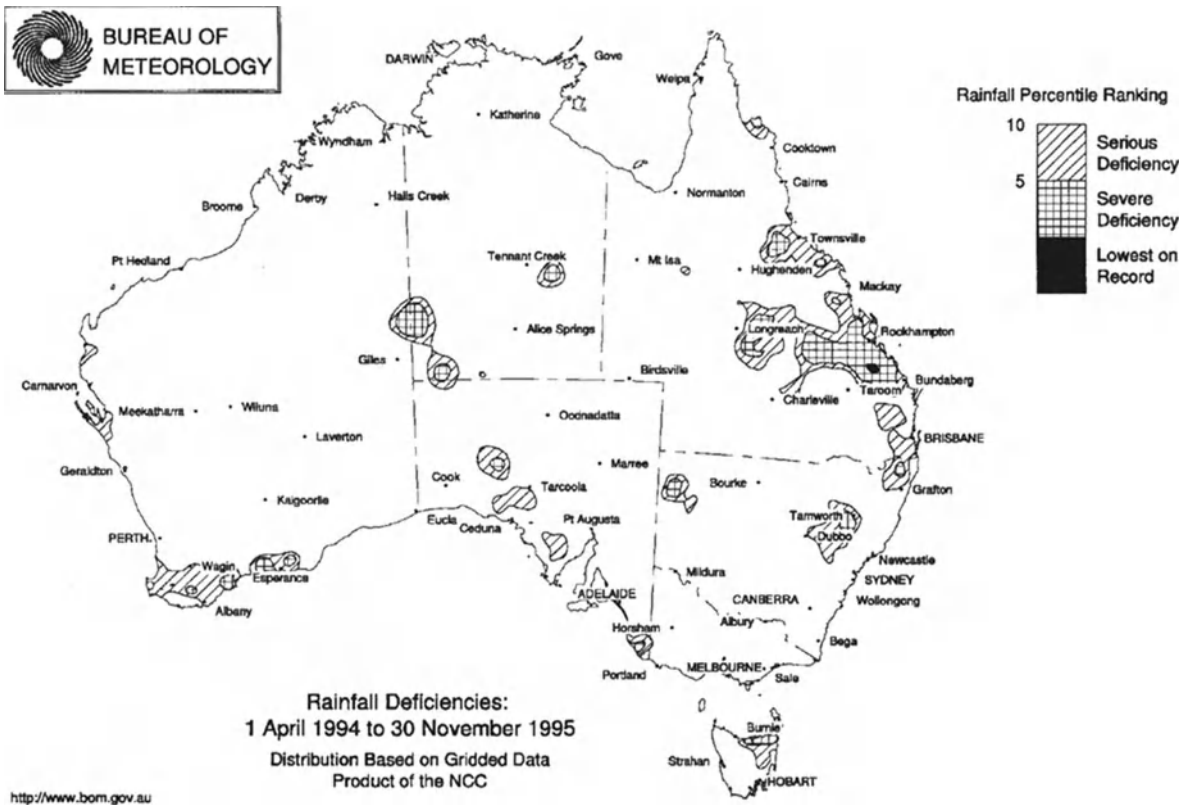


Fig. 16. Rainfall deficiency map for the twenty-month period 1 April 1994 through 30 November 1995. The identified rainfall-deficient areas stem from below-average winter and spring rains across most of Australia, the failure of the 1994–95 summer rains over a large area of eastern Australia, and successive poor winter rains over the southwest

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and the media if any area of Australia is experiencing serious or severe deficiencies (Fig. 16).

Climate research, particularly over the past two decades as part of the international Tropical Ocean Global Atmosphere (TOGA) project, has demonstrated the global controls over climate variability on interannual time scales, especially the role of the oceans. The strong coherence of climate anomalies in the Asia-Pacific region associated with the El Niño/Southern Oscillation and Walker Circulation phenomena, has provided a scientific basis for seasonal to interannual forecasting within the framework of the international WMO CLIPS (Climate Information and Prediction Services) programme.

The Australian Bureau of Meteorology currently operates a Seasonal Climate Outlook (SCO) service. The methodological basis for this service is the statistical relationship between observed rainfalls interpolated to grid-points, the Southern Oscillation Index (SOI) and global sea surface temperatures. Both displacement from the mean and trend are included as SOI predictors. In addition, the degree of persistence of rainfall anomaly between adjacent but non-overlapping seasons (e.g., from winter to spring) is also used as input. These predictors, as well as a measure of climatology, form the basis for the current statistical seasonal rainfall probability forecasts issued from the Bureau's National Climate Centre for Australian districts and towns.

The SCO is usually confined to expected conditions over the upcoming three months. However, there is an important exception, and that is when an El Niño episode is in progress. In most cases, key indicators from the tropical Pacific can be used to confirm the presence of El Niño by late winter (August), particularly if large areas of eastern Australia have been deficient in rainfall. In such circumstances, it may be possible to issue general advice to the effect that dry or drought conditions may persist in eastern and northern Australia at least until the following summer.

An assessment of the accuracy of the SCO methodology has been made by cross-validation of the statistics over a set of hindcasts covering a recent period of forty years. A forecast was independently produced for each year within the period based on parameters derived from all other years. Results of cross-validation indicate that the accuracy peaks over eastern and northern Australia and for outlooks issued between July and October. This is particularly so during El Niño and La Niña events, when there is a strong link between the SOI and eastern Australian rainfall. For those periods and locations where the method shows little skill, the outlook reverts to the climatological (or unbiased) forecast.

Recent international initiatives such as the establishment of the U.S. International Research Institute for Climate Prediction (IRI), Drought Monitoring Centres in Nairobi and Harare and the African Centre for Meteorological Applications for Development (ACMAD) in Niamey foreshadow the development of a global framework for scientifically based drought prediction over the next decade.

8 Future Opportunities and Challenges to Progress

There is no doubt that the 1990s have seen great progress in the skill and effectiveness of forecasting and warning systems around the world as a result of scientific, technological and organisational initiatives at both the national and international levels, and especially as a result of the international focus on their importance through the IDNDR (Jeggle 1997). There is, however, much scope for further improvement both through new scientific and technological developments and through the better application of existing knowledge and experience. But there are also many formidable challenges ahead for those whose task it is to enhance the effectiveness of meteorological and hydrological warning systems within individual countries in order to realise their enormous potential for the protection of life and mitigation of damage in prospective disaster situations. Indeed, there are some influences on the international scene which, if not clearly recognised and quickly addressed, could lead to serious degradation rather than improvement in the effectiveness of warning systems in many countries.

While any such list must be highly selective, the following may be identified as amongst the most important opportunities and challenges facing the natural disaster warning community over the coming decades:

- Increased forecast skill. There is still a long way to go to reach what is probably ultimately achievable by way of scientifically

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based forecasting of the development and behaviour of natural hazards on time and space scales from severe local storms to El Niño-induced drought. For the shorter timescale phenomena, an achievable goal by, say, 2020 might be a level of forecast skill which would make the concept of "alert" or "watch" no longer relevant or necessary because of the high level of confidence in the longer-lead forecast.

- Exploiting technological progress. It is clear that emerging and prospective observational, computing, communications and information display technologies offer enormous opportunities to enhance the efficiency and effectiveness of warning systems. The expanding capabilities of meteorological and communications satellites and of new observation tools such as the aerosonde and new image visualisation software hold particular promise in this respect.
- Maintaining cooperation and avoiding duplication. Like public weather services in general, but of even more critical importance to their success, meteorological and hydrological warning services are totally dependent on effective cooperation and avoidance of competition and duplication at every stage in their operation. The hard-won progress in warning system performance over the past decades is thus particularly at risk from current economic and administrative policies in many countries which favour the application of market principles, competition, outsourcing and privatisation to many traditionally public sector activities and services. It will be essential that governments be made fully aware of the serious threat to the effectiveness of warning systems posed by the introduction of competition into such an inherently cooperative sphere of activity as meteorological forecasting and warning.
- Data exchange. Again, like public weather services in general, the efficiency and effectiveness of warning system provision in every country is heavily reliant on rapid, free and unrestricted access to meteorological and related data from other countries. It is well known that the long-established convention of free and unrestricted exchange of meteorological data between member states of the World Meteorological Organization (WMO) has come under unprecedented stress from the commercialisation pressures on NMHSs in some countries. So far, the WMO has, through unanimous adoption of its Resolution 40 at the Twelfth World Meteorological Congress in 1995, succeeded in maintaining the global commitment to free exchange, but the continuing pressures are intense. It is of critical importance to the future integrity and effectiveness of warning systems everywhere that this commitment be maintained and strengthened at the highest levels of government.
- Integration of warning and routine service provision. The ability of NMSs to recognise and respond quickly, effectively and comprehensively to a wide range of potential disaster situations results from the arrangement, in almost all countries, in which the warning system is operationally embedded within the round-the-clock public weather service role of the NMS. It will be essential to ensure that pressures for compartmentalisation of the integrated operation of NMSs under purchaser-provider or business unit models do not compromise either the effectiveness or the essential internal consistency of the warnings with the public weather forecasts, of which they are frequently the most important part. It will be equally important to maintain the same tight integration of warning and other forecast information in the context of aviation, marine, agricultural and other services.
- Integration within overall disaster reduction programmes. There is compelling evidence that the full effectiveness of warning systems is only realised when they are carefully and fully integrated within overall national, regional or local strategies for natural disaster reduction; and there is close and continuous communication between those involved in monitoring and warning of meteorological and hydrological hazards and those guiding and coordinating the disaster preparedness activities. This will only be achieved when governments recognise the need for a holistic approach to natural disaster reduction, and put in place the necessary coordination mechanisms and channels of communication to make this possible.
- Partnership with the media. The mass media play a vital role in the communication of essential warning information to threatened

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communities. Apart from the general challenge of building close and enduring partnership arrangements between the NMHS warning centres and the mass media, especially radio and television whose immediacy is of particular importance in severe weather events, two formidable specific challenges will need to be addressed over the coming decades. The first follows from the lack of local or even regional focus of media outlets *within* countries as cost-cutting-induced media networking replaces local radio and television programming. The second follows from the need to ensure that global television network weather presentations either accurately reflect, or refer viewers to, the local official warnings to prevent dangerously conflicting or competing information finding its way to disaster management authorities and the general community in threatened regions.

- International warning centres. The concept of international centres operated by a single member country of WMO, or by a number of member countries jointly, but serving the needs of a geographical region or, for special purposes, the entire global community, has gradually been developing within the global meteorological community. Centres with a specific warning or quasi-warning role include especially the Regional Tropical Cyclone Centres of the WMO Tropical Cyclone Programme and those designated under the WMO Emergency Response Activities Programme. A significant challenge for the coming decade will be to interface such international advisory/warning centres more effectively with the NMHSs and emergency response agencies of individual Member countries.
- Increased community involvement. The relative rareness of severe meteorological and hydrological events means that affected communities usually have little experience or insight into what will happen when one strikes. Yet the effectiveness of warning systems in their contribution to disaster mitigation depends critically on community understanding of what to do on receipt of warnings and sufficient faith in the reliability of the warning to trigger immediate response. One of the most important challenges for those responsible for the design and operation of warning systems in the post-IDNDR environment will be to build and maintain an appropriate level of community involvement in, and ownership of, the warning system to ensure maximum effectiveness in generating community response on the rare occasions when disaster threatens.
- Coping with increasing vulnerability. One of the largest worries for counter-disaster agencies in many countries centres on the increasing vulnerability of communities to the impacts of severe events as population density on exposed coasts and flood plains and in fire-prone forest areas steadily increases and the stakes become higher as increasing numbers of people and their property become exposed to the threat of severe weather or the impacts of drought in marginal agricultural lands. The increasing vulnerability of cities (cf. Munich Re 1997) will pose particular challenges for those responsible for warning system development and operation in the decades ahead.
- Implications of climate change. Although the scientific assessments of the Intergovernmental Panel on Climate Change (IPCC) are not conclusive on the likely impact of increased greenhouse gas concentrations on the frequency, severity and areal extent of severe weather and climate events, there are clear implications that disaster managers will need to carefully monitor the evolving scientific thinking on the prospects of more severe meteorological and hydrological events in a greenhouse-warmed world.

9 Conclusions

This brief stocktake of the role and effectiveness of meteorological and hydrological warning systems in the closing years of the IDNDR leads to a number of general conclusions which may provide a useful starting point for planning for warning system development and improvement in the early years of the twenty-first century. In summary, it is evident that:

- Warning systems constitute an essential and highly cost-effective component of national and international strategies for natural disaster reduction.
- To realise their full potential, warning systems must be properly embedded in integrated and coordinated national natural disaster reduction programmes.

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- The overall efficiency, effectiveness, responsiveness and reliability of warning systems will be greatest if they are operated as the core element of the routine meteorological and hydrological monitoring and service role of National Meteorological and Hydrological Services.
- In order to avoid conflicting advice and dangerous public confusion, there must be only one official source of warning information to the community at large in potentially life-threatening situations.
- The effectiveness of warning services can be greatly enhanced through improved community understanding of their vulnerability to natural hazards and of the operation of the warning system.
- Detailed studies are needed of the benefit-cost characteristics of warning systems of different levels of sophistication to enable governments to optimally balance their use of the resources available for natural disaster reduction.
- Regular public education in the interpretation and use of warning information is essential.
- The design and operation of warning systems must be based unambiguously on a commitment to cooperation and information exchange and the concept of partnership in the overall public interest.
- National warning systems must be carefully integrated into, and designed to make full use of, the international warning and disaster reduction initiatives of the World Meteorological Organization and its partner agencies and programmes.
- In addition to its immediate role in minimising loss of life and property, natural disaster warning systems must be viewed as an integral element of long-term strategies for sustainable development in both developed and developing countries.
- The World Meteorological Organization and other involved agencies, including especially the IDNDR Secretariat, should develop an integrated strategy to enhance the contribution of warning systems to the goals of natural disaster reduction and sustainable development in the twenty-first century.

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IVa Early Warning Systems for Tropical Storms

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Track Forecast Guidance Improvements for Early Warnings of Tropical Cyclones

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Abstract

The disastrous impacts of tropical cyclones in terms of loss of lives and damage to the economies of all nations affected by these storms are well known. This paper will present an overview of progress achieved in the last decade in providing tropical cyclone track forecast guidance at a number of regional and national centers. In many cases, the accuracy of the 72-hour track forecasts is equivalent to that of the 48-hour forecasts only 10 years ago. Contributions from various factors that have led to these track forecast improvements will be described. Future needs to continue this improvement will be proposed. A number of issues that must be addressed to convert improved track forecast guidance to more accurate and earlier warnings will be suggested.

1 Introduction

1.1 Impacts of Tropical Cyclones[1]

Tropical cyclones are one of the most damaging of the natural disasters. Even as recently as 1991, more than 125 000 people were killed in a tropical cyclone that struck Bangladesh. Most of these people were killed on low-lying islands or coastal areas by the storm surge. Typical increases of sea level associated with surges are several meters, but extreme surges of up to 10 m may occur. The spatial distribution and amplitude of the storm surge depend in a complicated way on the ocean bottom topography as well as the size, intensity, direction and speed of movement of the tropical cyclone. The definition of storm surge does not include shorter term phenomena such as surface waves, breakers, or spray, but the peak water level will be in association with the astronomical tides.

[1] The generic title tropical cyclone will be used here to include all stages, which include: tropical disturbance – a region of organized convection with diameter of 200–600 km having a non-frontal migratory character; tropical depression – weak tropical cyclone with a definite closed surface circulation and highest sustained wind speeds (averaged over one minute or longer period) of less than 17 μm/s (34 kt); tropical storm – a tropical cyclone with closed isobars and highest sustained wind speeds of 17 to 32 m/s (34 to 63 kt) inclusive; typhoon/hurricane – a tropical cyclone with highest sustained winds of 33 m/s (64 kt) or more.

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The wind damage from a tropical cyclone generally increases with at least the square of the wind speed. For many developing nations, the high winds may cause complete collapse of houses and other structures, loss of fruit trees and other agriculture. Although the tropical cyclone may have some positive effects such as bringing rainfall to semi-arid or drought-stricken areas, the torrential rains may cause great damage and flooding. These heavy rains may continue well inland from the coast. For example, Typhoon Nina (1975) caused torrential rains of 1060 mm in 24 h on the third day after landfall. The tropical cyclone does not necessarily have to be intense to cause severe flooding in regions of steep topography. A tropical storm during 1993 struck a mountainous region of the central Philippine Islands with 350–550 mm of rain in about 4 h (L. A. Armadore, private communication, 1993). Because the rain fell in a limited area with steep slopes from which trees had been removed, flash floods killed about 5000 people. Even in countries with advanced flood control facilities, landslips in association with tropical cyclone rainfall are a continuing problem.

Damage estimates collected by the Typhoon Committee of the World Meteorological Organization (WMO) have documented typhoon-related economic losses exceeding 4 billion US dollars annually to the countries along the rim of the western North Pacific (Chen 1995). During 1985–1988, 52 of the 59 typhoons that affected the region caused great damage. Economic losses in the US caused by hurricanes have been drastically rising during the last 30 years, even as the number of deaths has remarkably decreased from better warnings. A single hurricane named Andrew caused up to 30 billion US dollars damage during 1992. Recent estimates of hurricane-related damages in the US are 4–5 billion US dollars per year. These increasing losses arise because of the population and industry shifts to coastal areas – not from larger numbers of hurricanes.

Given that a tropical cyclone landfall occurs, a certain fraction of the losses are not avoidable. Closing down commerce and industry, and disruptions in transportation, incur costs that cannot be avoided. Evacuating people and mobile assets such as ships and aircraft from high-risk coastal areas to safe havens is a necessary expense. As the number of people living at the coast or on barrier islands has increased, the clearance time has increased because the number of evacuation routes is limited. The clearance time is also increased if people who really do not need to evacuate feel at risk and add to the traffic burden. Evacuations from the oil drilling rigs, e.g., along the Gulf of Mexico in the US, and closing down the petrochemical industry are expensive in terms of direct costs as well as lost revenue to the industry and lost tax income to the government.

In the optimum case, only those industry closing and public evacuations that were actually necessary would be carried out. In practice, the uncertainties in the observations and understanding of the hurricane, and the inaccuracy of the forecasts, make it prudent to warn a larger area than will be affected. As an example, the cost of preparations along the 300 miles of coast typically put in warning in the US is approximately US$ 300 million. To the extent that reductions in the overwarned area are possible through better observations, understandings, and forecasts of hurricane landfall, the nation will benefit.

Meteorological considerations are not the only factor in damage. Improvements in building codes, and enforcement of those codes by adequate inspections, could save billions of dollars. In the US, the Hurricane Andrew event has caused a re-examination of the wind-induced losses during hurricane landfall because damages were larger than would have been expected from the pre-landfall intensity estimates. Research that would contribute to a better understanding of the threat from local wind damage would have a benefit in terms of improved mitigation efforts such as building codes or structure safety standards.

A rapid and accurate assessment of damage from storm surge or wind may also reduce the hurricane landfall impact. Getting rescue and repair crews with the necessary supplies and equipment to the areas of most severe damage may save lives and will hasten the restoration of power, transportation, commerce, etc. Simply having the proper cover over damaged houses following a tropical cyclone may prevent additional water damage from a subsequent heavy rain event. In many nations, disaster relief agencies are attempting to be more proactive (rather than reactive) in moving teams and emergency supplies into tropical cyclone landfall zones.

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An excellent meteorological forecast will not necessarily result in minimal damage. That forecast has to be translated into warnings that communicate to the public the actual threat. Not a lot of information is available as to what motivates the public to take the proper actions to prepare or to evacuate. Presumably, a better perception of the actual intensity will prompt more appropriate precautions or evacuations. However, the whole psychological aspect of public response to warnings, what is the actual experience level with tropical cyclones, what percentage of the people will take actions in each situation, what impact information from different media may have, etc., and how these social factors might contribute to the avoidable damage, is uncertain. Clearly, a high level of public confidence in the tropical cyclone landfall warning system must be a goal.

1.2 Meteorological Aspects of the Tropical Cyclone Landfall Forecast Problem

Each national weather service will have specific procedures for issuing tropical cyclone warnings. In the US, the National Hurricane Center (NHC) is tasked to issue a Tropical Storm (TS) or Hurricane *watch* when the center is forecast to cross the US coast within 36 h. More importantly, a TS or Hurricane *warning* is issued when the center is forecast to cross the coast within 24 h. The objective is to provide the public at least 12 h of daylight to complete preparedness activities. In addition to preparing buildings or closing down businesses, this may include evacuation of an area that is expected to be inundated by a storm surge across the coast, or expected to experience severe wind damage. An important consideration in determining the size of an evacuation area is the storm intensity, because the storm surge inundation area will generally be much larger for a Category 5 hurricane than for a Category 1 hurricane. As more and more people have moved into the US coastal areas, the time it takes to complete an evacuation from a threatened area has also increased. Considerable reductions in structural and other property damage could be achieved by an improvement in landfall timing forecasts that would allow two daytime periods for preparations.

The function of the local emergency managers is to motivate the public to undertake disaster preparedness activities that are appropriate to the threat represented in the tropical cyclone watches and warnings. Whereas the 36-h watches and 24-h warnings issued by NHC in the US are relative to the center coastal-crossing time, the key consideration for the emergency managers is that the disaster preparedness activities or evacuations need to be *completed prior to the arrival of gale-force (35 kt) winds*, or the heavy precipitation that would make such activities or evacuations hazardous. Because of the forecast track errors and the uncertainty in the radius of the gale-force winds, the length of coast that is placed under a watch, or in a warning, must be longer than the length that will actually experience those winds. In the US, a typical ratio of *overwarning* is 4:1. Being aware of this overwarning, the emergency manager may delay issuing the call for preparedness activities or evacuations until more solid evidence of the threat is available. However, such a delay raises the risk that the activities or evacuations will not be completed safely, especially if the tropical cyclone suddenly accelerates toward the coast.

Even though the tropical cyclone watches/warnings are related to center coastal crossing times and the emergency management considerations are related to the arrival of 35-kt winds at the coast, psychological factors evidently link these different considerations. That is, some emergency managers do not believe the public can be motivated to initiate preparedness activities or evacuations unless the national weather service has placed the coastal area under at least a warning. Presumably, the public are more likely to initiative preparedness activities or evacuations if the warning is for a severe hurricane or typhoon than for just a tropical storm. Consequently, an accurate intensity forecast at about 36 h prior to center coastal-crossing time (when the first watch is issued) is a requirement to motivate public action appropriate to the threat.

To minimize overwarning, and thus the perception that the national weather service and emergency management community have "cried Wolf" too frequently, the accuracy of the track forecast to the *landfall point*, which is defined here to be when the 35 kt winds have first reached the coast, must be improved. Since the outer wind structure (specifically the 35-kt wind radius, or other damage-threshold wind) is a fac-

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tor in the timing of the emergency management activities, this is another important tropical cyclone characteristic to be analyzed and forecast.

The inner-core wind structure is also critical for the storm surge prediction and estimating the ocean surface wave run-up at the coast. Because the uncertainty in the 24-h track prediction is greater than the horizontal scale of the storm surge, a deterministic storm surge prediction is usually not done in real-time operations. In addition, the imperfect knowledge of the inner-core wind structure prediction would also prevent an accurate calculation of the storm surge in real-time. Thus, the approach used in several nations is to utilize a Maximum Envelope of Water (MEOW), which is an atlas of maximum surge elevations for an ensemble of storms of different intensities approaching the coast from a variety of directions. The forecaster then attempts to match the forecast characteristics of the present tropical cyclone with one of the storm surge atlas solutions, which is then the worst-case elevation along the coast. However, this does not give the distribution of the surge elevations along the coast if the track or inner-core wind structure deviates significantly from the forecast. This surge distribution is important for post-storm damage assessment if inundation has occurred, because the need/locations for focussed relief efforts will be a function of what areas were under water and for how long.

Another important consideration in the coastal and inland regions is the rate, duration, and total amount of precipitation that will be associated with the hurricane landfall. This precipitation determines the threat of urban or inland flooding, and many water management activities (e.g., releasing water to lower reservoirs or protect levees) depend on accurate precipitation assessments. Even though the winds may decrease below gale-force shortly after the hurricane center has crossed the coast, the precipitation can still cause flooding, especially in a slow-moving storm. Indeed, the remnants of the hurricane circulation may persist while travelling 500 miles inland and they interact with a mid-latitude front and continue to cause heavy precipitation. Upslope motion against topography can greatly enhance precipitation and embedded meso-scale convective systems may trigger extreme precipitation events. For these reasons, the precipitation associated with a landfalling hurricane may be spread over large inland areas and yet have highly localized maximum amounts.

Post-hurricane damage surveys have often indicated that the wind fields may include very localized regions that cause extreme destruction just across the street from similar structures with relatively little damage. Where these differences are not due to shoddy construction practices or poor enforcement of building codes, the extreme damage is attributed to tornadoes, or to straight-line winds that are greater than would be normally associated with that hurricane intensity. Hypotheses as to the trigger mechanism and wind speeds to be expected in these straight-line events have recently been posed. Although some characteristics of tornadoes associated with hurricane landfall are known, their occurrence is a difficult forecast problem because of the small horizontal scales and generally short durations. In the US, a network of Doppler radars recently installed along the coast is anticipated to assist in detection of the tornado events.

In meteorological terms, a forecast is required as the three-dimensional wind, thermal, and moisture fields in the cyclone are being modified by interaction with coastal waters and land to cause localized wind damage or other hazardous conditions including storm surge, extreme rainfall, flooding, and tornadoes. This landfall condition continues as long as hazardous winds or precipitation are possible from the storm remnants having warm-core tropical characteristics, even though this may be 500 miles inland and be days after the center crossed the coast. For some marine activities (e.g., offshore oil drilling), it would be useful to have some early warning outlook for a period of up to 120 h prior to landfall when the tropical cyclone is moving toward the coast. This track forecast problem will be the primary focus of this paper. Although a much improved intensity forecast will be required to portray accurately the degree of threat in the landfall region, this topic will be left to Sir James Lighthill in this chapter.

1.3 Meteorological Forecast and Warning Infrastructure

In conjunction with the World Meteorological Organization (WMO) efforts to promote the exchange of observations, the members have or-

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ganized Regional Specialized Meteorological Centers (RSMC) for the purpose of sharing tropical cyclone analyses and forecasts. These five centers and their areas of interest are indicated in Fig. 1. Annual average occurrences of tropical cyclones are indicated with the percent of the total number (80) of tropical cyclones around the globe. Each of these centers is hosted by a national weather service as a service to the other WMO members. Each center monitors the tropical disturbances, names those that achieve tropical storm (34 kt) intensity, analyses and forecasts the tropical cyclones in their area of responsibility. These centers are thus a resource for the national weather services in that area, and communication between the RSMC and the national forecast center is common.

It is emphasized that each nation is responsible for issuing the warnings (watches) for their country. Many of the individual countries have advanced satellite and other observing systems, analysis, and forecast tools independent of the RSMC for that region. Thus, they are able to compare their own forecast guidance with that from the RSMC. A number of global forecast centers also communicate their track forecasts. Nevertheless, the ultimate decision for which area of the nation is to be warned resides entirely with that nation's forecasters based on whatever guidance they have available.

An effective tropical cyclone warning system must be concerned with more than just the meteorological content, e.g., the content and language of the warning must be appropriate for the population. The criteria for issuing warnings, the gradual increase in the warnings to indicate an increasing threat, and the timing of the warning must be designed to meet the needs of affected groups in the threatened area. The distribution system for tropical cyclone warnings may include: the meteorological telecommunication network; media such as radio, television, and newspapers; administrative communications between different levels of the government; navigation and maritime telecommunication systems; and specialized user telecommunication networks. Because this warning distribution system is the critical link between the forecast center, government agencies at different levels, and the public, it is common to have trial simulations prior to each season to make certain all systems are in readiness.

The effectiveness of the warning system is directly linked with the social and economic benefits of disaster prevention and preparedness activities. Each country has different telecommunication technology, so it is difficult to make comparisons as to the timing and efficacy of the warning transmissions. In a (somewhat dated) survey in 1985, only half of 30 responding countries indicated a capability to prepare warnings within 1 h and transmit the warnings to the affected areas within 4 h.

1.4 Plan of Paper

The primary focus in this paper is on tropical cyclone track forecasting (Sir James Lighthill will address the intensity forecast problem). First, the progress during the last decade in track forecasting in various regions will be reviewed. Second, contributions from various factors that have led to these track improvements will be described. Third, some thoughts on what is needed to improve this track guidance will be offered. Finally, a number of issues that must be addressed to convert improved track guidance to more accurate and earlier warnings will be suggested.

2 Advances in Tropical Cyclone Track Prediction

2.1 Western North Pacific

2.1.1 RSMC-Tokyo Typhoon Center

As shown in Fig. 1, the western North Pacific is the most active tropical cyclone region with approximately 30 named storms per year. The RSMC-Tokyo Typhoon Center provides forecast guidance for the WMO Typhoon Committee members. The Director of that center, H. Ohnishi (1992) proposed a year 2000 goal of reducing the annual average 24- and 48-h track forecast errors to 100 km and 250 km, respectively.

Long-term trends in the track forecast errors of RSMC-Tokyo are shown in Fig. 2 to indicate the progress towards the year 2000 goals. Notice that the 72-h track errors were smaller than the 48-h errors a decade earlier, which is a notable achievement! Much improvement in 48-h fore-

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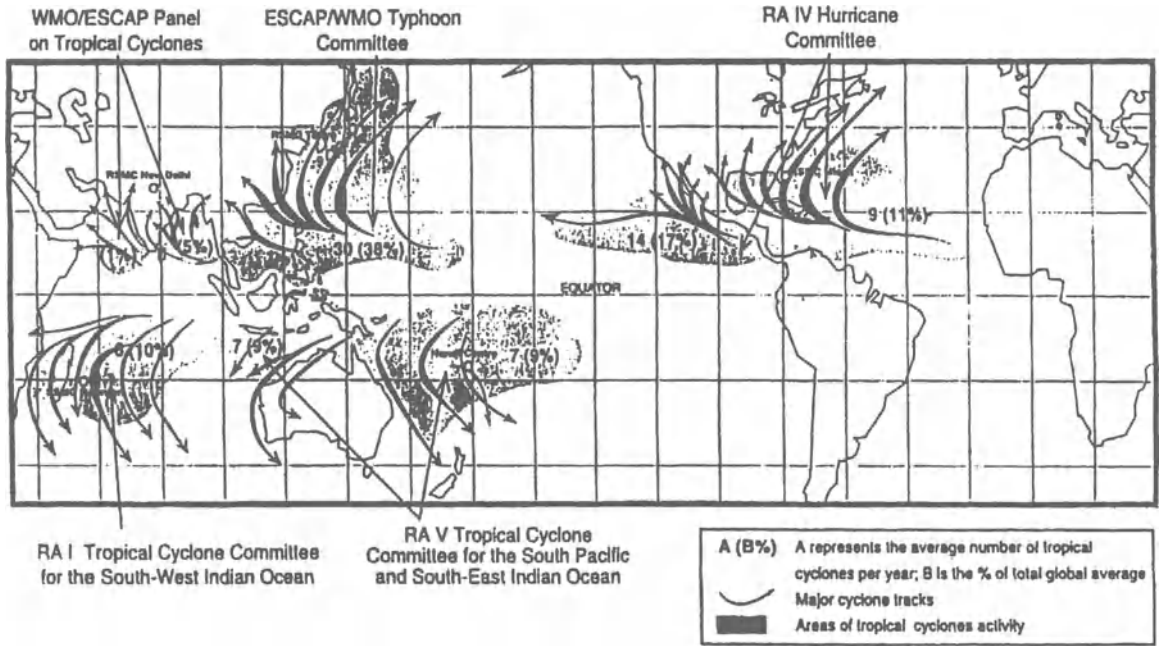


Fig. 1. Annual number (percentage in parentheses) of tropical cyclones in various regions of the globe and major tracks (arrows). Areas of tropical cyclone activity are shaded, and the WMO regional groups addressing tropical cyclone concerns are indicated (provided by K. Abe, WMO)

cast accuracy has been achieved since 1988, when the errors were almost 400 km. In 1997, the 48-h track errors averaged slightly more than 250 km, so that achievement of the year 2000 goal of 250 km is likely. Progress toward the goal of 100 km errors at 24 h has been more slow.

Nagata et al. (1997) have described the major revisions during March 1996 in the numerical analysis and two prediction models of the Japan Meteorological Agency (JMA) that have led to enhanced typhoon track prediction accuracy. The Global Spectral Model (GSM) makes 84- and 192-h predictions from 00 UTC and 12 UTC, respectively. At 06 UTC and 18 UTC, a spectral limited area Typhoon Model (TYM) makes 78-h forecasts. Three kinds of model revisions were made: (1) Improved horizontal and vertical resolution for the GSM to T213 (from T106) and 30 layers (from 21), and for the TYM to 40 km (from 50 km) and 15 layers (from 8); (2) Both models now use the Arakawa-Schubert cumulus parameterization scheme; and (3) Improved four-dimensional data assimilation cycle employing a statistical interpolation method in three dimensions on the prediction model levels. Both models include synthetic observations to represent the initial location and structure of the symmetric vortex in the analysis. An estimate of the asymmetric vortex component is extracted from the 6-h prediction of the GSM, or of the TYM (since November 1997), as appropriate.

Performance of the GSM and TYM are given in Fig. 3 for the 1994–1997 seasons. Interannual variations in the degree of difficulty are not taken into account in these summaries. Notice that 1995 was a more difficult season (not just for RSMC-Tokyo, but other forecast centers in this region also had larger errors). Dramatic decreases in errors for periods 36 h through 72 h are found for the GSM (Fig. 3a) during 1996 and 1997, which are attributed to the three model revisions given above. Although less dramatic, the TYM 36- to 60-h errors during 1997 seem to indicate continued improvement in track prediction. The TYM has only been integrated to 78 h since the new computer was installed during March 1996. Notice that 72-h GSM and TYM guidance provided to the RSMC-Tokyo forecasters during 1997 had about 400 km errors, which is the accuracy of the RSMC-Tokyo forecasts a decade earlier (Fig. 2). Furthermore, the model guidance during 1997 had 48-h errors of about 250 km, which was the Ohnishi (1992) goal for year 2000. This is not the same as meeting the official forecast goal because the model guidance is not actually

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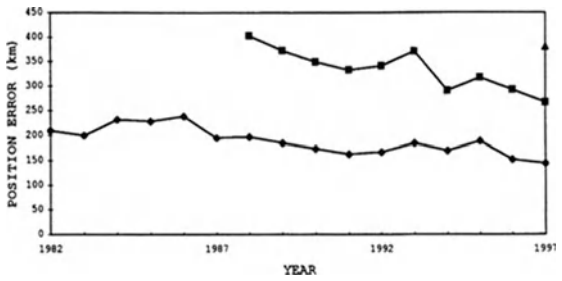


Fig. 2. Annual mean official track forecast errors at 24 h and 48 h for the RSMC Tokyo-Typhoon Center

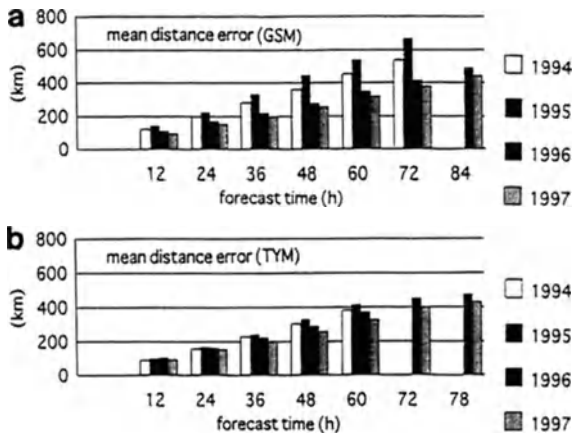


Fig. 3. Annual mean track forecast errors during 1994–1997 seasons for JMA Global Spectral Model (top) and Typhoon Model (bottom)

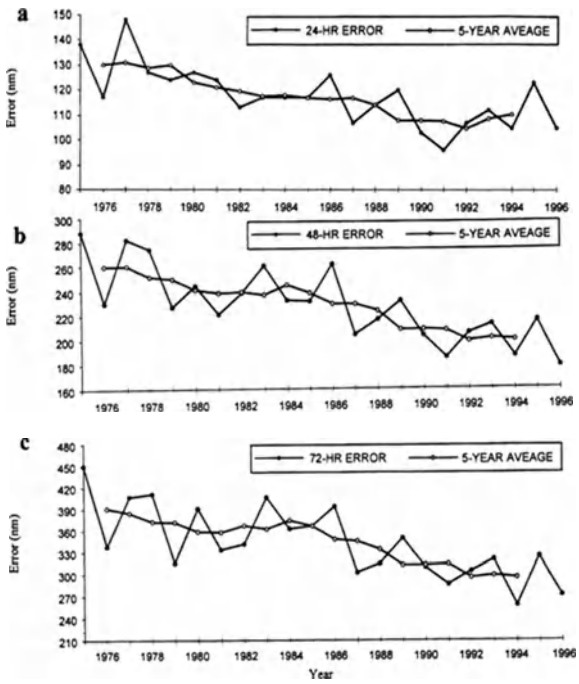


Fig. 4. Annual mean track forecast error (n mi) and 5-year running mean for (a) 24 h, (b) 48 h, and (c) 72 h made by the Joint Typhoon Warning Center, Guam for western North Pacific tropical cyclones during 1976–1996

available until 4–5 h after the synoptic time, so the forecaster cannot use it until the next 6-h forecast. Nevertheless, the March 1996 revisions in the GSM and TYM appear to have substantially improved the track forecast guidance for western North Pacific tropical cyclones.

2.1.2 Joint Typhoon Warning Center

The Joint Typhoon Warning Center (JTWC) in Guam provides track forecasts for US interests in the western North Pacific. The primary dynamical model guidance for JTWC is the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the Navy version of the Geophysical Fluid Dynamics Laboratory (GFDL) model called GFDN. The NOGAPS horizontal resolution is T159, which is intermediate between the old and new JMA global models. The GFDN is a triply nested, limited area model with an inner-grid resolution of 1/6° lat./long., which is about one half the resolution of the JMA TYM. Similar to the procedure at RSMC-Tokyo, the NOGAPS guidance is available to JTWC about 4–5 h after either 00 UTC or 12 UTC, and the regional GFDN is integrated following the 06 UTC and 18 UTC synoptic times.

Trends in track forecast errors in the western North Pacific are available from JTWC (Fig. 4) for a longer period than for RSMC-Tokyo in Fig. 2. Notice that JTWC has been issuing 72-h forecasts since at least 1975. Whereas JTWC had achieved a slow improvement in 24-h track forecasts prior to 1987, the trend at 24 h since that time has been essentially flat with some year-to-year variability (Fig. 4a). The 48-h (Fig. 4b) and 72-h (Fig. 4c) forecast error trends have continued to indicate an improvement, as the 1997 forecast errors at these forecast intervals were smaller than in 1996 (not shown).

Both the RSMC-Tokyo (Fig. 2) and JTWC (Fig. 4) error statistics are mean values for an entire season. A large non-Gaussian variability exists about these means. For example, the frequency distribution of 24-h errors has a median value of only 85 n mi, but the standard deviation is 76 n mi. More importantly, a long "tail" of large errors occurs, with three 24-h forecasts exceeding 300 n mi. These large errors

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decrease confidence in forecasts and the emergency managers must plan for greater uncertainty. Clearly, one goal for the forecaster is to reduce the number of these forecast error outliers or "forecast busts".

One contributor to the 24-h forecast error is the uncertainty in the initial positions (Fig. 5a). This is true because the short-term forecast is heavily weighted toward a "persistence of past motion" forecast that is the difference between the initial (warning) position and a 12-h old position. Thus, both of these positions need to be known accurately. Although the median initial position error is only 13 n mi, the mean error is 25 n mi, and five of the 922 cases had initial errors exceeding 100 n mi. Clearly, if the initial position is not known within 50 n mi or more, it will be difficult to reduce the 24-h forecast errors to 50 n mi. It is more than coincidence that the essentially flat 24-h track error trend seems to extend backward to about 1987, which is the year in which the US stopped flying aircraft reconnaissance in the western North Pacific?

A new dynamical forecast guidance for JTWC during 1996 was the GFDN described above. The mean track errors for GFDN forecasts during 1996 stratified by initial intensity are shown in Fig. 6. It is important that the GFDN guidance is most accurate for the typhoon stage. Some degradation in track prediction is found for tropical storm stage. However, significantly poorer track guidance is provided by GFDN for tropical depressions. Again, one reason for this degradation is that the initial

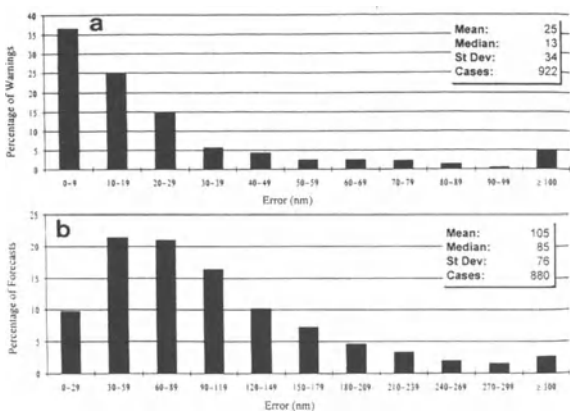


Fig. 5. Frequency distributions of (a) initial warning position errors in 10 n mi increments and (b) 24-h track forecast errors in 30 n mi increments made by the Joint Typhoon Warning Center, Guam, for western North Pacific tropical cyclones during 1996

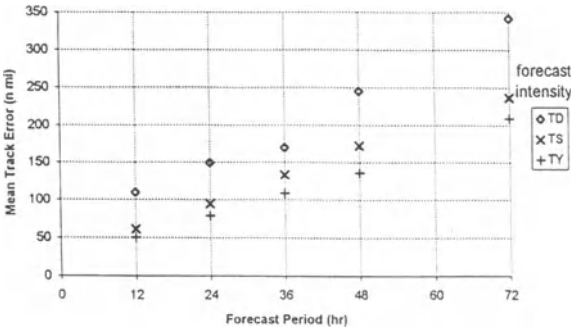


Fig. 6. Mean track forecast errors of the GFDN model stratified by the forecast intensity of western North Pacific tropical cyclones during 1996 as a tropical depression (TD, diamonds), tropical storm (TS, X symbols), or typhoon (TY, cross symbols)

position errors are larger for tropical depressions than for typhoons. An important consideration in the tropical cyclone warning process is that one of these poorly positioned and forecast tropical depressions may develop rapidly into a typhoon within 72 h and strike an area that has not been adequately warned.

2.2 Atlantic

Although only about 11% of the global tropical cyclones are found in this region, they cause some of the largest damage totals because of the concentration of the population and industry in coastal areas (see section 1a). Another anomalous aspect of this region is the availability of aircraft reconnaissance, which makes observational coverage in this region unrepresentative of the remainder of the world.

An indication of the recent improvement in track forecasts in this region by the National Hurricane Center (NHC) in Miami, Florida (US) is given in Fig. 7. Some substantial (about 30%) improvements have been achieved in 36- to 72-h track forecasts relative to the 1986–1995 forecast errors. One factor to be considered in such interannual comparisons is the degree of difficulty of the storms in each yearly sample. This is particularly important when the sample sizes are small, as it often the case in Atlantic tropical cyclones (not so much of a problem in 1996 when this region had one of its most active seasons). A normalization by comparison with a CLImatology and Persistence (CLIP) forecasts for the same situations is given in Fig. 7. That is, the 1996 storms may be considered to be easier to

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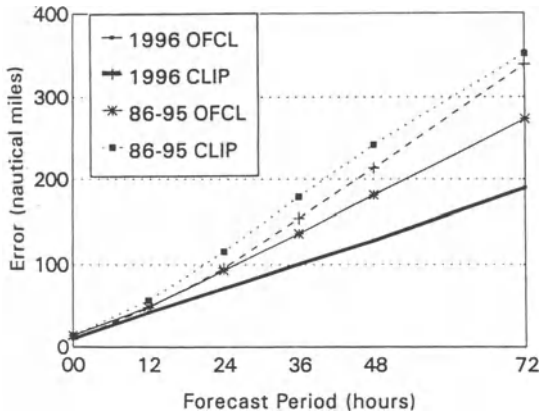


Fig. 7. Official (OFCL, solid lines) and CLImatology and Persistence (CLIP, dotted or dashed) track forecast errors during 1996 and during 1986–1995 for Atlantic tropical cyclones. The number of forecasts ranges from 290 at the initial time to 183 at 72 h

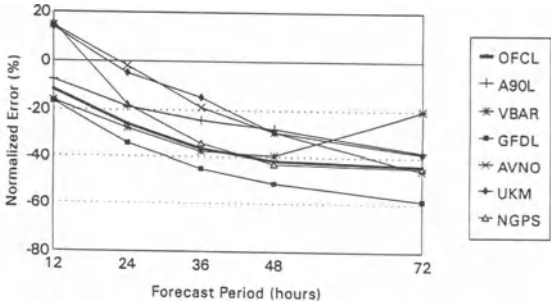


Fig. 8. Track forecast errors normalized relative to CLIP for the official (OFCL) and various objective techniques (see legend for symbols) in the Atlantic during 1996. These techniques are said to have skill for negative normalized errors. The number of forecasts in this homogeneous sample ranges from 61 at 12 h to 36 at 72 h

forecast than the 1986–1995 sample because the CLIP forecast errors are smaller. However, the margin of skill (improvement over CLIP) of the Official NHC forecasts during 1996 is clearly greater than in the 1986–1995 sample.

Improvement in the dynamical track prediction guidance, and especially the GFDL model, has been a primary contributor to this increase in official NHC track accuracy. The clear advantage of the GFDL track guidance compared to other objective aids is illustrated in Fig. 8. As in Fig. 7, the errors of these techniques are normalized by the CLIP technique, with negative (positive) values having skill (no skill). Three global models (AVNO – Aviation Model of the US National Centers for Environment Prediction; UKM – United Kingdom Meteorological Office; NPGS – NOGAPS) have no skill at 12 h and then have skill at 24 h and beyond. From 36 h to 72 h, the NOGAPS forecasts essentially have the same skill relative to CLIP as do the Official (OFCL) NHC forecasts. However, the GFDL model skill is greater by about 10% at 36 h and nearly 20% at 72 h. Although a one-layer model called VBAR has good skill at small forecast intervals, this limited region model provides the least skilful 72-h forecast. Finally, the statistical-dynamic model (A9OL) that was the best track guidance tool in the late 1980s and early 1990s is no longer the most useful. It has been replaced by the GFDL model as the primary guidance tool for the Atlantic tropical cyclones.

Several explanations may be given as to why the Official (OFCL in Fig. 8) NHC forecasts in the Atlantic during 1996 had larger errors than the GFDL track forecasts. First, the GFDL (and other "late" guidance in this diagram) track predictions do not reach the NHC until 4–5 h after the 06 and 18 UTC synoptic times, and thus a comparison with the OFCL forecast issued at the synoptic time give a 6-h advantage to the GFDL model. Second, the GFDL model had been operationally available for only one year (1995) prior to this season. Although the GFDL had been demonstrated to have considerable advantage over other guidance and the OFCL during 1995 (Kurihara et al. 1998), the NHC forecasters needed to gain experience in when and how to utilize this new guidance. It is relatively common that a newly introduced technique will have an advantage for 2–3 years before the forecasters accept and learn to improve on that guidance. Third, it is possible that one track guidance technique will be more accurate for a certain type of storm tracks (e.g., recurvers versus westward movers), and will then appear to be superior if the season has an abnormally large number of cyclone with that track type.

2.3 Eastern North Pacific

This area is the second most active tropical cyclone region in Fig. 1 with 17% of the global total. The NHC (RSMC-Miami) is also responsible for forecasts in this area. A summary of official and CLIP forecast errors during 1996 in comparison with the 1988–1995 period is presented in Fig. 9. Using the CLIP forecast errors as a skill measure, the cyclones in this region

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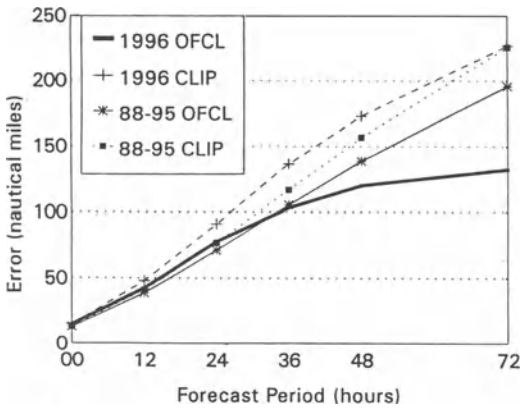


Fig. 9. Official and CLIP track forecast errors as in Fig. 7, except for the eastern North Pacific tropical cyclones during 1996 and the number of forecasts range from 108 at the initial time to 30 at 72 h

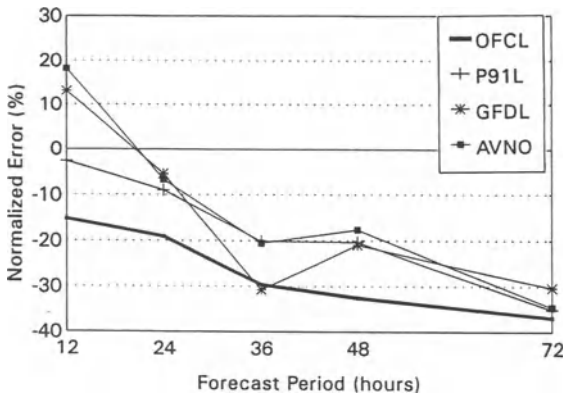


Fig. 10. Track forecast errors normalized relative to CLIP as in Fig. 8, except in the eastern North Pacific during 1996 and the number of forecasts range from 42 at 12 h to 7 at 72 h

are among the most easy (Pike & Neumann 1987). Notice that the 72-h CLIP errors in the eastern Pacific (Fig. 9) are about 225 n mi versus about 350 n mi in the Atlantic (Fig. 7). The larger CLIP errors at 24 h to 48 h during the 1996 season than during 1988–1995 suggests these 1996 storms were more difficult to forecast. Only at 48 h and 72 h is it clear that the official NHC are improved relative to the 1988–1995 period. Although the improvement at 72 h is impressive, it is based on only 30 forecasts, and thus may not be statistically significant.

A normalized comparison of the official forecast errors and the guidance techniques is given in Fig. 10. It is interesting that the GFDL model, which is so skilful in the Atlantic (Fig. 8), does not have skill at 12 h and does not improve as much relative to CLIP with increasing forecast intervals. In general, the errors for the limited-area GFDL model are not much different from the global model (AVNO) that provides the initial and boundary conditions for the GFDL model. A statistical-dynamical model (P91L) also has similar skill as the two dynamical models from 24 h through 72 h. In contrast to the GFDL-OFCL comparison in the Atlantic in Fig. 8, the official NHC forecasts improve on this guidance by about 10% in the eastern North Pacific.

2.4 Southern Hemisphere

It is convenient to summarize the entire western South Pacific and South Indian Ocean using the JTWC performance in this entire region rather than examining separately the three Australian Bureau of Meteorology Centers in Perth, Darwin, and Brisbane plus the RSMC Fiji and RSMC La Reunion statistics. Based on the CLIP track forecast errors as a measure of difficulty, the tropical cyclones in the South Pacific area are the most difficult to forecast in the world (Pike & Neumann 1987). A recent study of Southern Hemisphere tropical cyclones by Bannister et al. (1997) finds common environmental steering circulations in the South Indian and western South Pacific, so that the South Indian Ocean is also a difficult track forecast area. It is also noted that the meteorological observing system to support forecasting in the Southern Hemisphere is not as good as in the Northern Hemisphere.

Both the 24-h (Fig. 11a) and 48-h (Fig. 11b) JTWC error trends indicate improved accuracy since about 1988. However, a distinct two-year signal is superposed on this trend that may be related to the two-year cycle of duty for forecasters at JTWC (Jarrell et al. 1978). Both the 24-h and 48-h track errors for the Southern Hemisphere are larger than in the western North Pacific (Fig. 4).

Another characterization of the Southern Hemisphere track errors is the histogram of 24-h track errors in Fig. 12b, which may be compared with a similar histogram for the western North Pacific in Fig. 5b. Notice that the Southern Hemisphere median (mean) values of 108 (125) n mi are about 20 n mi larger than in the western North Pacific. On a percentage basis, a larger fraction of the Southern Hemisphere forecasts have large errors, e.g., five of

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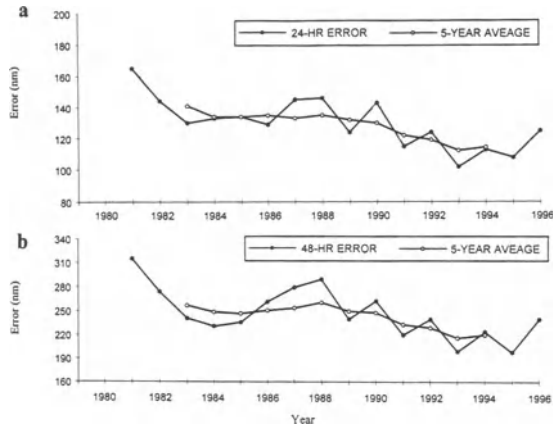


Fig. 11. Mean track forecast errors (n mi) as in Fig. 4, except for South Indian and South Pacific tropical cyclones during 1981 to 1996

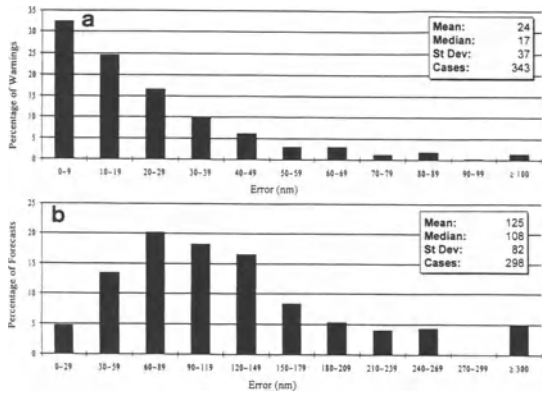


Fig. 12. Frequency distributions at (a) initial warning position and (b) 24-h forecast errors as in Fig. 5, except for South Indian and South Pacific tropical cyclones during 1995–1996

the 298 cases have errors exceeding 300 n mi. Part of the explanation for these larger short-term errors in the Southern Hemisphere is larger initial position errors (Fig. 12a) on which the persistence of past motion forecasts are based. In comparison to the western North Pacific (Fig. 5a), the median initial position error of 17 n mi is about 30% larger in the Southern Hemisphere. As indicated qualitatively by the histogram and quantitatively by the larger standard deviation (37 n mi versus 34 n mi), the uncertainty of the Southern Hemisphere initial positions is greater, which leads to larger short-term forecast errors. This is in addition to the greater degree of difficulty of Southern Hemisphere track forecasting compared to the western North Pacific (Pike & Neumann 1987).

2.5 North Indian Ocean

As noted in the Introduction, this area has experienced great loss of lives from tropical cyclones as recently as 1991. The economic losses are also catastrophic for a developing nation. It is fortunate that such a small fraction (6%) of the global tropical cyclones occur in this region (Fig. 1).

For a matter of convenience and the ability to intercompare with other basins, the JTWC performance (Fig. 13) is used as an indicator of skill in this region, rather than the error summaries for RSMC New Delhi or any of the national weather services affected by these cyclones. Because of the large interannual variability in the 24-h track errors (Fig. 13a), which is in part due to variability in the number of forecasts issued each year, the representativeness of the trend line is uncertain. The tentative conclusion is that the tropical cyclone 24-h forecasts have not improved in the last decade. Similar comments apply for the 48-h (Fig. 13b) and 72-h (Fig. 13c) forecasts by JTWC for the North Indian Ocean, since the numbers of such forecasts are even smaller. Whereas the accuracy of the JTWC 48-h and 72-h track forecasts has been improving in the western North Pacific (Fig. 4) and Southern Hemisphere (Fig. 11), this improvement cannot be documented for the North Indian Ocean tropical cyclones.

One of the practical reasons for the difficulty in forecasting is that many of the tropical depressions and tropical storms in this region originate in the monsoon trough. Consequently, the circulation centers frequently cannot be detected accurately from visible or infrared satellite imagery because of the monsoon cloud obscuration. In addition, the environmental steering flow, which may be a balance between equatorial westerlies and tradewind easterlies, is often not well defined. Finally, the outer wind structure of the cyclone vortex that determines the beta-effect propagation (Elsberry 1995) is not observed well. Given these uncertainties in the factors governing tropical cyclone motion, it is not surprising that the track forecast errors are relatively large considering the (post-storm derived) slow translation speed of cyclones in this region.

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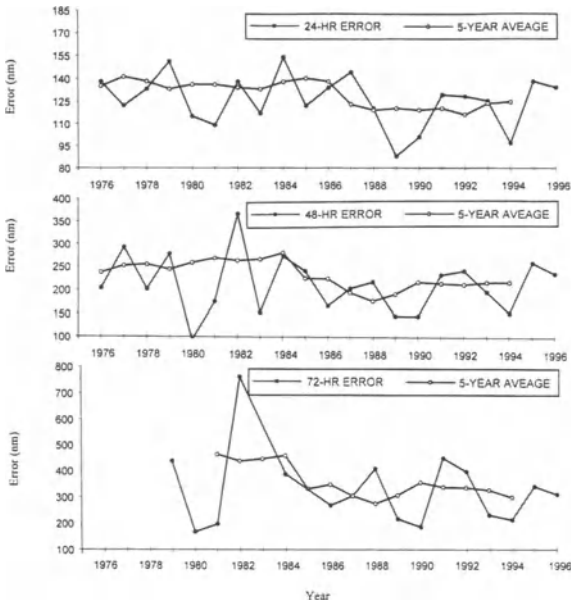


Fig. 13. Annual mean track forecast errors as in Figs. 4 and 11, except for North Indian tropical cyclones during 1976 to 1996

3 How has the Track Guidance Improvement Been Achieved?

A personal perspective on how this improved tropical cyclone track guidance was achieved will be offered here. Such a list cannot be complete given the limited space, and focus will be on selected items that then may indicate where further improvements in guidance materials will arise.

3.1 Understanding Track Motion

A special focus on understanding tropical cyclone motion began in the US during 1986 when the Office of Naval Research (ONR) initiated a five-year research program (Elsberry & Abbey 1991). This program funded research in motion theory, observational studies, and modeling. The timing was such that this research benefited from, and stimulated, on-going efforts in the US NOAA research laboratories, especially the Hurricane Research Division and the GFDL. Participation of forecasters from the JTWC and NHC also contributed to a focus on improving track prediction.

The ONR program also stimulated cooperative international field experiments during 1990 in the western North Pacific (Elsberry 1990). Four experiments were held simultaneously in which data collections were coordinated: US Tropical Cyclone Motion (TCM-90); WMO Typhoon Committee -SPecial Experiment Concerning Typhoon Recurvature and Unusual Motion (SPECTRUM); former USSR -TYPHOON 90; and Taiwan - Typhoon Experiment. Following the experiments, a combined data archive was gathered and distributed to all participants, and ONR provided a gridded analysis based on a four-dimensional data assimilation (4DDA) technique. Indeed, one of the benefits of the ONR program was the development of such a mesoscale 4DDA technique that was effective in the tropics. In addition, the automated techniques for calculating cloud-drift winds from visible and infrared satellite imagery animation were given an initial impetus from Chris Velden and Robert Merrill of the University of Wisconsin preparing high-resolution winds for TCM-90.

The increased understanding of tropical cyclone motion that originated from the combined research efforts in many countries and from the four international field experiments was shared in WMO conferences and national conferences. One simple measure of the new knowledge on motion is reflected in the contents of two chapters in books that were written following the first and third International Workshops on Tropical Cyclones (Elsberry 1987 and 1995). Another reflection of the number of new topics and the depth of the understanding achieved was that the number of motion chapter references in the second book chapter increased to 192, of which 120 were after 1987.

One of the important understandings arising from this research was recognition of the roles of the contributions to tropical cyclone motion (Elsberry 1995): (1) First-order role of the environmental steering flow; (2) Symmetric vortex structure influence on motion; (3) Interactions between the vortex circulation and environment that may lead to systematic deflections of the motion from the environmental steering flow, and the change the environment and subsequent motion. With this understanding came improvements in observations, analyses, and prediction models that have improved the track guidance. Evidence that the forecasters have learned how to better utilize this guidance was provided by the trends toward more accurate tropical cyclone track forecasts in almost all basins during the last decade (section 2).

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3.2 Observations

It is noteworthy that advancements in track guidance have been achieved in the face of alarming degradation of the conventional rawinsonde observations in the tropical regions. To some unknown extent, the improvements in space-based remote sensing have offset the loss of rawinsondes – although it should be noted that special, more frequent rawinsonde launches are requested in the region of tropical cyclones. Because wind is the most important meteorological variable for tropical cyclone motion, the high-resolution cloud-drift wind estimates from satellites have been the most important in defining the environmental steering flow of tropical cyclones. More recently, the water vapor winds from satellite imagery and sounders have improved the horizontal coverage in cloud-free areas, although the vertical resolution is limited. The impacts of the surface wind estimates from scatterometers are being assessed. In many instances, the scatterometer winds provide the first evidence of the presence of the tropical cyclone, and give a solid basis for estimating the size of the gale-force winds, i.e., whether this is a large, average, or small cyclone. Data impact studies of these scatterometer-based winds on numerical model analyses and predictions are in progress.

3.3 Analysis and Data Assimilation

The non-homogeneous distribution of tropical observations in space (horizontal and vertical) and in time makes analysis rather difficult. As indicated above, the decrease in the number of rawinsondes has meant a shift to more space-based observations. Four-dimensional data assimilation techniques have been developed in which these observations, expressed as increments from the 6-h numerical model-predicted values, are blended with the first-guess or background field to define the environmental flow. Recall from section 2a that the JMA attributes the introduction of a new statistical interpolation as a contributor to their improved tropical cyclone track predictions from their GSM. Several centers (e.g., European Center for Medium-range Weather Forecasts – ECMWF, and the US NCEP) have demonstrated that direct use of satellite raw radiances provides a positive impact relative to the prior practice in which the radiance information is inverted to derive a rawinsonde-like vertical temperature sounding. One implication is that satellite radiance information appears to now have usefulness in the tropics is that earlier indications of tropical depression developments are appearing – albeit with a number of false alarms.

Elsberry (1995) describes the techniques used to represent the tropical cyclones in dynamical track prediction models. Introduction of such synthetic observations improves the initial location and vortex structure in the models. Such synthetic observations are used at nearly all global forecast centers. The notable exception is the ECMWF, which not coincidentally has larger initial position errors than the other centers. The US Navy (NOGAPS) and UK Meteorological Office both significantly improved their tropical cyclone track predictions in October 1994 when they added an adjustment to these synthetic observations that incorporated the past motion of the storm.

One of the chief contributors to the success of the GFDL technique has been the initial condition specification of the environment, symmetric vortex, and the asymmetric circulation. This specification made early use of the new understanding of tropical cyclone motion, and further improvement in the representation of the asymmetric circulation based on the most recent forecast is expected during 1998.

3.4 Numerical Models

As indicated in section 2, much of the recent improvements in tropical cyclone track guidance has been attributed to better numerical models. Improvements in horizontal and vertical resolution that were mentioned in section 2 are just one aspect. The better use of observations in the data assimilation, and the introduction of synthetic tropical cyclone observations, mentioned in section 3c are also part of the improved dynamical guidance. Better representations of the physical processes, especially convection, are also important. For example, the JMA found that the introduction of the Arakawa-Schubert cumulus parameterization technique greatly reduced the poleward bias in low-latitude tropical cyclone tracks that had existed in their dynamical models.

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4 Future Strategy for Track Guidance Improvement

4.1 Understanding and Research

Just as the ONR tropical cyclone research initiative stimulated research collaboration with NOAA and other US agencies in the late 1980's and promoted cooperative international field experiments during 1990, some new research opportunities may be opening. In the US, a Hurricane Landfall focus has been developed as a part of the US Weather Research Program (USWRP) that is proposed to begin in October 1999. Although funding levels are not determined yet, the proposal preparations have stimulated discussions on the special research problems and new observational opportunities related to hurricane landfall (Marks et al. 1998). They proposed consideration of a broad range of basic and applied research topics. They also suggested a focused, comprehensive mobile observing system in a translating storm-coordinate system to improve understanding of physical processes and provide initial conditions for predictions/simulations. The USWRP also sponsored a workshop in November 1997 to develop specific research goals and priorities. At the time of this writing, the final workshop report is not available. However, some of the discussions at this Workshop will be included below.

In a parallel development, the WMO has in February 1998 adopted a World Weather Research Programme (WWRP) that contains a suggestion for a Tropical Cyclone Landfall program. The objectives are broadly related to improved short-term prediction of landfalling tropical cyclones, and the assessment of impacts associated with these events. One WWRP strategy is to develop Research and Development Projects (RDPs) that would facilitate integration of weather prediction research advances achieved via relevant national and international programs. For example, the WWRP Tropical Cyclone Landfall program may become involved in the USWRP Hurricane Landfall focus. A stated objective of the WWRP RDP is to demonstrate new forecast capabilities, and transfer technology along with related training.

In summary, new research opportunities appear to be opening that may contribute to future improvements in early warnings of tropical cyclones.

4.2 Observations

Because tropical cyclones develop and move over the data-sparse tropics, efforts must be made to maintain as many rawinsondes as possible in the tropics in the face of rising costs that are exceeding the capability of many developing nations. Similarly, any upgrade in the quality and quantity of existing observations is likely to have benefits. As the dynamic models are improved, the ultimate limitation in tropical cyclone prediction will more and more be the initial data limitations.

New satellite instrument developments that would provide needed winds, moisture, and temperature observations in the tropics should be explored. Combined satellite measurements in multiple wavelengths may provide improved observations from any single instrument. Space-based lidar wind profiles have been proposed, but may be several years away.

A new observing platform that has potential to improve the environmental specification is the Unmanned Aerial Vehicles (UAV). Developments in this area should be followed, especially as related to the tropical cyclone environment. Just two examples are the Aerosonde developed jointly in Australia and the US, which was field tested in Australia during the 1997–1998 season, and the US NASA ERAST program that is developing a Global Positioning System (GPS) sonde capability on a UAV called Altus.

Targeted observing strategies attempt to determine at what locations (horizontal and vertical) and which meteorological variables would most sensitively contribute to a better initial condition specification for dynamical models. This approach could have an immediate application for improving hurricane track prediction guidance from numerical and statistical models, because mobile observing platforms are already available to be directed to the indicated areas. The new US Gulfstream IV jet is a high-speed, high-altitude platform that is equipped with the new Global Positioning Satellite (GPS) dropwindsondes that are providing data of unprecedented resolution and accuracy. In conjunction with the NOAA WP3D research aircraft and the US Air Force reconnaissance aircraft, an outstanding opportunity exists to demonstrate the targeted observing strategies, and improve the initial condition specification for dynamical prediction of hurricane landfall.

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In addition to encouraging the on-going efforts, the research community should be involved in developing targeted observing strategies appropriate to the tropics, and landfalling tropical cyclones in particular. If UAVs could achieve the soundings dictated by a targeted observing strategy, then other nations could also afford and benefit from such observations.

4.3 Analysis and Data Assimilation

The approach considered to be most likely to achieve significant improvements in the track forecast guidance is to improve the initial environmental and vortex specifications in the global and regional dynamical models. A highly promising investment would be in the three- and four-dimensional variational assimilation applications to improve specifically the initial environmental conditions in the tropics. These applications will require development of "forward models" for key observing instruments. Such assimilation research is on-going in many countries because it is believed to be critical to improve the initial analysis throughout the globe. An augmentation may be required especially to encourage direct incorporation of the multispectral water vapor channel radiances for vertical profiling and wind estimation in clear air that is likely to be beneficial to the tropical analysis based on encouraging preliminary studies.

4.4 Numerical Models

Since dynamical model track predictions have become so important in the tropical cyclone forecast procedure, it follows that numerical model improvements should further improve the guidance provided to forecasters. Investment to improve numerical weather prediction (NWP) model guidance may be separated into items that are not specifically related to the tropical cyclone and to tropical cyclone-specific items. Each NWP advancement that leads to better initial conditions and better environmental predictions in the tropics should translate to more accurate tropical cyclone track forecasts. Among the non-cyclone specific items are: (1) Data assimilation, especially three- and four-dimensional variational techniques; (2) Physical initialization of the initial fields with cloud or rainfall distributions from satellites, radar or precipitation gauges (3) Incorporation of water vapor winds and scatterometer winds; (4) Numerical improvements; and (5) Moist physics representations. Since synthetic observations have been inserted in global models to better represent the location and structure characteristics of the tropical cyclone, the cyclone may be tracked (except for weak or dissipating systems) throughout the integration period. The validity and accuracy of the global model track predictions beyond three days needs to be evaluated to determine if useful guidance to the forecaster can be provided.

Although improved dynamical guidance has contributed to the recent decreases in track forecast errors, the dynamical guidance is not always of high quality. A high priority goal is to reduce the outliers in the forecast error distribution (busts). Research studies are needed to characterize and understand the sources of these large track forecast errors. For the longer forecast intervals, the errors may evolve from the poor environmental specifications discussed above. Some examples might include an incorrect phasing between westward-moving tropical cyclones and eastward-moving midlatitude troughs, or multiple storm interactions. One approach has been to develop conceptual synoptic models that appear to provide a basis for categorizing systematic errors and large error scenarios in the track guidance.

It would also be useful for the forecaster to have a reliable prediction of the accuracy of the track guidance. One research approach is the ensemble technique, in which a number of forecasts are made from perturbed initial conditions that hopefully represent the likely initial analysis error distribution. A theoretical basis for the midlatitude ensemble prediction is being developed based on baroclinic instability processes leading to rapid error growth. It is not clear that this theoretical basis applies in the tropics. At least three research groups in the US, Hong Kong, and Australia are applying ensemble prediction techniques to tropical cyclone track forecasting. It would be most beneficial if the spread in the ensemble forecasts about their mean was an accurate representation of uncertainty in the track forecast. If so, the hurricane forecaster could reduce the size of the warned area whenever high confidence

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in the track forecast was indicated. As noted previously, reductions in the overwarned area would avoid unnecessary preparations and increase public confidence in the warnings.

Nearly all tropical cyclones making landfall across warm shallow water, and then being modified by interaction with the land, have track deflections so that the center coastal crossing point departs from a projection of a smoothed offshore track. Although the direct and indirect frictional effects that change the cyclone circulation and convection distribution are a root cause, the modifications of the thermal and moisture distributions are also likely contributors. Numerical model simulations and predictions are needed to understand the relative importance of these processes in these near-coast track deflections. Supporting observational studies, particularly with radar and aircraft data seta are required as well.

5 From Better Track Guidance to Earlier Warnings

As indicated in the introduction, the tropical cyclone landfall warning should include: (1) high wind distribution; (2) heavy precipitation and flooding along the coast and inland; (3) storm surge elevations along the coast and inundation maps where this surge will overtop levees; and (4) severe weather from tornadoes or straight-line winds. Warnings must be timely, in the sense that they must be received in time to complete preparedness activities or evacuations. Warnings need to be accurate with minimal overwarning of areas that will not experience damage. Of the meteorological variables describing the tropical cyclone threat, the track is the most important because it determines which areas will be struck. An accurate track is especially required for the storm surge forecast because variations in ocean bottom topography may result in different surge elevations for different tracks, and the timing of track is critical relative to the time of the astronomical high tide. The track is also critical in determining which river drainage basin will be affected and whether a slowly moving storm will result in large accumulations of rainfall. Clearly, the intensity is important, especially if rapid intensification to the most intense stages (Categories 3, 4, or 5 in the US cause 80% of the damage) occurs just prior to landfall. The special problems related to tropical cyclone intensity will be left to Sir James Lighthill's paper in this chapter.

One of the objectives of this paper has to document the improvements in tropical cyclone track guidance during the past decade. As indicated in section 2, evidence of such an improvement, especially at 48 h and 72 h, is available in all tropical cyclone basins except the North Indian Ocean (based here on the JTWC track forecast error trends – national weather services or RSMC New Delhi may have contrary evidence). Where improvement in track forecasts have been achieved, it is generally attributed to better dynamical track prediction guidance from global or regional models. Present models have finer horizontal resolution and more vertical layers, and better physical representations of the tropical cyclone. Introduction of synthetic observations to better represent the initial position, outer vortex structure, and track direction and speed have contributed to this improved track guidance. Although the number of rawinsonde launches has decreased alarmingly from some tropical nations, satellite-based wind observations have better coverage and accuracy. That is, higher resolution (in space and time) cloud-drift winds and the new water vapor winds have helped. From polar-orbiting satellites, scatterometer surface winds may give an earlier indication of tropical cyclone development, or the microwave imagery may indicate cloud organization that is obscured in the visible or infrared imagery. Direct use of satellite radiances, versus an inversion to derive a temperature profile that resemble rawinsondes, is an example of how the modeling centers are making better use of existing data. One hope for better environmental wind fields for tropical cyclone track prediction is the introduction of three-dimensional and four-dimensional variational assimilation, which is being actively pursued in centers around the world.

Although the model guidance may become more accurate, it may be some years before the forecaster learns how to use this guidance. Because the dynamical model guidances occasionally fails, the forecaster must learn when to not follow the guidance. One problem with the dynamical model guidance is a lack of timeliness, because the track forecast arrives 4–5 h after the synoptic time, and thus cannot be used un-

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til the next 6-h warning. However, several centers now provide global model guidance following the 00 UTC and 12 UTC synoptic times and regional model guidance following the 06 UTC and 18 UTC times. Issues may arise regarding time consistency between the global and regional models, or even the 12-h consistency of the same model. At times, the dynamical model track guidance suddenly becomes poor, and then later suddenly locks onto a much better track. The forecaster needs assistance to recognize both scenarios.

It is emphasized again that only the national weather service (not a regional forecast center) that can issue a warning for that nation. Thus, the local forecaster needs access to the best guidance available from the RSMC, and from the international modeling centers. As indicated above, training in the proper use of such guidance is essential. Only when the local forecaster has evaluated the most likely track, and considered carefully the likelihood of other possible scenarios in view of the track uncertainty, can he/she add the essential local knowledge of topography, risk factors of the public/industry, etc., that must be a part of the warning. Special storm surge or heavy precipitation and flooding warnings require this local knowledge. Evacuation and other disaster preparedness plans also require local expertise.

The above discussion has only considered the meteorological aspects of the tropical cyclone warnings. Although the outlook for more accurate and earlier warnings is good from this perspective, this discussion has not considered the essential step of communication and coordination with the users of the warnings. Much can be gained by improved knowledge of user needs with respect to tropical cyclone warnings – what is the most important meteorological parameter for each class of user and what benefit would be achieved by a possible increase in forecast accuracy? Critical communication deficiencies must be addressed because an accurate and timely warning is of no use if it does not reach those at risk. Education of the users as to the meaning of, and possible uncertainties in, tropical cyclone warnings is also essential if the maximum benefit, i.e., minimal damage and loss of life, is to be achieved when a tropical cyclone does strike.

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The Tropical Cyclone Warning System in the Southwest Pacific

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1 Introduction

Tropical cyclones are frequent visitors to the North and South Pacific Ocean. In the Southwest Pacific region (south of the equator from the east coast of Australia to French Polynesia), approximately eight cyclones occur on average each year during the tropical cyclone season, which runs from November to April inclusive. The variability in tropical cyclone occurrence is high, ranging from as few as two (e.g., 1990/91) to as many as eighteen (e.g., 1997/98). Much of this variability is attributed to the influence of the El Niño/Southern Oscillation (ENSO) phenomenon as the warm oceanic waters move eastward and contribute to more favourable formation conditions.

In recent times, many Pacific Island nations have suffered the impacts of tropical cyclones including death and destruction that have severely arrested economic and social development. By virtue of their geography, Southwest Pacific island nations and territories are highly vulnerable to tropical cyclone impacts. Often entire islands and even entire nations are devastated during cyclone impacts. The social and economic prosperity of Southwest Pacific island countries and territories is generated through activities that are particularly vulnerable to tropical cyclones, such as agriculture, forestry, fishing, and tourism.

The South Pacific region is home to some 16 island nations and territories (Fig. 1). They range from island archipelagos with substantial land area such as Papua New Guinea (462 000 km^2) and Fiji (18 000 km^2) to single atolls such as Nauru (21 km^2). The entire population of the region is less than 6 million people, and over 80% of this number are settled in Papua New Guinea and Fiji. The South Pacific is home to three distinct groups of indigenous peoples: the Melanesians, Polynesians, and Micronesians. Within the islands there are significant differences in language, culture, and social order. As well as the indigenous people, there are significant populations of Chinese, Indian, and European people on some islands.

Traditionally, the vast expanses of ocean meant that communication between islands and peoples was difficult. In recent times, the advent of satellite technology and air transport has improved communication. However, providing such communication infrastructure for so many islands with so few people is very expensive, and as a result contacts between island communities remain limited. Similarly, the lack of resources and land necessitates a high level of reliance on foreign materials for economic activity. Regional cooperation is commonly used to minimise or alleviate these costs.

A number of programs and institutions have been established to handle the economic, social, environmental, and educational requirements of the region. The political leaders in the region maintain on-going dialogue to foster regional cooperation through consensus in order to catalyse national development.

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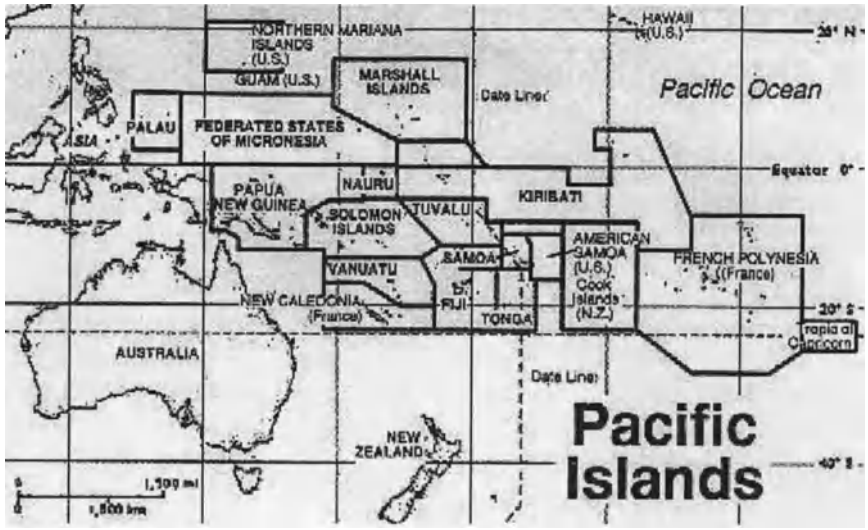


Fig. 1. Map indicating the locations of some of the Southwest Pacific island nations served by the RSMC-Nadi Tropical Cyclone Centre

2 Regional Specialised Meteorological Centre Nadi–Tropical Cyclone Centre (RSMC Nadi–TCC)

2.1 Roles and Responsibilities

In June 1995 the World Meteorological Organisation (WMO) executive council approved the designation of the Meteorological Center in Nadi, Fiji as an RSMC joining Miami (USA), Tokyo (Japan), New Delhi (India), and La Reunion (France), to provide a combined global coverage of tropical cyclone warning and advisory services. Under WMO guidelines, the RSMC Nadi–TCC is responsible for issuing advisories on tropical cyclones in the broad area south of the Equator extending from the east coast of Australia to the French Polynesia and beyond. However, due to existing arrangements between Nadi and other centres (New Zealand and Brisbane) in the Southwest Pacific, Nadi's primary area of responsibility now covers *Equator to 25*°S and 160°E to 120° W.

RSMC Nadi–TCC names and tracks all tropical cyclones in this area and issues regular tropical cyclone and other warning and advisory services for the marine and public interest and safety. Marine forecasts for international waters are issued twice daily, while high seas warnings are issued six-hourly or whenever necessary. These products are disseminated on the Global Telecommunication System (GTS) circuit and also broadcast at regular intervals from the marine radio transmitting station in Auckland, New Zealand.

As a RSMC, the Centre issues twice daily a *Tropical Disturbance Summary* on any significant disturbance(s) in the area, and six-hourly *Tropical Disturbance Advisory* bulletins on named systems and also on tropical depressions that are likely to form into tropical cyclones. These bulletins are sent to all National Meteorological Centres (NMC) in the region and are intended to update them with information concerning the current and forecast situation of the cyclone. The bulletin contains sufficient information to allow the NMCs to compile and issue their own domestic warnings, forecasts, and briefing statements, for disaster management authorities.

2.2 Tropical Cyclone Advisory and Warning System

The cyclone advisory system adopted for RSMC Nadi by the Tropical Cyclone Committee for the South Pacific and Southeast Indian Ocean (RAV) is described in the Operational Plan for the region. The system has two phases:

ALERT is issued six-hourly to give information on the development of an incipient cyclone or on the progress of a cyclone still some distance away.

- Indicates the significant probability that a cyclone could cause gale force or stronger winds over part of a country within 48 hours from the time of issue of the bulletin.
- Is intended to place the community on alert and give enough daylight hours to check their preparedness and take precautions, as necessary.

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WARNING tropical cyclone warnings are issued generally every three hours for **specific areas** as:

- **Gale Warning** if sustained winds *over 33 knots and up to 47 knots* are expected in the area within 24 hours.
- **Storm Warning** if sustained winds are expected to range *between 47 and 63 knots* in the area within 24 hours.
- **Hurricane Warning** if sustained winds *over 63 knots* are expected in the area within 24 hours.

All alerts and warnings are issued in the form of *Special Weather Bulletins*. In addition, Nadi provides six-hourly *Special Tropical Disturbance Advisories* to the Vanuatu Tropical Cyclone Operational Centre. This advisory serves the same purpose as the Tropical Disturbance Advisory. However, it contains general comments with reference to geographical locations that would be affected by the cyclone.

2.3 Preparation of Warnings and Advisories

After recent upgrading of software systems at the Fiji Meteorological Service (FMS), possible through the generous aid from the Government of Japan, Nadi is now equipped with the latest technology and computer systems that are comparable to any other meteorological centre in the world. The FMS used to have only the high-resolution Geostationary Meteorological Satellite (GMS) imagery and three hourly low-resolution Geostationary Orbiting Environmental Satellite (GOES) imagery, which was not enough to cover any cyclone(s) east of 160°W. However, Nadi is now able to receive high-resolution imagery from both geostationary satellites every hour, which provides full coverage of the Nadi area of responsibility. In addition, the centre receives real time high-resolution images from polar-orbiting U.S. NOAA and Russian Meteor series satellites twice daily.

RSMC Nadi does not have a tropical cyclone prediction model of its own. Real-time bulletins and advisories are received from other meteorological centres that help in decision making. Some centres from which Nadi receives these bulletins include: PGTW – Joint Typhoon Warning Centre, Guam; KGWC – Global Weather Centre, Nebraska; PHNL – U.S. National Weather Service, Honolulu; KWBC – U.S. National Meteorological Centre, Washington; and ABRF – Tropical Cyclone Warning Centre, Brisbane. These advisories contain position and movement, an intensity estimate (Dvorak T-no.), and brief descriptive comments on the cyclone and have proved very useful for the RSMC Nadi.

Tropical cyclone forecasts are based on climatology and persistence and are heavily dependent on numerical model guidance received from other meteorological centres. A five-day tropical cyclone motion forecast is received from Bracknell, UK Meteorological Office twice a day. A warning to 72 hours is received from JTWC in Guam, which contains information such as cyclone position, intensity, and wind distribution, forecast position, and other descriptive comments. In addition to these products, global model guidance from the U.S. AVN model, ECMWF model, and Australian GASP model are also used.

2.4 Dissemination of Products

Product delivery is an essential part of a Tropical Cyclone Warning System as warning information loses value rapidly if the community cannot access it in time. Therefore, an effective and efficient means of communication must exist. Since most countries in this region depend on tropical cyclone forecasts and warnings from Nadi, a reliable communication network has to be maintained between the countries to ensure that the products reach the people in sufficient time for preparation. A primary objective of the ACP/EU Project[1] to upgrade facilities and equipment in the Southwest Pacific countries so that warnings can be delivered quickly has now been accomplished. The introduction of the Emergency Managers Weather Information Network (EMWIN) is an example of what has already been done.

The communication network in the widely spread Southwest Pacific islands has made great progress in recent years. The introduction of a GTS link between Nadi and Melbourne, Australia has increased the amount and speed of data being transmitted. Nadi is connected to all countries in the region via the Aeronautical Fixed Telecommunications Network (AFTN).

[1] ACP/EU Project: Cyclone Warning Upgrade Project for US$ 2 million funding from 1996 to 2000.

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The Fiji Meteorological Service (FMS) products are now available to the users through the GTS, AFTN, fax, electronic mail, Internet Web pages, and telephone.

Dissemination of forecasts and warning products within each country is a function of the communications infrastructure and warning systems of the individual countries. Upon receipt of a bulletin from Nadi, the responsibility for its internal distribution lies with the national authority, which is usually its Meteorological Service. The Pacific Island countries have made great efforts to improve the common communications systems such as telephone and facsimile within their countries. However, a lot remains to be done in this area.

2.5 Public Response

As for any other region in the world, tropical cyclone response in the Southwest Pacific depends greatly on public education and awareness. This responsibility lies with the authorities of the individual countries. While all Pacific island people have learned to live with the threat of tropical cyclones, it is still important to ensure that information intended for the public is easily understood.

A Disaster Awareness Week is organised by the disaster awareness committee prior to every cyclone season and is conducted in all towns, cities and schools. They generally provide information on what preventative measures to take when a cyclone alert/warning is issued. It is also meant to educate the general public on the meaning of the weather terms in relation to the strength of the winds. Steps are continuously being taken to address this problem, with meteorologists and disaster managers working together to develop guidelines for basic information in warnings that can be understood by all.

3 The Regional Tropical Cyclone Warning Service

In addition to its RSMC responsibility, FMS provides weather forecasts two to three times daily for the coastal waters and land areas of nearby South Pacific Island nations. Countries for which such a service is provided are Kiribati (including Banaba), Tuvalu, Niue, Tonga, Wallis and Futuna, Samoa, Tokelau and Northern and Southern Cook Islands. These countries possess little or no forecasting capabilities of their own and, in most cases, the information from Nadi is the only source of information available to them.

Traditionally, as one of the larger and more developed countries in the region, Fiji has assisted the smaller countries by providing such information as part of our daily duties. Such an arrangement is unusual and possibly unique to this region. While it represents prudent use of the resources available, some difficulties arise because of this arrangement. Perhaps the most significant is the need to maintain continuous and reliable communication of meteorological information between island countries.

Such communication links are required to ensure that all synoptic data are received in Nadi, and that the forecast and warning bulletins can be sent from Nadi to the country requiring this information. In the past, there have often been problems due to unreliable communication that have led to the late arrival of information. In such cases, delays in warnings have resulted in confusion and in some cases inappropriate response by the local community. Significant efforts are presently underway to improve regional communication and, thus, to reduce such problems.

Once a tropical cyclone warning from Fiji reaches the country under threat, it becomes a national issue. The local meteorological service and disaster management centre will liaise to determine the best response to the information from Nadi. The warning message from Nadi is first translated from English into the local language(s). Additional information relating to community response and actions may be added before warnings are broadcast locally.

4 Conclusion

The problems associated with such a tropical cyclone warning system are common to every basin. However, it may be more pronounced in the Southwest Pacific region due to its geography and location of the widely spread small island nations. Measures have been taken in the past to improve the existing system so that warning information provided by the RSMC Nadi–TCC is available to the users in time for action.

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This is an ongoing process and further improvements are expected in the future. Tropical cyclone detection and monitoring capabilities have greatly increased since the upgrading. With the upgrade of computer equipment, reporting facilities (mainly automation) and infrastructure, Nadi has improved its capabilities in analysing, tracking and forecasting movements of tropical cyclones. The increased satellite coverage of the RSMC area of responsibility, especially east to 160°W, is expected to improve significantly the detection, positioning, and analysis capabilities of the cyclone centre. The aim is to achieve an effective early warning system for the Southwest Pacific that would minimise the impacts of tropical cyclones in the region.

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CHAPTER 4.5

Early Warning System for Tropical Storms in India

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Abstract

The cyclone warning service of India Meteorological Department (IMD) is more than a century old. Cyclone warnings are provided by IMD from the Area Cyclone Warning Centres (ACWCs) at Calcutta, Chennai and Mumbai and Cyclone Warning Centres (CWCs) at Bhubaneswar, Visakhapatnam and Ahmedabad. IMD has developed the necessary infrastructure to originate and disseminate the cyclone warnings at appropriate levels. It has operationalised a satellite based communication system called Cyclone Warning Dissemination System for direct dissemination of cyclone warnings to the cyclone prone coastal areas. IMD runs operationally limited area Analysis and Forecast System (LAFS), based on OI analysis and limited area, PE model, to provide numerical guidance. Forecasting of Tropical Cyclones (TCs) is done mainly through conventional synoptic methods. This paper describes the facilities available in IMD for TC analysis and forecasting, the warnings and bulletins issued by it, the numerical model in vogue and lastly a case study of the recent Gujarat Cyclone of June 1998.

1 Cyclone Warning Services

The extensive coastal belts of India are exposed to TCs which originate in the Bay of Bengal and the Arabian Sea every year. These TCs, which are accompanied with very heavy rain, gales and storm surges popularly known as 'tidal waves', cause heavy loss of human lives and cattle, and damage to standing crops and other livestock.

It is the endeavour of IMD to minimise these losses by providing early warning of the TCs. Cyclone warning is one of the most important functions of the IMD and it was the first service undertaken by the department. Cyclone warning for the different sectors of coast line and maritime states are provided by the respective Cyclone Warning Centres. The complete cyclone warning work is supervised and coordinated on a real time basis by the Forecasting Division at Pune. A Cyclone Warning Division (CWD) has been set up at New Delhi to coordinate and supervise the complete cyclone warning programme in the country. Information on cyclone warnings is furnished on a real time basis to the control room set up in the Ministry of Agriculture, Government of India. Along with other Ministries & Departments of the Government, the CWD advises the Government of India at the Apex level. Furthermore, the CWD New Delhi also serves as RSMC – Tropical Cyclones under the World Weather Watch Programme of WMO.

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In addition to the above, the Cyclone Warning Division also has the following functions at the International level:

1. To serve as RSMC – Tropical Cyclones New Delhi.
2. To implement the Regional Cyclone Operational Plan of WMO/ESCAP Panel on Tropical Cyclone.
3. To prepare a yearly comprehensive scientific report on cyclones in the North Indian Ocean.
4. To issue daily Tropical Weather Outlook for the North Indian Ocean (the Bay of Bengal and the Arabian Sea) to the Panel Countries.
5. To provide Cyclone Advisories four to five times a day to the Panel Countries, Thailand, Myanmar, Bangladesh, Pakistan, Sri Lanka, Maldives and Oman.

2 Radar and Satellite Facilities

High power Cyclone Detection Radars (CDRs) installed along the coastal belt of India, have proved to be a very useful tool to the cyclone warning work. CDRs are now functioning at Calcutta, Paradeep, Visakhapatnam, Machilipatnam, Chennai, Karaikal, Goa, Mumbai, Bhuj and Cochin. These radars can locate and track approaching TCs within a range of 400 km. As the tracking of the cyclones using radar has proved very successful, it is planned to replace the old Cyclone Detection Radars with modern Doppler Weather Radars.

Satellite imagery received from weather satellites is extensively used in locating the development and movement of TCs over oceanic regions particularly when they are beyond the range of the coastal radars. Apart from facilities for receiving low resolution satellite pictures at Bhubaneshwar, Mumbai, Calcutta, Guwahati, Chennai, Pune and Vishakhapatnam, Advanced Very High Resolution Radiometer (AVHRR) facilities are available at Delhi and Chennnai for monitoring high tresolution cloud imageries from the polar orbiting satellites. These cloud pictures from the cyclone field have proved very useful in the tracking of the cyclonic storms.

India made a tremendous leap forward in 1980s by launching geostationary Indian National Satellites (INSATs). Cloud imagery of currently operational INSAT-1D is received round–the–clock at the INSAT Meteorological Data Processing System (IMDPS) at New Delhi. The processed cloud imageries are transmitted by IMDPS to the 27 Secondary Data Utilisation Centres (SDUCs) of the Department. A variety of numerical products are currently routinely being derived from INSAT data.

Preparations are in full swing for reception and processing of meteorological data from the more versatile INSAT-2E satellite scheduled to be launched towards the end of this year. In addition to visible and infrared data, water vapour imagery will also be available from this satellite which will carry an additional payload Charge Couple Device (CCD) to provide 1.0 km imagery in two visible and one shortwave infrared channel.

3 Conventional Network

In addition to 559 surface observatories, which provide at least two synoptic observations every day, IMD operates 65 Pilot Balloon Observatores, 34 Radio-Sonde/Radio-wind observatories, one Radio-Sonde Observatory for upper air data. National Institute of Oceanography (NIO), Goa operates a few drifting buoys and the Department of Ocean Development (DOD), Govt. of India has installed 12 buoys in the north Indian ocean for making meteorological and oceanographic observations under the National Data Buoy Programme (NDBP).

Four High Wind Speed Recorders (HWSRs) were installed and commissioned at Paradeep, Karaikal, Vishakhapatnam and Machilipatnam. The data from these will be utilised for the assessment of maximum wind and gust associated with cyclones. It is planned to augment the network of HWSRs.

4 Bulletins and Warnings

The following is the broad list of bulletins and warnings issued by Cyclone Warning Centres for their respective areas of responsibility:

1. Sea Area Bulletins for ships plying in coastal areas and high seas.
2. INMARSAT bulletins under the new GMDSS programme of WMO.
3. Port and Fisheries Warnings.
4. Two stage warnings for State Govt. Officials.

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5. All India Radio and Press Bulletins.
6. Warnings for the Album Page Warnees and Aviation.

Cyclone warnings are communicated to Govt. officials using all available telecom facilities. Police Wireless are also used when possible. The cyclone warnings are issued to State Govt. officials in two stages. According to the "Two Stage Warning Scheme" the collectors of coastal and few immediate interior districts and the Chief Secretary of the concerned maritime State are warned in two stages whenever any coastal belt is expected to experience adverse weather (heavy rain/gales/tidal wave) in association with a cyclonic storm or a depression likely to intensify into a cyclonic storm. The first stage warning known as "Cyclone Alert" is issued 48 hours in advance of the expected commencement of adverse weather over the coastal areas. The second stage warning known as "Cyclone Warning" is issued 24 hours in advance. There has been a vast improvement in forecasting techniques and cyclone warning services in recent years. This helped in the considerable reduction of the loss of human lives and damage to properties caused by cyclones. The warning services provided by the Department in recent years were highly acclaimed by the Government and the media.

5 Cyclone Warning Dissemination System (CWDS)

In addition to the existing mode of dissemination of cyclone warnings to various State Governments, P&T Officials, port officials etc. through high priority telegrams, telephones, Telex and Fax by IMD a new scheme called the Cyclone Warning Dissemination System (CWDS) using INSAT was implemented for coastal areas of South Andhra Pradesh and North Tamilnadu in December, 1985 by establishing 100 CWDS receivers. State Government officials of Andhra Pradesh found this scheme useful especially in rural areas. This communication method is more reliable as they do not use terrestrial links which are disrupted during severe weather conditions.

After the successful demonstration of this scheme in the limited area of Tamilnadu and South Andhra Pradesh, it has been extended to other cyclone prone coastal areas. So far, about 250 CWDS receivers have been installed in the cyclone prone areas of the east and west coasts.

6 Operational Cyclone Analysis and Forecasting

6.1 Conventional and Numerical Analysis and Forecasting

IMD is running a limited area Analysis and Forecast System (LAFS) on CYBER-2000U operationally. The requirements of early warning of tropical storms are mainly carried out by conventional empirical analysis and forecasting. Surface analysis of tropical cyclones is done manually by taking into consideration all the ships, buoys and rigs data and also data from the adjoining land stations. Surface data are usually lacking in the sea areas. The satellite imagery is analysed on anhourly basis and the position and intensity of the tropical disturbances estimated from the satellite imagery is taken into consideration in estimating central pressure. For upper air analysis, data from upper air observatories and non-conventional sources such as SATOB and SATEM reports and also AIREPS extracted from GTS stream are taken into consideration. Apart from the objective analysis scheme discussed in the subsequent section, manual analysis of this upper air data is also performed. Analogue, persistence, climatology and cliper models are run for predicting movement of tropical storms. The average 24 h track forecast error is about 175 km in the analogue model and over 200 km in all other models. The position forecast becomes much worse at 48 h when the error exceeds 500 km.

For storm surge forecasting, nomograms (Ghosh, 1977) are used to compute surge at different places along east and west coasts of India. Storm surge forecast requires a good TC model that uses available meteorological parameters such as minimum (estimated) central pressure and radius of maximum winds. Though several methods have been tried by research workers for surface wind specification in the operational scenario, the maximum wind estimate determined from satellite imagery is used to compute peak storm surge likely near the point of landfall of TC.

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6.2 Satellite Imagery Analysis

The Dvorak (1984) technique for TC intensity analysis has been in vogue in IMD also. The most intriguing aspect of the evolution of TCs is the genesis because it is least understood. As in other tropical oceanic basins, even in the Indian seas, preexisting convective disturbance consists of loosely organised cluster or group of clusters which evolve over meso-time scale and is usually not seen after a day or so (Kalsi 1993). The persistence of convection was seen as the first sign of cyclogenesis. The initial development seems to be triggered by large-scale surges in the equatorial westerlies and trade wind easterlies. The eye usually appeared as a rain band pattern at the hurricane stage first in the VIS and later in the IR or enhanced IR imagery (Kalsi, 1993). Although the eye is seen in the radar imagery in the pre-hurricane stages in most cases in the Bay of Bengal, it is seen in the VIS and IR satellite imagery only after the hurricane stage has been reached. Kalsi et al. (1996) have documented structural variability of tropical disturbances using satellite imagery. Kalsi et al. (1993) showed in a particular case of the Machilipatnam cyclone of May 1990, the persistent double eyewall that was seen in the radar imagery continuously for about 48 hours. Raghavan (1997) has also studied and documented numerous cases of development of eyewall and other structures in TCs from the radar imagery. Multiple eyewall structures have been observed only in two intense TCs in the satellite imagery which had an intensity of super hurricanes and which also had a high Outer Core Strength (OCS) as per Table 1 on some aspects of 9 intense TCs in the Bay of Bengal discussed below. Although the Dvorak technique has been widely used for intensity analysis, satellite based motion techniques have not gained wide acceptance. A mass of middle-level cloud streaming poleward is seen in association with cyclones deflecting towards north/northeast

7 Some Aspects of a few Intense Tropical Cyclones in the Bay of Bengal

Although only 7 per cent of the global crop of TCs are spawned over the north Indian ocean, some of them acquire deadly proportions owing to the convergent shape of the coastline, the shallow offshore waters and the high density of population which gets exposed to the fury of these TCs. Owing to the limited extent of the two basins of the north Indian ocean, the problems of recurvature and looping as seen in some other basins are not that acute in the Bay of Bengal and the Arabian Sea. Similarly episodes of double eyewall cycles and their interactions that exercise a powerful control on the intensity of TCs have been very few in these basins. Double eyewalls were not seen in small core intense TCs such as the Kavali TC of November 1989 and Sriharikota TC of November 1984. However, Sriharikota TC developed double eyewall characteristic after landfall. Their OCS and gale force wind area were also relatively smaller as compared to some other intense TCs as seen in the Table on some aspects of 9 intense TCs. These are the TCs that formed in the current quarter of this century for which full satellite and radar surveillance is available. Their intensities though estimated largely through interpretation of satellite imagery using the Mishra and Gupta (1976) technique have been well documented. Chirala TC of 1977 has been the most intense TC in the Bay of Bengal as per IMD records. The pressure deficit in the earlier TCs of 1864, 1876, 1885, 1927 and 1942 were not as high as in this TC. The total elevation of sea surface was 40 feet in the case of Backergunge TC of 1876 in which storm surge itself was of the order of 30 feet (Eliot, 1890). It was a TC with a pressure deficit of about 80 hPa whereas in the False Point TC of 1885 with a pressure deficit of about 90 hPa the storm wave above mean sea level was 22 feet. Although the storm surge in the Chirala TC of 1977 was only 5.2 m, the winds were the strongest of all the TCs that have formed in the Bay of Bengal as per the records of IMD. This TC had the pressure deficit of 97 hPa. The lowest pressure ever recorded by a ship was 912 hPa in the eye of the Machilipatnam TC at 12 UTC of 8 May 1990 while the satellite derived estimate for the same was 920 hPa.

8 Recent Gujarat Cyclone of June, 1998

It developed as an onset vortex at the leading edge of monsoon. A depression formed over the south-east Arabian Sea on the evening of 4 June. It intensified into a Cyclonic Storm on

Table 1. Some Aspects of a few Intense Cyclones in the Bay of Bengal

S.No	Cyclone	T. No	Peak Intensity (m/sec)	Pressure Deficit (hPa)	OCS (m/sec)	Size (km) [Diameter of area of 17 m/sec wind]	Peak Surge (m)	Loss of human lives	Loss of property (millions of Indian Rupees)
1.	Chirala Cyclone of November 1977	7.0	70	97	28.5	750	5.2	10 000	3500
2.	Machilipatnam Cyclone of May 1979	6.0	58	66	22.2	600	3.5	700	1700
3.	Sriharikota Cyclone of November 1984	6.0	58	66	11.5	300	3.2	604	4000
4.	Bangladesh Cyclone of November 1988	6.0	58	66	28.4	800	4.5	2 500	1377 [India] 9400 [B'desh]
5.	Kavali Cyclone of November 1989	6.5	65	80	10.3	250	3.5	51	140
6.	Machilipatnam Cyclone of May 1990	6.5	65	80	23.2	550	3.5	967	22 480
7.	Bangladesh Cyclone of April 1991	6.5	65	80	23.0	500	6.0	138 882	
8.	Kakinada Cyclone of November 1996	4.5	38	29			2.5	978	21 500
9.	Porbandar Cyclone of June 1998	5.0	50	40	17.0	470	2.0	1257	13 340

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5th June over the same area. It further intensified into a Severe Cyclonic Storm on 6th evening. Moving northwards, it intensified into a Very Severe Cyclonic Storm on 7th afternoon about 700 km south-west of Mumbai. While continuing to move northwards, it deepened further with estimated core winds of 140 to 180 km/h on 8th evening, 350 km south-west of Porbandar. The system recurved and crossed the Gujarat coast near Porbandar on 9th June. The maximum wind recorded (>98 knots) at Jamnagar was higher than that at Kandla (85 knots). Similarly lower pressure has been recorded at Jamnagar in comparison to Kandla. But as the cyclone moved with a speed of about 20 km/h before landfall, the CDR at Bhuj could be used only for a couple of hours before landfall before being flooded. The radar images obtained from 0530–0730 hours on 9th June showed no closed eye which usually appears in cyclones with much less intensity. In this case, the CDR Bhuj observed 5 to 6 spirals of length less than 180 deg. INSAT imagery continuously displayed solid dense overcast. The eye was seen in the satellite imagery though it was not very sharp and clear. The satellite derived intensity estimate was T 5.0 on the Dvorak scale which means a maximum sustained wind speed of about 165 km/h before landfall. The track of this TC along with 24 and 48 hour forecast positions (Fig. 1) is discussed in the next section.

These has been no case of a TC in this region which after making a landfall near Porbandar, seems to have maintained its fury even after crossing Saurashtra. It is interesting to note that winds experienced at Jamnagar and Kandla were stronger than at Porbandar. The residencey period of this TC on the Gulf waters was about 3 hours. The width of the water channel (Gulf) was less than three fourth of a degree. The maintenance of the intensity of this TC over land seems to be enigmatic.

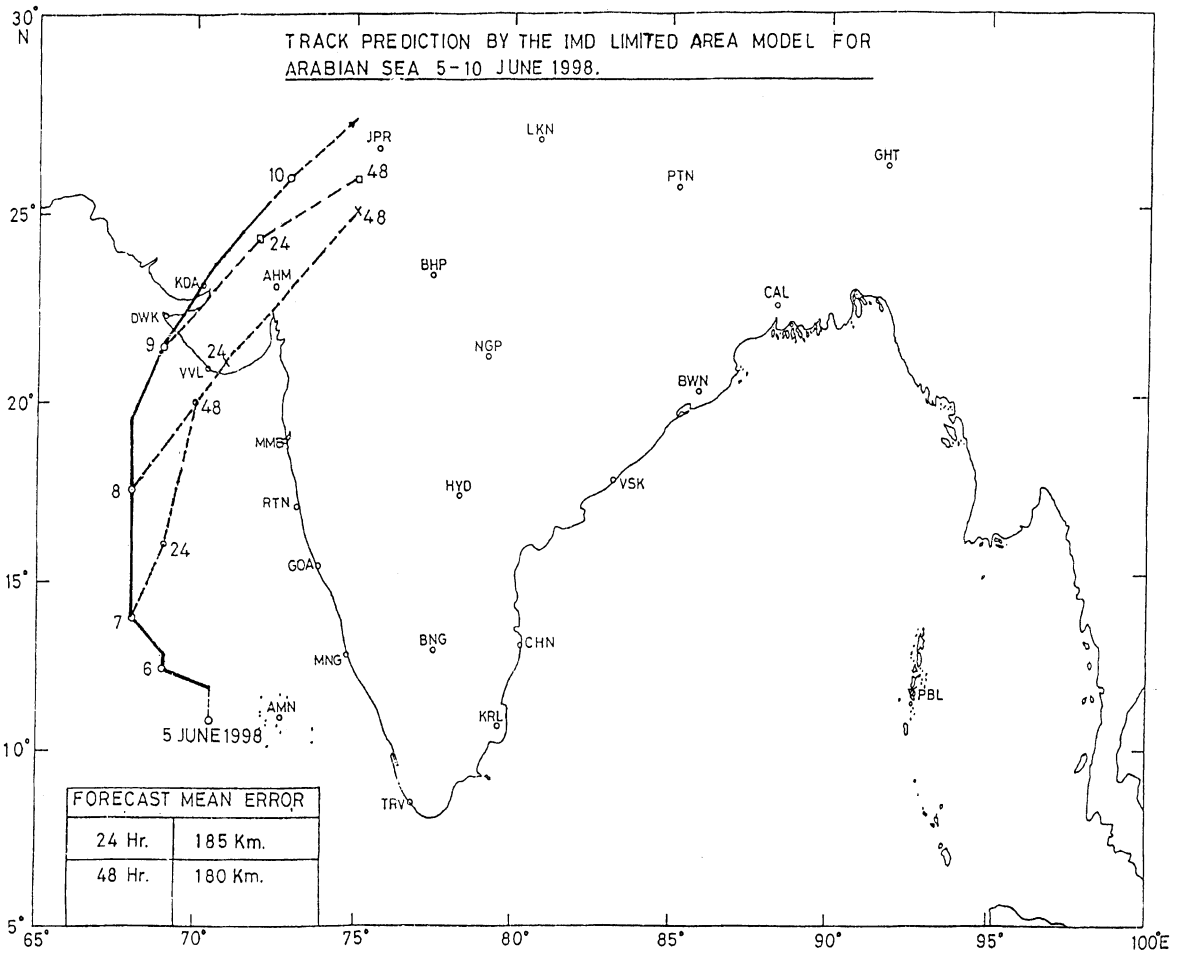


Fig. 1. Track Prediction by the IMD limited area model for Arabian Sea 5-10 June 1998

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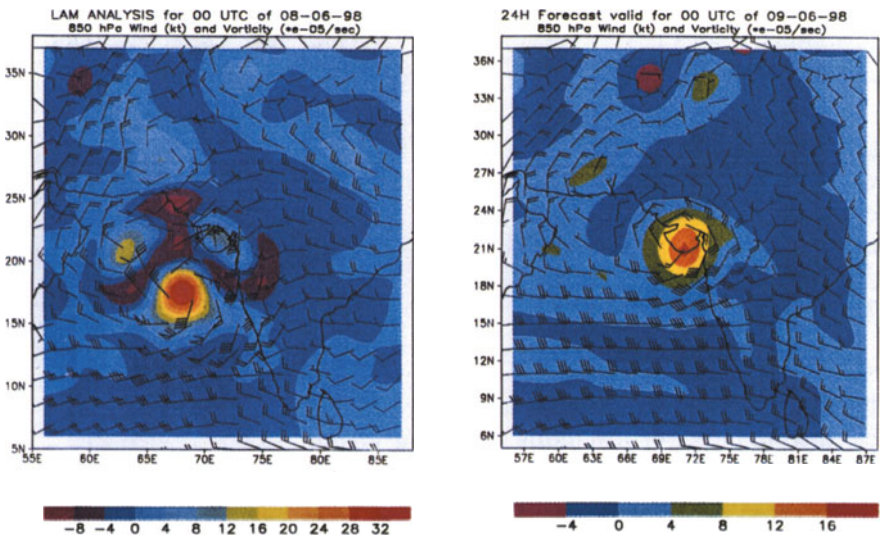


Fig. 2. LAM Analysis for 00UTC of 08-06-98 24h forecast valid for 00UTC of 09-06-98

Mandal and Gupta (1992) have produced pressure and wind profile for several intense TCs using the analytical model of Holland (1980). Computation for the Gujarat Cyclone of June 1998 indicate that its OCS was larger than that of the intense Kavali TC of November 1989 and the Sriharikota TC of November 1984. There are other interesting aspects of this TC. The rainfall over Gujarat was also insignificant although it was fed by the monsoon current. Further landfall occurred on a full moon day when an astronomical tide of 6–7 metres was also expected. There were varying versions of the storm surge that inundated large tracts of the Salt-Pan area, where 935 human lives of poor salt-pan workers perished. The total damage caused to property in Gujarat amounts to rupees 1334 crores. Besides causing enormous damage to life and property in Gujarat, the Cyclone also caused 12 deaths and huge loss of livestock in Rajasthan where it eventually dissipated.

9 Limited Area Analysis and Forecast System

Prasad et al. (1995) discussed details of a Limited area Analysis and Forecast system (LAFS) run operationally by IMD. It consists of an automated data decoding procedure, a multivariate optimum interpolation scheme of objective analysis and a high resolution (10×10 lat/long. Grid) multi-layer (12 sigma levels) primitive equation model. It runs in operational mode on a Cyber 2000 U computer system in IMD, twice a day based on 0000 UTC and 1200 UTC inputs. The analysis system used observational data from surface (SYNOP/SHIP), Upper air (TEMP/PILOT), satellite (SATEM/SATOB) and aircraft (AIREP) which are extracted and decoded from the raw GTS data sets. All the data are quality controlled and packed into a special format for objective analysis. First guess and lateral boundary data files are constructed from the global model forecasts run by the National Centre for Medium Range Weather Forecasting (NCMRWF).

The forecast model is a semi-implicit semi-Lagarangian multilayer primitive equation model cast in a sigma coordinate system and staggered Arakawa C-grid in the horizontal. The present version of the model has a resolution of 1°×1° lat/long. (91×51 grid; covering a domain 10°S–40°N and 40°–130°E) in the horizontal and 12 sigma levels (1.0 to 0.05) in the vertical.

A synthetic vortex generation scheme is applied for the numerical forecasting of TCs. The scheme basically generates radial distribution of surface pressure within the vortex from an empirical formula proposed by Holland (1980). Basic inputs for generating the surface pressure are paramters such as central pressure of the storm, its environmental pressure, radius of maximum wind, current position, movement and intensity of the storm, which are inferred from the surface synoptic charts and satellite imagery, Fig. 1 shows the actual tracks and 24 and 48 hour forecast positions of the Gujarat

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cyclone. Fig. 2 indicates the synthesized wind and vorticity field on 8 June and the forecast on same fields on 9 June, 1998. The track error for a few forecast runs made for this TC was less than 200 km. The LAM model has skill which is comparable to other similar models being operated elsewhere.

10 Conclusions

Satellite imagery has become a powerful tool for cyclone analysis and forecasting. No tropical disturbance worth naming has been missed after the launch of the INSAT programme. A fairly reliable estimate of the intensity of tropical cyclones has been yielded by the Dvorak scheme. With the proposed launch of INSAT-2E towards the end of this year, use of its water vapour channel data would be further exploited for the forecast of tropical cyclones. It is also proposed to augment the Cyclone Warning Dissemination System network. The Limited Area Model with its poor resolution is not able to capture the cyclone development properly. It is being planned to upgrade the model to a high resolution version subject to availability of resource.

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Success and Failure of Early Warning Systems: A Case Study of the Gujarat Cyclone of June, 1998

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1 Introduction

A devastating Tropical Cyclone (TC) with maximum sustained wind speeds of the order of 160–180 km/h caused a landfall near Porbandar on the Saurashtra coast of the state of Gujarat in India at 0230 UTC on the morning of 9 June 1998 and wreaked havoc along its track. This TC was well tracked using satellite, radar, buoys, oil rigs and coastal observatories data. The landfall was very well predicted to be near Porbandar. The two-stage alert and warning were given to the State Authorities well in time. Despite the adequate warning, the TC took a toll of about 3000 people, damaged 200 000 houses, and resulted in losses worth over 700 million dollars. Unfortunately, the cyclone warnings did not reach the community level. The failure in the dissemination of the early warning is attributed chiefly to the low frequency of very severe cyclonic storms in the Kutch area, which resulted in low preparedness levels. This paper provides the synoptic history of the evolution of this TC, the inferences derived after a careful scrutiny of all available meteorological data, the warnings issued, the failure of the dissemination system, and the lessons learned from the experience.

2 Synoptic Description

The TC developed as an onset vortex at the leading edge of the summer monsoon. A depression formed over the southeast Arabian Sea on the evening of 4 June (Fig. 1). It intensified into a Cyclonic Storm on 5 June over the same area. It further intensified into a Severe Cyclonic Storm by the evening of 6 June. Moving northward, it intensified into a Very Severe Cyclonic Storm on the 7th about 700 km south-west of Mumbai. While continuing to move northward, it deepened further with estimated core winds of 140 to 180 km/h on 8 June at about 350 km south-west of Porbandar. The system recurved and crossed the Gujarat coast near Porbandar on 9 June.

3 Monitoring

Kalsi (1998) has summarised in this volume the capability developed by India Meteorological Department (IMD) for providing early warnings for TCs in the North Indian Ocean. The whole infrastructure comprising of the Indian National Satellite (INSAT) system, the Cyclone Detection Radars (CDRs), oil rigs, buoys, and ships data, and also data from the land stations, was used for analysis and forecasts of this TC, and these warnings were distributed to a large number of recipients.

4 Important Signals on Intensity

As the cyclone moved with a speed of about 20 km/h before landfall, the CDR at Bhuj could be used for only a few hours before the landfall occurred in the southern portion of the radar

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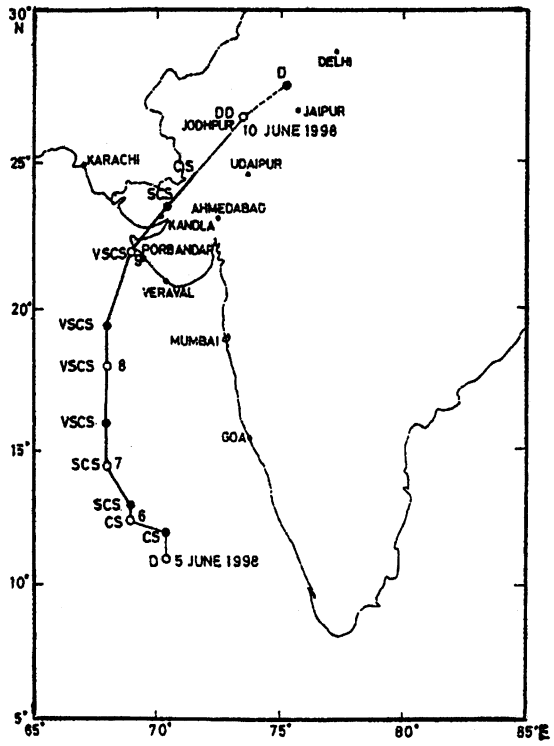


Fig. 1. Track (12 h intervals, alternating open and solid dots) during 5–10 June 1998 of the Gujarat cyclone. Intensities are indicated by CS – Cyclonic Storm, SCS – Severe CS, and VSCS – Very Severe CS

coverage. The radar images obtained from 0000–0200 UTC 9 June had no closed eye, which usually appears in cyclones with much less intensity. In this case, the Bhuj CDR observed 5 to 6 spirals with arc lengths of less than 180 deg. The INSAT imagery continuously displayed solid dense overcast. An eye was seen in the satellite imagery, although it was not very sharp and clear. The satellite-derived intensity estimate was T 5.0 on the Dvorak scale, which means maximum sustained wind speed of about 165 km/h before landfall. This appears realistic in view of actually recorded wind speeds of 160–180 km/h, which again confirms that the Dvorak (1984) scheme can yield a realistic assessment of intensity of at least intense TCs in the North Indian Ocean (Kalsi 1992).

Historical records for this region indicate that no TC after a landfall near Porbandar has maintained its intensity even after crossing Saurashtra. Normally, a TC weakens considerably just after landfall. In this case, winds experienced at Jamnagar and Kandla were stronger than at Porbandar, which is closer to the landfall point. The residency period of this TC on the Gulf waters was about 3 hours. The width of the water channel (Gulf) is less than three fourth of a degree. Thus, the maintenance of the intensity of this TC over land seems to be enigmatic.

Mandal and Gupta (1992) have produced pressure and wind profiles for several intense TCs using the analytical model of Holland (1980). Computations for the Gujarat Cyclone of June 1998 indicate that its outer-core strength (OCS) was larger than that of the intense Kavali TC of November 1989 and the Sriharikota TC of November 1984. Along with the high inner-core intensity of about 160 km/h near Kandla, which is thought to have been responsible for a storm surge of about 3 metres height, it is the higher OCS that is believed to be instrumental for other damages encountered over that area.

Furthermore, landfall occurred on a full-moon day when an astronomical tide of 6–7 metres was also expected. There are varying versions of the storm surge that inundated large tracts of the Salt-Pan area. Another interesting aspect of this TC is that the rainfall released over Gujarat was almost insignificant considering the TC circulation was fed by the monsoon current.

5 Warnings

The first cyclone *alert*, which is usually issued 48 hours before the commencement of bad weather associated with the cyclone, was issued at 1200 UTC 7 June when the cyclone was 650 km west-south-west of Go. At the alert stage, it is difficult to identify the time and place of cyclone landfall. Along with its position and intensity, only the likely direction of motion of the cyclone was indicated so that preparations should have begun to face the storm fury during next 24–48 hours. A series of four cyclone alerts were issued in a span of 10 hours up to 2300 UTC 7 June, during which the cyclone moved a distance of 200 km. However, the TC was still about 500 km south-south-west of Veraval, the nearest point on the coast. It continued to move northward along 68°E until the morning of 9 June, and then the TC took a track toward the north-north-east, which had actually been forecast since the afternoon of 7th.

The first cyclone *warning* was issued at noon on 8 June. Landfall was predicted between Veraval and Dwarka by the morning/afternoon of the next day. The cyclone did cross the coast 20

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hours later in the predicted coastal belt. It has to be conceded that the landfall warning was a remarkable success from a scientific perspective. All of the cyclone alerts issued in the beginning, and the first two cyclone warnings later were addressed to the districts mostly on the south Gujarat coast, as these districts were likely to first face directly the fury of the cyclone. Indeed, a large number of precious human lives were saved in these districts where timely action by the disaster management administration occurred.

Kandla, which is the second largest port in India, was informed by IMD during the afternoon of the 8th about the cyclone, and was alerted to hoist Great Danger Signal (No. Eight), which means that the port is likely to experience severe weather from a severe cyclone with the port to the left of the track. As acknowledged by the Kandla Port Trust (KPT), this message that was issued by the forecast office at 0630 UTC (noon) was received at 1030 UTC on 8 June, which is about 16 hours before the arrival of the TC over Kandla. An alert to hoist Local Warning Signal (No. Four) had also been received by the KPT authority before noon on June 8th.

The first two cyclone warnings were not specifically addressed to the Kutch district, which is a relatively large area to the north of the Gulf of Kutch. The fury of the TC was not expected to spread over this whole area and as seen later, was confined to a much smaller area around Kandla Port for which adequate warnings had been given. Special warning messages for strong winds in excess of 120 km/h and heavy rainfall exceeding 125 mm up to 03 UTC 10 June were sent to a number of functionaries including District Collector, Kutch at 1530 UTC 8 June. These messages were sent on police wireless channels and it is understood that they were only received with much delay, which defeated the purpose for which they were sent. However, the KPT area that bore the brunt of the TC was well informed in advance of the TC arrival.

6 Vulnerability of the Region

The region of India affected by the Gujarat cyclone lies along the north Arabian Sea. This region has experienced a total of 46 cyclonic disturbances during the period of 1890–1998, and out of these only 17 have intensified to cyclonic storms or its higher stages of evolution. Thus, the number of TCs experienced in this region is far less in comparison to the maritime states bordering the Bay of Bengal where the cyclogenesis is five to six times more frequent.

The infrequent occurrence of TCs in the region, and the unusual intensity with which it struck, were factors in the loss of lives and damage from the Gujarat cyclone. With only 17 cyclonic storms in 108 years, the local experience with such cyclones was not high. Certainly, a severe cyclone with 160–180 km/h winds is rare in this region. Thus, the lack of local appreciation for the vulnerability of the community, and the response capacity for disaster management administration resulted in more damage than expected.

One of the most important questions is – why did so many people die in a region that has a population density of only about 27 persons per square kilometer, which is among the lowest in the country? Although the high wind zone was confined to the districts of Porbandar and Jamnagar, the greatest loss of life in the Gujarat state was in the Kutch district, which is a semi-desert area. The population is mostly concentrated along the coast, where in addition to the port activities, fishing and salt production are the principal occupations. In the neighbouring district of Jamnagar, most of the people are employed in agriculture or in large industrial complexes. The region has a high immigration from other parts of India due to better employment opportunities.

During the Gujarat cyclone, the highest causalities were among three distinct vulnerable groups – villagers, the fishermen, and the casual labourers. Most of the people who died were totally unaware of the impending cyclone and the storm surge, and as a result they did not take any precautionary measures.

The Salt Pan workers have been involved in the trade for many generations. They migrate to the salt pans for employment eight months a year and are exploited thereafter. Most of the workers and their families in the salt pans had no idea of the impending cyclone. This is the reason for the highest casualty and loss of life among them. Evidently, the cyclone warnings never reached them.

The fisherfolk along the coast are mostly dependent on small catches, selling whatever fish

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they catch to a contractor. They have their own small boats and live with their families in huts very close to the sea. Due to privatisation of ports and development of coastal areas for commercial and tourism interests, the fisherfolk have been involuntarily displaced from their places of residence to areas that are viewed as more disaster-prone. These fisherfolk were affected by a storm surge (up to 3 m high), and entire settlements were washed away. Being new to areas where they had been displaced, and without good communication lines, they were highly vulnerable.

The industrial complexes that have been built in recent years as part of the port activity employ a large number of casual immigrant labourers who stay within the complexes, usually in temporary dwelling units. An unknown number of such persons died as their dwelling units were blown away by the fierce winds.

In addition to the three vulnerable groups, damages and casualties were reported among inland villagers as well as urban dwellers who suffered from structural collapse and flying debris. A freak case worth mentioning here occurred in the suburbs of Kandla Port city, where a cyclone warning siren followed a rumoured ammonia gas leak from an industrial unit that had caused people to move outdoors. The resulting traffic jam due to this sudden movement left people directly exposed to the strong winds.

7 Conclusions

The capability of the India Meteorological Department in monitoring and forecasting development and movement of the Gujarat cyclone is once again demonstrated. However, the disastrous experience in Gujarat raises some basic issues.

Perhaps, the most important questions are: What can be done in an area that does not experience tropical cyclone hazards very often? How do we ensure that the community is informed of the impending danger and is aware of the measures it needs to take for its own safety? Have all vulnerable groups in the community, which in this case had very limited means of communication, been taken into consideration? In spite of a warning issued by the Meteorological Department well in advance, the response by the local disaster management administration left much to be desired. Unfortunately, the cost of this inadequate response had to be paid by the people. The least a community, state or nation can do is to put together a system with accountability, and sufficient capacity to respond appropriately.

Large investments in new technology used to advance forecasting skill and issue warnings against natural hazards can only be justified when the warning effectively reaches every citizen who is likely to be affected by the hazards. Obviously, this requires putting together a system that involves teamwork and effective coordination in a very short and stressful time. Often, the easier part of buying necessary forecasting equipment and meteorological training is already done. However, the community who is the ultimate beneficiary of such a warning system must have received the necessary equipment and, more important, be capable of using it and thus reacting favourably.

Community awareness and training, especially of vulnerable groups, is a difficult and drawn-out process. It forms as essential part of any effective early warning system. The role of facilitators (e.g., the Non-Governmental Organisations – NGOs) in bridging the gap that exists between the government and the community becomes important. Experience (e.g., Mount Pinatubo, Philippines) has shown that with a well coordinated team effort between the forecasting agencies, the administration, the NGOs as facilitators, and the community, many more lives can be saved.

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CHAPTER 4.7

From Good TC Track Forecasts Towards Good Early Warning of Intensity Changes

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Abstract

Tropical Cyclone EW has benefited from recent improvements in storm-track forecasts derived from refinement in global Numerical Weather Prediction systems using atmospheric initial data. Yet coastal populations threatened by Tropical Cyclones will increasingly need EW based, in addition, on forecasts of those intensity changes which may result from powerful air-sea interaction. Such needs, readily demonstrated from cases of grave intensification of Tropical Cyclones on passage over warm ocean areas shortly before landfall, may well be met relatively soon, now that appropriate ocean data in real time are becoming available – as initial data – for use in fully comprehensive programs where a modern Numerical Weather Prediction model is coupled to a fine-mesh multi-layer ocean model.

1 The Interdisciplinary WMO/ICSU Project on Tropical Cyclone Disasters

In the report (Lighthill 1991) from its Vienna Workshop (held Aug. 1990), the International Council of Scientific Unions (ICSU) proposed to the World Meteorological Organisation (WMO) an interdisciplinary WMO/ICSU project on Tropical Cyclone Disasters within which ICSU's special contributions would be on Tropical Cyclone Oceanography and Air-Sea Interaction. It was above all the presumption, that track forecasting – for all its importance – would increasingly need to be supplemented with forecasts of intensity changes, which appeared to call for such an interdisciplinary development.

After the proposals had been agreed (March 1991) by WMO, G.J. Holland represented WMO's Commission for Atmospheric Sciences (CAS) in preparing, jointly with ICSU representatives, the International Symposium (Beijing, Oct. 1992) on Tropical Cyclone Disasters (Lighthill et al. 1993). Like earlier meetings on Tropical Cyclones (TC), this one was concerned in detail with improving EW for such disasters; nonetheless, an important new feature of the Beijing Symposium emerged through ICSU's insistence on the inclusion of numerous specialists on TC oceanography and air-sea interaction. Their very successful cooperation with meteorologists at the Symposium was recognised as making a powerful case for continued interdisciplinary collaboration in the future.

Later meetings within the WMO/ICSU project have been held as part of a series of International Workshops on Tropical Cyclones (IWTC) which, besides producing Workshop reports, embrace also an additional goal: the updating of WMO's 'Global Guide to Tropical Cyclone Forecasting' at even-numbered Workshops and the updating of a scientific textbook on Tropical Cyclones at odd-numbered ones. The first and second Workshops (IWTC-I, Nov. 1985 and IWTC-II, Nov. 1989) had been organised by WMO on its own but the third and fourth (IWTC-III, Nov. 1993 and IWTC-IV, Apr.

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1998) were organised jointly by WMO and ICSU and followed the Beijing precedent in giving detailed attention to TC oceanography and air-sea interaction. Thus the latest textbook update 'Global Perspectives on Tropical Cyclones' (Elsberry 1995), planned at IWTC-III in Huatulco, Mexico, includes the 60-page, Chapter 5, 'Ocean Response to Tropical Cyclones' as one of its six chapters.

Then at the succeeding meeting held in Haikou, China (IWTC-IV, Apr. 1998) a very active Working Group on Air-Sea Interaction, consisting of 3 delegates from ICSU and 3 from WMO, made strong representations about the future importance of this subject for improving EW of TC intensity changes. They pointed out that the former Global Guide to Tropical Cyclone Forecasting (Holland 1993), compiled before IWTC-III, had hardly mentioned TC oceanography and air-sea interaction, while its brief account (2.3.3) of Forecasting Intensity Changes had concentrated on 'evaluating intensity tendency from cloud patterns' – rather than by any use of ocean data. They saw it as essential that the newly updated Global Guide, being planned at IWTC-IV, should take into account the following important issues (to be further discussed below in sections 2, 3 and 4 respectively);

1. that instances of substantial intensity growth from TC motion over warm currents, or warm-core eddies, are now copiously documented;
2. that ocean-data acquisition systems have expanded hugely, and lend themselves to use with coupled atmosphere-ocean models; and,
3. that the close coupling of an atmospheric model specialised for TC forecasting with a high-resolution multi-layer ocean model is now developed far beyond the level described in Elsberry (1995) and is confirming, not only major increases of intensity from passage over warmed ocean areas, but also significant decreases in the presence of oceanic heat-source depletion.

Valuable debate on these issues during IWTC-IV led finally to all three of them being incorporated into the Workshop's Report and Recommendations and also to agreement that the Global Guide update will be strongly influenced by them.

2 Intensity Growth Over Warm Ocean Areas

Even though TC intensities can be reduced by certain key air-sea interaction mechanisms, this section aims to highlight the importance of oceanic data for forecasts and warnings by dramatic evidence that dangerous intensification has often accompanied passage of a TC over warmer waters. Briefly, over a pre-existing warm ocean structure, strong latent-heat fluxes are able to re-energise the storm.

During 1995 in the Gulf of Mexico, just before striking the coast, hurricane Opal moved (Marks & Shay 1998) over a warm-core eddy which was detected by radar altimeter data from the NASA TOPEX mission, and deepened from 965 hPa to 916 hPa over 14 hours (Fig. 1). Shay et al. (1998), using surface height anomaly and the underlying density field, inferred a net oceanic heat loss after TC passage more than sufficient to have produced the observed intensification.

This very detailed evidence supplements three well documented cases of hurricanes which similarly intensified, but this time on passing over the warm Gulf Stream. Out of them, by far the most damaging was Andrew; where a combination (Willoughby & Black 1996) of low wind shear with warm water east of Florida deepened it to 920 hPa just before landfall on 24 August 1992. In subsequent years (Black 1998), intensification from the same cause was observed for hurricanes Jerry (1995) and Bertha (1996).

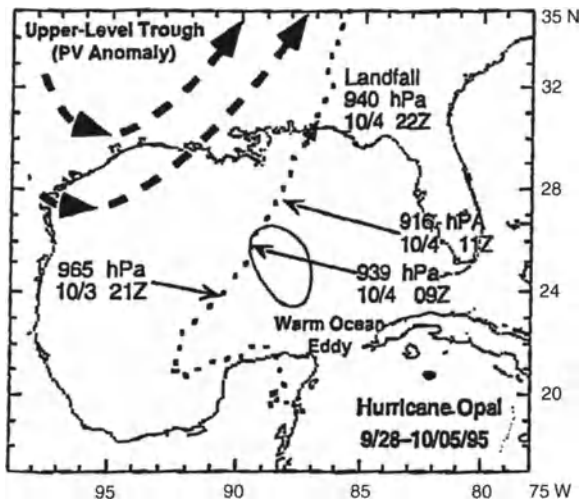


Fig. 1. Intensification of hurricane Opal as it passed, on 4 October 1995, over a warm ocean eddy (redrawn after Marks & Shay 1998)

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3 Advanced Ocean Data Acquisition and its Uses

Any combined use of air and ocean data for future intensity forecasting will demand routine acquisition of relevant ocean data in real time. This section lists promising acquisition systems which have already shown their worth in experimental studies – both in cases of intensification (see above) and in other important cases where depletion of the oceanic heat source reduced a storm's intensity.

Satellite systems, with their global applicability, appear specially promising. Admittedly, direct determination of sea-surface temperature (SST) from polar-orbiting meteorological satellites can be misleading (Schluessel et al. 1990, Wick et al. 1996). Fortunately, however, a significant coefficient of expansion for warm seawater ($\acute{a} = 0.00032\ K^{-1}$ at 28°C) allows the presence of a substantial mass of water at elevated temperature to be inferred by use of existing NASA and ESA satellites which register local distortion of the geoid by means of radar-altimeter measurements. Yet another parameter affecting air-sea interaction is surface roughness, which can now be routinely determined with a satellite-borne C-band radar measuring Bragg back-scatter from the rough ocean surface. This usefully yields a directional spectrum for waves generated by strong local winds – and thus can be of additional value as suggesting an approximate distribution of surface wind vectors (Quilfen et al. 1994).

In more limited areas, mobile drifting buoy arrays deployed from aircraft have proved highly effective for demonstrating TC intensity changes from air-sea interaction. Surface wind speed and direction are themselves measured by some of these buoys, while others determine SST and ocean mixed-layer depth together with ocean current profiles. Recent analysis (Shay & Mariano 1996) of 1988 data using airborne expendable buoys showed complex interactions when hurricane Gilbert passed to the left of a warm eddy, with wind stress generating a near-inertial wave field tending (Nilsson 1995) to entrain colder water into the mixed layer. In 1995 again, a huge array of moored buoy platforms demonstrated the oceanic heat-source depletion from successive hurricanes Felix, Luis and Marilyn, with the later hurricanes weakening as they entered the cold wakes of earlier ones (Black 1998).

4 Coupling TC Forecasting Models to Fine-mesh Ocean Models

Among those TC forecasting models which predict track best is the 'movable triply-nested mesh model' developed at the Princeton Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration (NOM). After being put into regular operational use by the U.S. National Weather Service in 1995 (Kurihara et al. 1998), it has been further refined (for example, by incorporation of particular initial conditions obtained by the technique known as 'asymmetric bogusing') so as to yield still greater track-forecasting accuracy; yet it offers relatively poor intensity forecasts (over-predicting weak and under-predicting strong storms), probably because it assumes fixed SST.

By contrast, certain numerical experiments (Bender et al. 1993, Falkovich et al. 1995a, b) used an SST computed after the TC model's fluxes of momentum, heat and moisture had been passed into a fine-mesh multi-level ocean model (generating currents in the mixed layer and upper themocline layer) and then iterated to obtain a fully interactive model, satisfactorily tested against comprehensive measurements made in 1984 of ocean response to hurricane Norbert. In the coupled model, as might be expected from chapter 5 of Elsberry (1995), a slower-moving TC both cools the ocean more and itself suffers greater weakening as a result; yet both efforts are predicted to remain significant for TC travel speeds up to 7.5 m/s (Fig. 2). Moreover binary TCs, common in the West Pacific, experience still stronger TC-ocean interaction as each TC crosses the other's wake, with computations from the coupled model confirmed by 1974 observations of the lonelkirsten binary system off Guam.

More recently (Ginis et al. 1997) the GFDL model was coupled to a high-resolution version of the Princeton Ocean Model. Experiments were then run (Bender and Ginis 1998) for a large number of hurricanes including Gilbert (1988), Felix and Opal (1995), Fran (1996) and Erika (1997), with the coupling improving intensity prediction in every case.

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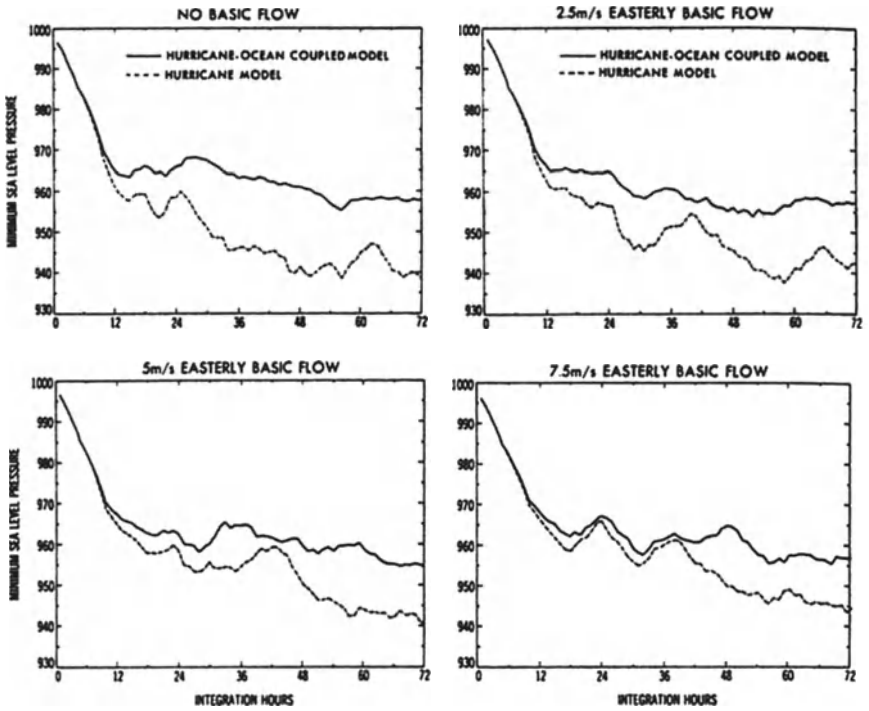


Fig. 2. Time series of minimum sea-level pressures (hPa) for a deepening hurricane found (Bender et al. 1993) in numerical experiments, run with hurricane-ocean coupling (solid curves) and without coupling (dashed curves), for different speeds of 'basic flow' (that is, hurricane travel speeds)

5 Conclusion

This paper's principal conclusion is a message of hope for those TC forecasting authorities who need to achieve, not only good track forecasts, but also good intensity-change forecasts. That will demand real-time oceanic data, and developments can be envisaged in which their routine acquisition – for use as initial data in a TC forecasting model coupled to a fine-mesh multi-level oceanic model – will significantly improve the prediction of intensity change.

Acknowledgement

The author offers warm thanks to all fellow-members of the Air-Sea Interaction Working Group at IWTC-IV (P. G. Black, I. Ginis, K. B. Katsaros, V. D. Pudov and L. K. Shay) for their invaluable assistance in the preparation of this paper.

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CHAPTER 4.8

Improving the Tropical Cyclone Warning System and its Effective Dissemination in Mauritius

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1 Introduction

Mauritius is an island of volcanic origin lying in the South West Indian Ocean between latitudes 19°58.8′ and 20°31.7′ South and longitudes 57°18.0′ and 57°46.5′ East. It covers an area of 1,865 km^2 and has a population of about 1.1 million.

The main economic activities are agriculture (sugar cane), textiles industries, tourism, offshore banking, and freeport services. The first three sectors are vulnerable to tropical cyclones.

The island of Rodrigues that forms an integral part of Mauritius lies about 560 km to the east. It has an area of 108 km^2 and a population of about 35000. Like Mauritius, Rodrigues is affected by tropical cyclones. The Mauritius Meteorological Services (MMS) is responsible for the issue of tropical cyclone warnings for Rodrigues.

Mauritius enjoys a tropical maritime climate. There are two seasons: summer, which lasts from November to April, and winter, from May to October. The South-West Indian Ocean is prone to tropical cyclones during summer and the most active months for tropical cyclones are January and February.

On average, 10 named tropical storms are tracked every year and of these, 3 attain tropical cyclone intensity. Tropical storms usually form well to the northeast of Mauritius on the Intertropical Convergence Zone (ITCZ), which lies between latitude 5° and 10° South. They initially move westward while intensifying and are named on reaching moderate tropical storm intensity (mean wind speed of 33 knots). The storm eventually turns towards the southwest and thus may approach Mauritius or Rodrigues while at their most intense stage.

2 The Tropical Cyclone Warning System

The Tropical Cyclone Warning System is based on the likelihood of surface gusts of 120 km/h or more occurring over Mauritius. It consists of four distinct phases that are issued depending on the degree of risk and the time factor.

Class I: Is issued 36–48 hours before Mauritius is likely to be affected by a tropical storm or cyclone.

Class II: Is issued so as to allow as far as practicable, 12 hours of daylight before the occurrence of gusts of 120 km/h.

Class III: Is issued as far as practicable in time to allow 6 hours of daylight before the advent of gusts of 120 km/h.

Class IV: Is issued when gusts of 120 km/h have occurred and are expected to continue.

3 Dissemination of Tropical Cyclone Warnings

The main method of dissemination of tropical cyclone warnings is by radio. Television and newspapers are other ways by which the population is kept informed of the evolution of tropical cyclones.

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4 Upgrading of National Meteorological Services

The small island states of the South-West Indian Ocean, namely Madagascar, Comoros, Seychelles, and Mauritius have upgraded their national Meteorological Services to improve their capabilities to monitor and track tropical cyclones so as to provide more accurate forecasts and warnings to their population in a timely manner. This project, which has been implemented under the umbrella of the Indian Ocean Commission with funding from the European Development Fund, is of direct relevance to the activities of the International Decade for Natural Disaster Reduction (IDNDR).

Mauritius was given a soft loan of about 1 million ECU for the purchase of equipment that includes a Primary Data User Station (PDUS), High Resolution Picture Transmission (HRPT), and a radiosonde station. In addition, the Forecast Office has been computerised with the acquisition of a workstation fitted with the SYNERGIE software that allows the visualisation of Numerical Weather Prediction (NWP) models from the World Meteorological Centres. The MESSIR Message Switching System has also been installed and allows weather bulletins and tropical cyclone warnings to be prepared and disseminated by fax in a very efficient manner.

The MMS receive all the Numerical Weather Prediction (NWP) products prepared by the World Meteorological Centres through the Meteorological Data Distribution (MDD) system and through an Internet link with the Regional Specialised Meteorological Centre (RSMC) at La Reunion.

The project also contained a training component that has been financed by the European Development Fund (EDF). Technicians received factory training in the maintenance of the new equipment being acquired and Meteorologists were trained in Tropical Meteorology and Numerical Weather Prediction.

Tropical cyclone forecasting is being done using a tropical cyclone workstation developed by Olivier Rajaonerivelo of the Madagascar Meteorological Services. It uses the CLIPER (CLImatology and PERsistence) method and the only drawback is that its track data extend to longitude 70° East only.

The Australian Tropical Cyclone Workstation has just been made available to MMS. It operates under Windows 95 and uses the CLIPER method. It has the great advantage of being applicable to any tropical cyclone basin.

Tropical cyclone advisories and forecasts are received from RSMC La Reunion, Bracknell, Perth and Washington. An analysis of all these forecasts together with the synoptic situation is made before a decision is made on the official track forecast.

5 UK Flagship Project of the IDNDR

Under the Flagship Project of the IDNDR the United Kingdom (UK) Government has provided a low-cost weather presentation system to the National Meteorological Services under a World Meteorological Organization/Voluntary Cooperation Programme (WMO/VCP) project. This equipment has allowed Meteorologists to prepare and record weather forecasts for broadcast on television. The recording is done in a studio that has been set up at MMS. A desktop publishing workstation enables our staff to produce graphics that are used in publications and for display.

This project was completed in November 1996 and the dissemination of weather information, especially during cyclones and other adverse weather events, has been greatly improved.

Under the same project, a survey has been carried out by Prof. D. Parker of Middlesex University in the UK to assess and evaluate the response of the various socio-economic groups of the population to cyclone warnings. The final report has just been submitted and it contains some interesting suggestions for improvement of the dissemination of tropical cyclone warnings.

In particular, the report recommends that the MMS should have regular interactions with all its stakeholders so as to identify their needs. Particular reference is made to fishermen and factory shift workers who have special requirements in terms of early warning of tropical cyclones.

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6 Conclusions

The present Tropical Cyclone Warning System, of four classes described above, has been in operation for nearly forty years and has proved to be very effective. One of its strong points is that it is very simple and easy to comprehend. The whole population is well versed in its various aspects.

The recent improvements in the formulation and dissemination of tropical cyclone warnings has contributed to a large extent towards the enhancement of early-warning capacities of the system. In this respect, the IOC/EDF Meteorology Project has brought about significant improvements to the observing network, and the workstation assists the Meteorologist in analysing the tropical cyclone situation and making more timely and accurate forecast. In addition the improved communications links have also contributed towards better early-warning and dissemination systems. Finally, the provision of the weather presentation system as part of the UK Flagship Project of the IDNDR has made communication of the warnings to the public more effective.

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IVb Early Warning Systems for Floods

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Real-Time Flood Forecasting: Problems, Possibilities and Proposed Solutions

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Abstract

The paper describes the objectives and the state of the art of real-time flood forecasting by discussing the problems and the possibilities offered by the presently available measurement and modelling systems. In addition the paper shows the need for a Decision Support System (DSS) for Inundation Risk Evaluation and Emergencies Management from the emerging requirements for a holistic approach to flood management, recently advocated at national and EU levels. As a logical consequence, the paper proposes the development of FLOODSS, a DSS responding to the need of an integrated tool for planning and management that, taking advantage of available High Performance Computer platforms, allows (1) to locate areas at risk and to estimate expected damages; (2) to forecast floods and inundation phenomena on the basis of real-time analysis of the present meteorological situation and of forecasts available at different time and space scales; (3) to evaluate the effects of decisions aimed at reducing social, economical and environmental damages on the basis of planned or real-time forecasted scenarios and (4) the continuous training of personnel.

1 The Flooding Problem

The problem of flooding is as old as time. However, while natural flooding of large areas did not create situations more dangerous than others in a prehistoric world, the expansion of human activity and cities has made the prevention of damage caused by floods or harnessing over-bank flows for one's own purposes as in ancient Egypt a necessity that remains vital to this day.

From the end of the eighteenth century onwards, with the advent of the industrial age, there have been two courses of action: hydraulic works on the territory, such as land reclamation works, which in many cases upset a land's balance dependent on overflow, and the channelling of watercourses, especially in mountain and foothill sections, with the result that the problem of flooding is brought downstream even to areas that were originally protected.

Lastly, recent years have seen booming population and indiscriminate urbanisation create extremely dangerous situations, with floodplain

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areas that are inhabited, or that even house entire neighbourhoods sheltered by levees that are not particularly safe during prolonged periods of flooding, especially in the case of suspended bed rivers like the Po.

The flood problem is by no means limited to Italy. It is a global problem that has been increasing at a worrisome pace in recent years. A brief analysis of the following tables published by the National Land Agency Japan, 1994, which respectively show trends in flood-related damages (Fig. 1, in billions of dollars), number of people stricken (Fig. 2, in millions), and number of deaths (Fig. 3, in thousands), provides an idea of how serious the situation is.

This upward trend was if anything more pronounced in Europe, where damage was quite high-amounting to approximately one-fifth of the total (Fig. 4, in billions of dollars).

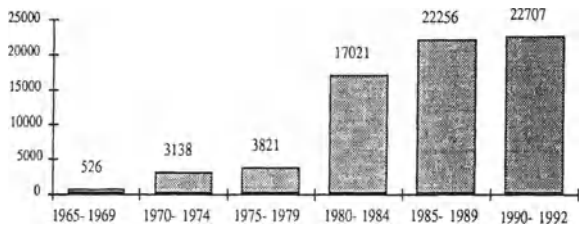


Fig. 1. Flood-related damages world-wide, in billions of dollars

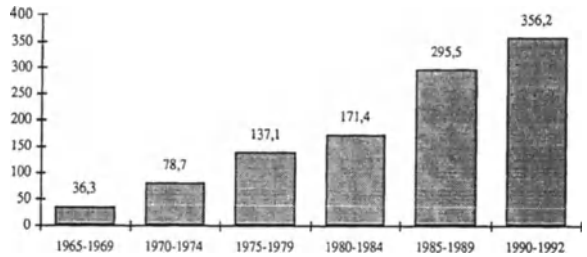


Fig. 2. Number of people stricken by floods world-wide, in millions

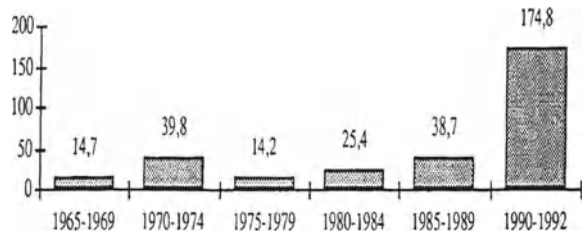


Fig. 3. Flood-related deaths world-wide, in thousands

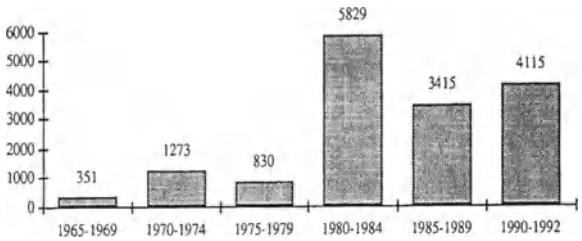


Fig. 4. Flood-related damages in Europe, in billions of dollars

Damages will rise inexorably in the years to come, partly due to the greater risks posed by larger urbanised areas, and partly due to climatic changes taking place. The considerable amount of carbon dioxide in the atmosphere, which is produced mainly by the combustion of hydrocarbons, exacerbates the greenhouse effect increasing the Earth's capacity to retain the long-wave radiation that it produces as a black body subject to solar radiation. This radiation cannot be released into space, thereby upsetting the balance of energy trapped by the Earth and increasing the amount of available heat (Italian Ministry of the Environment, Conferenza Nazionale sul Clima, 1993).

Fortunately, thanks among other things to increasing computational and measurement capabilities, there has been a growing awareness in various areas of applied research that it is possible to predict emergency situations with a reasonable degree of approximation, especially in the fields of meteorology and hydrology. With the arrival of new measuring systems (Meteorological Radar and Meteosat Satellites), and especially with the new possibilities offered by Limited Area Models (LAM), it has finally become apparent that it is possible to create complex forecasting systems on a series of different time scales.

2 Precipitation Data Acquisition Systems

At present, there are essentially three basic systems for providing precipitation measurements, which can be used for real time flood forecasting.

The most commonly and widely used rain sensors for developing operational real-time flood forecasting systems are the conventional ground based tele-metering raingauges, generally linked to a central station by means of telephone lines or by radio links (VHF or UHF)

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or, less frequently, by means of Meteorburst equipment or via satellite through Data Collection Platforms (DCPs). There are several reasons in favour of the conventional equipment based upon raingauges. Firstly National Services have a long tradition in using raingauges, which means that long historical records are generally available for calibrating the rainfall-runoff models; secondly, in real time flood forecasting there is also need of other ground based hydro-meteorological measurements, such as for instance water levels in rivers and air temperatures close to the soil, which sensors may be integrated into the overall data acquisition system so that the cost of the additional rain sensors becomes marginal. Finally, in developing countries, training of local personnel and maintenance result more technically and economically accessible with ground based equipment rather than with other sources such as weather radars or satellites. The density of raingauge networks depend on several factors (WMO, 1981) and must be determined specifically for a single case depending upon the orography and the spatial correlation of observations. Techniques such as Factor Analysis or Kriging are generally used to provide an economically viable but sufficiently dense measurement network. The spatial description of the rain field based upon raingauges may not be accurate at very small scales (i.e. 100×100 m^2), but tends to be sufficiently accurate, for flood forecasting purposes, on larger scales of the order of $10\,000 \times 10\,000$ m^2.

Another precipitation measurement system is the weather radar system, whose importance has grown in the last decade, particularly after the introduction of the dual polarisation systems and the Doppler radars. There are now over 100 countries operating more than 600 weather radars and development programmes have been established in several countries as well (Rosas Dias 1994). The European Union sponsored COST72 (1985) and COST73 (Collier 1990) for establishing a weather radar network in the participating countries. In the USA NEXRAD (1984) is a programme for establishing a network of 175 S-band Doppler weather radars and in the UK the FRONTIERS programme combines radar and METEOSAT images to produce very short precipitation forecasts (Browning 1979; Browning & Collier 1982). There are two major benefits in using radars: the first one is a finer spatial description of the precipitation field and the second one lies in the possibility of observing approaching storms sometimes before arriving over the catchment of interest. A major disadvantage lies in the need for re-calibration of parameters used for converting reflectivity to rain, which generally also requires the installation of a conventional ground based raingauge network.

The third potentially useful measurement system is based upon the analysis of clouds shown by the geo-stationary satellite images (Milford and Dugdale, 1989). This approach has been successfully used for the development of the Nile Flood Early Warning System (Grijsen et al. 1992). Unfortunately, the methodology developed by the Dept. of Meteorology of the University of Reading is adequate for long time intervals and very large catchments (the Blue Nile catchment area is on the order of 500 000 km^2) in the Tropical region, while there have been no convincing applications of the technique for smaller catchments in the subtropical or in the temperate zones.

When planning an operational flood forecasting system, there is the need of choosing among these precipitation measurement systems which have extremely different characteristics from the point of view of the information content. This requires an analysis of the size and of the nature of the problem which may start from giving an answer to the following question: "When is the improved spatial description of precipitation provided by radar an essential requirement?". The answer is: "For very small size catchments, and in particular for small mountain or urban catchments". For these catchments in fact, given the very small sampling time required for runoff forecasting (5'–15') one radar image may be viewed as a snapshot of the spatial distribution of rain while, in order to obtain the same result an extremely dense raingauge network would be required. On the other hand, when the flood forecast is needed for small (100–1 000 km^2) or medium size (1 000–10 000 km^2) catchments the measurements provided by the conventional raingauge networks tend to be more than adequate.

With a view to providing a reference framework for the measuring systems to be adopted, it should however be stressed that reliance should be placed not on just a single precipitation data acquisition system but on several sys-

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tems of different kinds: remote rain gauges, Meteorological Radar, Meteosat, etc., each of them designed in such a way as to carry out the measurements independently of the other systems. In this way, in addition to the possibility thus offered to exploit the complementary nature of the information, there would also be the added advantage of turning to account the redundancy of the measurements in the case of intense meteorological events, when the probability of malfunctions in the single system solution is greater, and with it the attendant grave risk of losing the information.

3 The Predictability of Hydro-meteorological Events

Today the predictability of hydrological-meteorological events, according to the meteorologists themselves, is "good"; having said this, however, it should be made clear in which situations and contexts such forecasts may be regarded as "good".

Mesoscale models (with mesh sizes of $100\times100\,km^2$) were basically conceived as descriptive models of climate and weather. As these models evolved, the "precipitation" variable was added to them, which is not however one of those quantities which model designers call "state variable", i.e. a variable which is vital for the description of the physical state of the system. It is rather, in meteorological models, a derived variable or a by-product, a function of the humidity content, the energy content, the condensation point, etc. obtained by means of more or less empirical relations. This should not be taken to mean that precipitation forecasting is basically wrong; rather, the point being made is that a great deal of research work still needs to be done with regard to this variable. It should also be borne in mind that orography, which affects the precipitation quantity, is described in the mesoscale models by a mean value on $100\times100\,km^2$ meshes (i.e. $10\,000\,km^2$ equal to 7 meshes encompassing the whole of the River Po drainage basin, including the Alps and Apennines) with the result that its effects are marginally felt. A further advance in the representation of rainfall fields was achieved with the advent of the so-called LAMs or Limited Area Models, with mesh sizes as small as the design limit of representation for hydrostatic models of $10\times10\,km^2$, which on the one hand allow the orography to be introduced in greater detail and on the other allow a finer discretisation of the forecast precipitation quantities, and therefore a more realistic spatial variability.

At the present time, atmospheric forecasting models must be viewed as valid qualitative-quantitative rainfall forecasting tools at 24, 48 and 72 hours (insofar as absolute precision is not required at these forecasting horizons, but rather an order of magnitude) for events of great intensity and when these phenomena occur on a considerable scale and size (like for example the flood event of November 1994 on the Po river in Italy); nevertheless, they cannot yet be regarded as providers of quantitative rainfall forecasts in the short term (6–12 hours) to be used directly for flood forecasting purposes as an exciting force on hydrological models, since the quantitative forecasting of precipitation, on the time and space scales commensurate with the dynamics of the hydrological phenomena, has not yet achieved that degree of precision necessary to avoid on the one hand the non-forecasting of exceptional small-scale situations and, on the other, the issuance of unwarranted alarms.

3.1 The Predictability of Flood Events

As far as the predictability of flood events is concerned, it is necessary first of all to debunk a common misconception. Whilst it is true that there are hundreds of hydrological rainfall-runoff models, it has however been abundantly demonstrated that, for the purposes of flood forecasting, the most important effect is the dynamics of the overall soil filling and depletion mechanisms and the resulting variation in the size of the saturated basin area, as a result of which the rainfall that falls in the basin has a direct effect on the flood discharges which is not attenuated by the soil's absorption capacity. These concepts have spawned models which are very widely used today and have been extensively described in the literature, such as the TOPMODEL (Beven and Kirkby 1979) and the ARNO model (Todini 1996).

Table 1 gives a list of the real-time systems based upon EFFORTS, which includes the ARNO model, that have been installed and have

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Table 1. Installation date, size of basins and EFFORTS performances expressed in terms of explained variance

Basin	Inst. Date	Area (km^2)	Expl. Var.
Po at Pontelagoscuro	1992	70091	n.a.
Fuchun at Lan Xi	1991	18236	0.96
Tiber at Rome	1996	16545	0.96
Tiber at Corbara	1993	6100	0.98
Adda at Lago di Como	1993	4572	n.a.
Arno at Nave di Rosano	1994	4179	0.98
Danube at Berg	1994	4037	0.94

become operational in the last five years together with the calibration results, expressed in terms of explained variance, the size of the catchment for which they were developed and the installation date. All the systems, except for the Po which is only based upon a hydraulic flood routing model, combine rainfall-runoff hydrological forecasting to hydraulic flood routing. Due to the presence of an additional real-time error correction term, actual EFFORTS forecast are generally better than those expressed by the calibration explained variances given in Table 1.

An explained variance of the order of 94–98% shows that the hydrological forecasting problem has in itself actually been resolved: the existing problems are frequently upstream and downstream of the hydrological model. In point of fact there is a lack of reliable and up-to-date rating curves and the geometrical descriptions are frequently approximate and/or rarely controlled; at the same time, very few authorities responsible for flood management have thus far seemed to show any real interest, during flood events, in an "uncertain" discharge forecast for an 8–12 hour horizon; but of even greater concern is the fact that so far it has not been possible to convince the competent authorities to carry out any trials with the systems which have been developed and are fully functional, in order to assess their real forecasting capability.

3.2 Predictability Horizon and Operational Requirements

It has been pointed out in the American literature that it is necessary to have real-time flood forecasts with an advance warning time of six–eight hours in order for these forecasts to be of any use and to allow measures to be taken to reduce the danger level or the damage connected with the flooding. It follows that when a real-time flood forecasting system has to be developed for a hydrographic basin, it is necessary to provide for a detailed and congruent structure that can be integrated in the problem according to its scale. As a rough guide, and in view also of the fact that there are not at this time any definite procedures for the local management of emergency measures in the case of flood events, it is necessary to set an advance time to which a quantitative forecast of the flood discharge must refer. On the basis of the many trials and experiences that have been conducted, it is reasonable to set this forecasting advance time at twelve hours so as to enable an organisational early warning phase to be mounted before the actual operational emergency is triggered.

It should be stressed that, in order to organise a flood service at various warning levels, the sequence of forecasts must generally be structured in the following way, with the precision of the forecasts steadily increasing as the forecast advance time diminishes:

1. Mesoscale qualitative-quantitative rainfall forecasts at 48–72 hours with a degree of precision that is modest at the local level but which is revealing in terms of how the overall event will unfold and develop.
2. Qualitative-quantitative limited area rainfall forecasts with an advance time of 24–48 hours.
3. Quantitative flood forecasts with an advance time of up to 12 hours, and where necessary with reduced precision, that is more than anything an indication of trend, up to 24 hours.

In order to predict the flood discharge quantities (case C, not to be confused with the rainfall forecasts of cases A and B) and to allow a quantitative forecast up to 12 hours in advance, the basins must be subdivided into three broad classes:

- *Large basins (>10000 km^2)*, for which the flood forecast with up to 12 hours advance warning in one section can basically be made on the basis of the water levels (or discharge quantities) recorded in one or more upstream sections. In reality this situation is found in Italy only for the lowland reach of the Po, where the travel time of the flood

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waves is approximately 72 hours from Becca to Pontelagoscuro.

- *Intermediate basins (1 000–10 000 km²)*, for which the flood forecast with up to 12 hours advance warning can be made on the basis of the precipitation measurements alone; in other words, the future rainfall has a negligible effect on the discharges which will occur in the next 12 hours as a result of the absorption times, the release of meteoric water by the soil and the displacement times of the runoff on the slopes and through the drainage network.
- *Small basins (100–1,000 km²)*, for which the flood forecast with up to 12 hours advance warning can be made only when a precipitation forecast is available, such as one that might for example be generated by a Limited Area Model.

Within the framework of the AFORISM project (A Comprehensive Forecasting System for Flood Risk Mitigation and Control), financed by the European Union (University of Bologna 1996), the possibility was first put forward of a hook-up between limited area meteorological models and real-time flood forecasting models; in this context, attention was drawn to the need to subject the meteorological forecasts to post-processing in order to adapt them to the real-time flood forecasting. More recent developments in research have shown that it is possible, using a Kalman Filter, to combine the limited area precipitation forecasts with the recorded measurements on the ground in order to obtain a realistic meteorological forecast to be used effectively as an input to the flood models. As an example of systems implemented for large basins, various water level real-time monitoring stations have for some years now been installed on the main stream of the Po from Becca to Pontelagoscuro and the data needed to make the forecasts is therefore available:

- Cross sections describing the river;
- Rating curves;
- Flood levels in various sections of the river and its tributaries.

For this section an automatic flood early warning system has been designed and in operation for over two years. The system, installed with the Po Water Authority, is based on the EFFORTS package (European Flood Forecasting Operational Real Time System), which allows flood forecasts to be made at all the discharge measuring stations between Becca and Pontelagoscuro (Fig. 5) and to make hydraulic evaluations in all the intermediate reaches (Todini 1992). The hydraulic flood routing is performed on the PAB programme (Todini & Bossi 1986) which has been shown to be unconditionally stable – a vital condition for a system which is required to operate in automatic mode in real time – and which has furnished excellent results on the Po and on other water courses. Downstream of the hydraulic model is a Kalman Filter which allows the model to be continuously adjusted to the recorded measurements. The flood event in November 1994 was correctly forecast both in terms of its size and



Fig. 5. The Po river real-time flood forecasting system based on EFFORTS

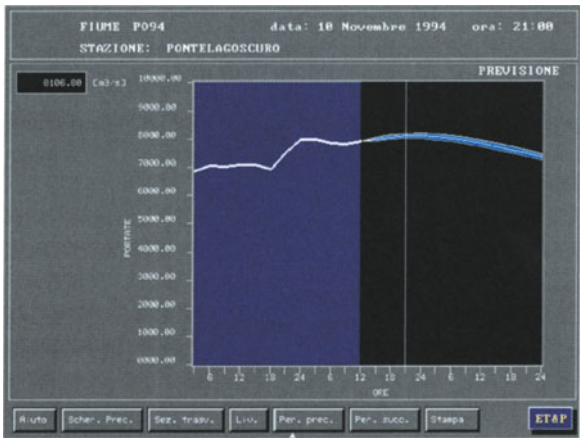


Fig. 6. Real time flood forecasts up to 36 hours in advance at Pontelagoscuro during the November 1994 flood in the Po river

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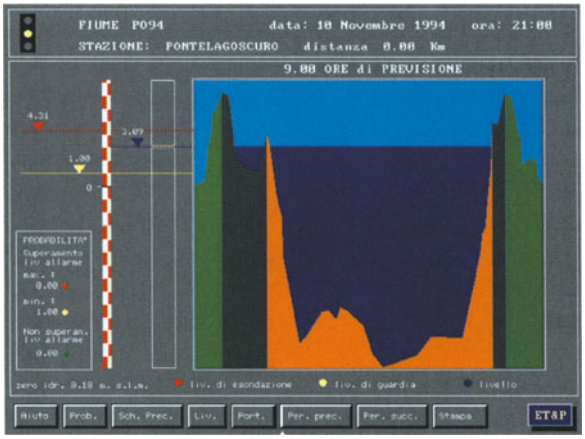


Fig. 7. The flood forecast and the cross-section at Pontelagoscuro (10-11-1994)

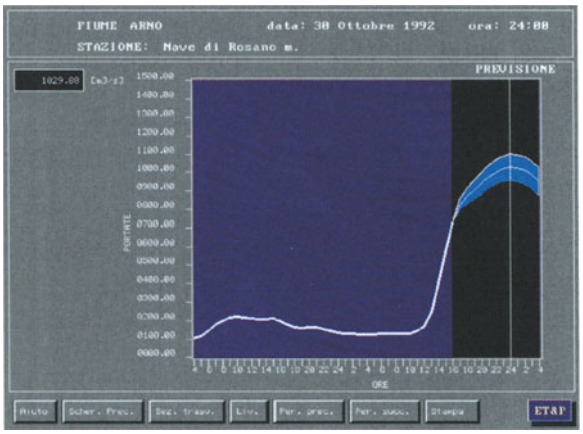


Fig. 9. Real time flood forecasts up to 12 hours in advance at Nave di Rosano during the 1992 flood event



Fig. 8. The Arno river real-time flood forecasting system based on EFFORTS

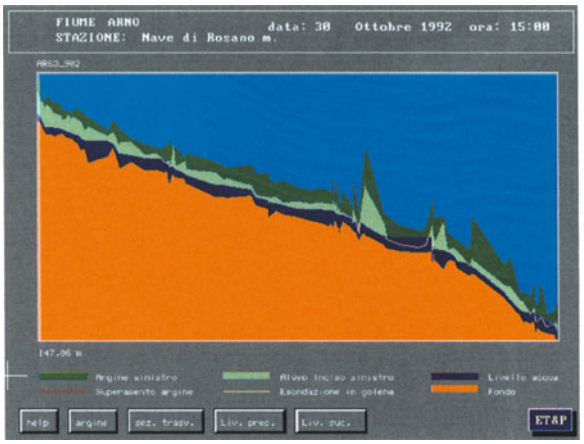


Fig. 10. Real time analysis of water profiles on the Arno to identify critical sections

in terms of time at Pontelagoscuro (Fig. 6 & 7), even though it was operating under impaired conditions as a result of the non-reception of the data from Becca, the upstream station and the most important site for the purposes of the forecasting. The system has since been enhanced with the possibility of transferring the data and the forecasts to another computer for follow-up analyses and for disseminating both through a local network and via remote modem link the information and displays available at the Po Water Authority's computation centre: at the present time the two peripheral centres of Rovigo and Mantua are linked up to the forecasting centre in Parma.

Examples of real-time flood advance warning systems for intermediate basins including both the rainfall-runoff models and the flood propagation models are provided by the systems designed, installed and in operation on the Arno at the Tuscany Public Works Office (Fig. 8, 9 & 10), on the Tiber originally developed for the control of the Corbara reservoir and successively extended as far as Rome for the Special Office for the Tiber and Agro Romano (Fig. 11), and lastly on the Danube, installed at the Flood Forecasting Centre at Baden Württemberg (Fig. 12).

Good quality results have been reported by several users: in 1993 on the Fuchun a peak flow forecast of 11 100 m^3/s was issued 36 hours in advance which compared very well with the actually recorded 11 200 m^3/s; on Lake Como, 12 hours in advance lake level forecasts have

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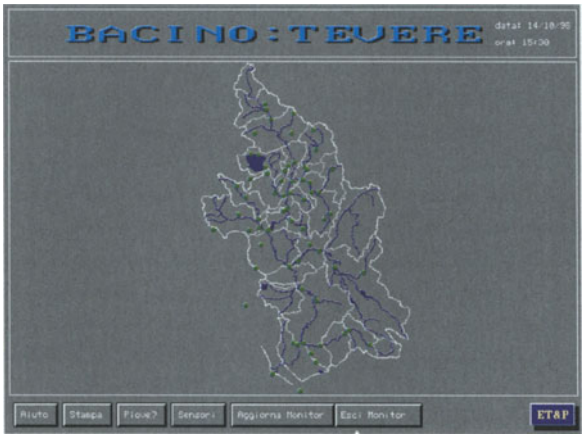


Fig. 11. The Tiber river real-time flood forecasting system based on EFFORTS



Fig. 12. The Danube river real-time flood forecasting system based on EFFORTS

Fig. 13. Operational real time flood forecasting on the Tiber at Rome during the period December 22nd 1993 – January 10th 1994. 12 hours in advance forecasts compared to the measured discharges

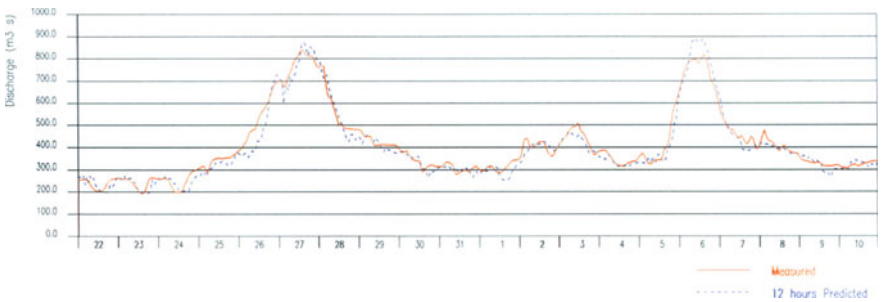
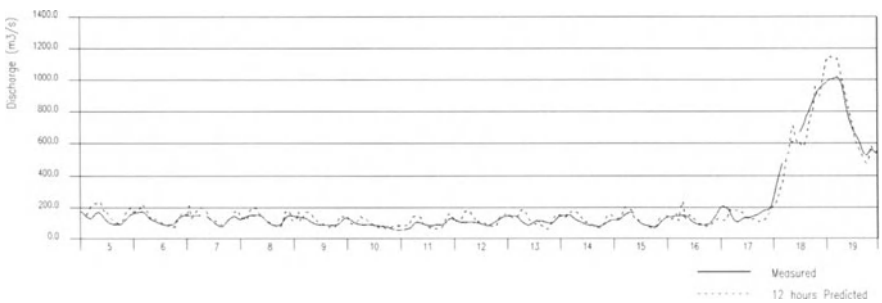


Fig. 14. Operational real time flood forecasting on the Tiber at Rome during the period November 5th 1996 – November 19th, 1996. 12 hours in advance forecasts compared to the measured discharges



been reported to be exceptionally accurate, with errors of the order of 1 cm; Figs. 13 and 14 show the succession of 12 hours in advance forecasts compared to the actual recorded flows on the Tiber for several flood periods and one can observe that the system operational forecasting reliability and accuracy are in line with the needs for implementing river control and flood remediation strategies.

As can be seen from these results, the problem of the short-term predictability of a flood event (up to 12 hours) can already be resolved for medium-large basins provided one has a real-time precipitation data acquisition system in place. However, the forecasting problem remains unresolved for a large variety of minor basins which would require quantitative future rainfall forecasts of a quality far superior to that provided by the present models. It should also be noted that all of this is well outside the field of what is known as "now-casting", which is very much in vogue among meteorologists and which could be of some use in the intermediate basins category.

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4 Extending Flood Forecast to Smaller Size Rivers: The Link to Limited Area Atmospheric Models

With regard to the problem of forecasting floods with at least 12 hours of forecasting lead time in smaller basins, different studies were recently undertaken aimed at operationally using the rainfall forecasts, provided by limited area meteorological models, better known as LAMs, as inputs to rainfall-runoff models.

Within the frame of the AFORISM project (A Comprehensive Forecasting System for Flood Risk Mitigation and Control), financed by the European Union (University of Bologna 1996), the possibility was first put forward of linking LAMs to real-time flood forecasting models. In a successive study carried out on behalf of the Flood Forecasting Centre of Baden Württemberg, it was concluded that it is still not possible to make direct use of LAMs meteorological forecasts, as input for the rainfall-runoff models and attention was drawn to the uncertainty of these precipitation forecasts which resulted in the need of developing a post-processor in order improve their reliability. Therefore, a realistic quantitative flood forecast for time horizons up to twelve hours in advance was obtained for the German part of the Danube by combining three successive forecasts provided by the German Meteorological Service (DWD) LAM (which operates on a $13.5 \times 13.5\ km^2$ mesh) with the precipitation measured on the ground by a remote rain gauge network.

The following figures illustrate the results. Figure 16 shows the discharges observed at the outlet of a small mountain sub-basin measuring approximately $290\ km^2$ as indicated in Fig. 15, and the forecasts made at 4, 8 and 12 hours in advance on the assumption that no more rainfall will follow the last measurement time: the pronounced underestimation of the discharge values provides verification that if the forecast is to be extended to short time horizons, then the future rainfall must be known.

Figure 17 shows the flood forecast performed on the basis of the rainfall predicted by the DWD without any processing: in this case it is seen that the discharges are markedly overestimated to such an extent that they cannot realistically be used for an operational flood forecasting system designed for the management of emergency situations.

By contrast, Figure 18 shows that, after processing the data using a Kalman filter, the rainfall forecast, and consequently the flood forecast, generates values that are only slightly dif-

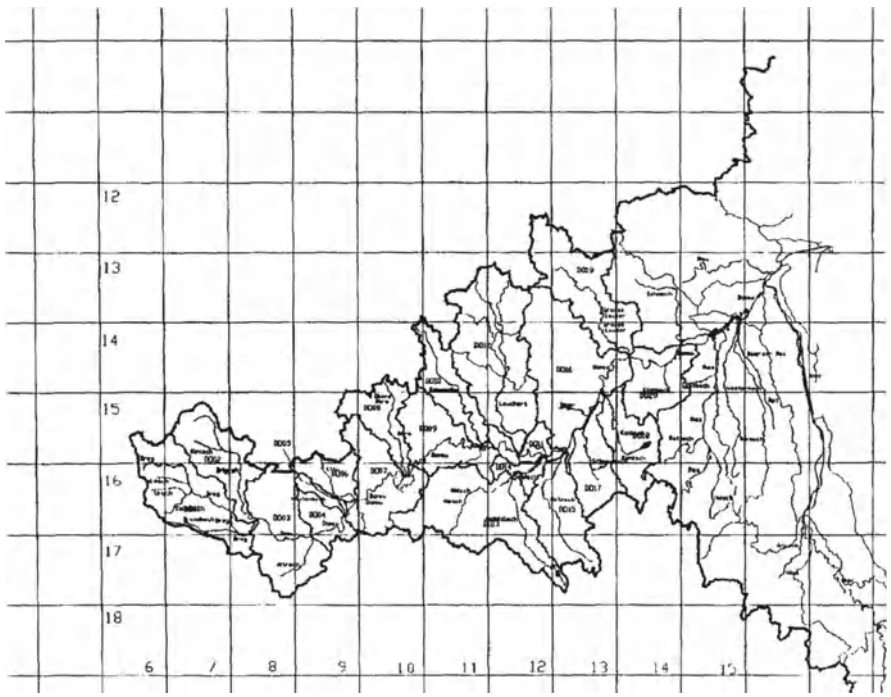


Fig. 15. The catchment and the sub-catchments in the Danube real-time flood forecasts model and the DWD Limited Area Model grid points

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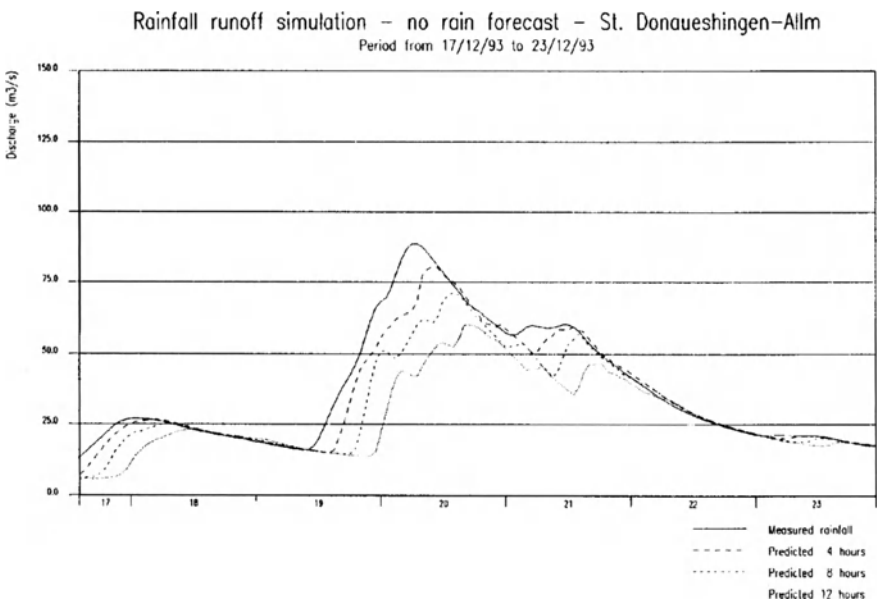


Fig. 16. 4-8-12 hours in advance real-time flood forecasts on the Danube at St. Donaueschingen-Alm setting future rain equal zero

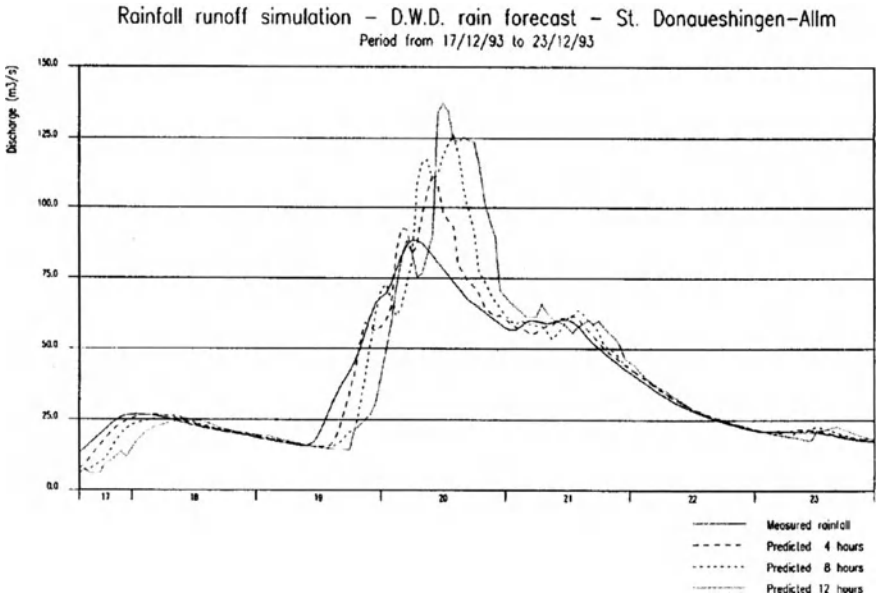


Fig. 17. 4-8-12 hours in advance real-time flood forecasts on the Danube at St. Donaueschingen-Alm using DWD precipitation forecasts

ferent from the observed data and can therefore be used at the operational level.

As mentioned earlier, research in this domain is still under development with the projects TELFLOOD and PRIMAVERA. Within the frame of the PRIMAVERA project this link is under assessment, and very soon real time precipitation forecasts based on a combination of ground measured precipitation and the one predicted by the Atmospheric Limited Area Models will be available.

The study is carried out on a sample catchment: the Reno at Casalecchio (Italy), whereby the catchment of approximately 1 000 km^2, shown in Fig. 19, was divided into 7 sub-catchments (Fig. 20). Data were collected for 26 raingauges, 10 temperature gauges and 2 level gauges on a hourly basis over a period of six years. Nine flood events, listed in Tab. 2 in descending order of importance, were identified and used in the study.

Using the selected case studies, the ground measured precipitation was compared with the one forecasted at different lag times by the LAM in terms of average hourly precipitation over the entire catchment. Figure 21 shows

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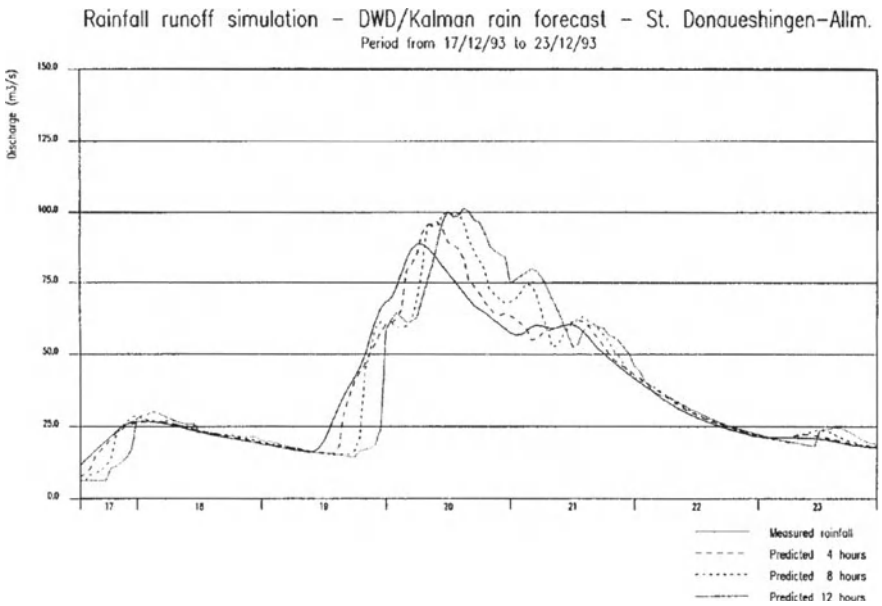


Fig. 18. 4-8-12 hours in advance real-time flood on the Danube at St. Donaueschingen-Alm using Kalman filter corrected DWD precipitation forecasts

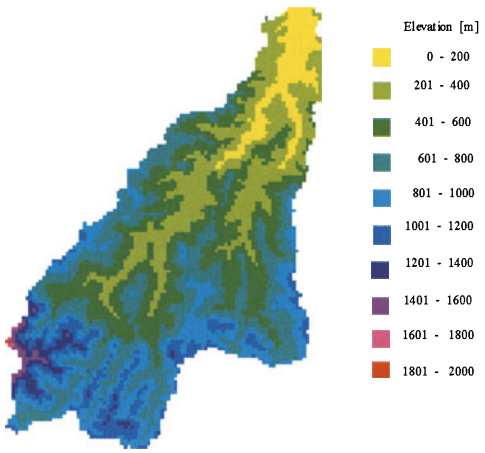


Fig. 19. Digital elevation map of the Reno river at Casalecchio

Table 2. Flood periods used as case studies in the PRIMAVERA project

Event	Date	Year
1	18–25 September	1994
2	10–17 June	1994
3	2–11 December	1992
4	27–2 October/November	1992
5	29–9 September/October	1993
6	4–11 November	1994
7	30–3 December/January	1993–94
8	13–18 April	1994
9	18–22 October	1993

both the bias and the standard deviation of the differences, assumed as forecasting errors. A marked daily cyclicity can be observed with larger errors during the night and values of the standard error oscillating between 0.7 mm/h and 1.5 mm/h. At a first glance one could consider these errors as small, nevertheless one has to bear in mind that with a catchment area of 1 000 km^2 these values correspond to 200–400 m^3/s in terms of discharge.

Although a more accurate analysis will only be possible using the rainfall runoff model to account for the dumping effect of the filling and draining of the soils, if one assumes, as a first order approximation, that errors are normally distributed, it follows that 98% of the precipitation forecasting errors will fall between 400 and 800 m^3/s, in a river where the maximum observed discharge is less than 2 000 m^3/s; these values are definitely excessive to allow for an operational real time flood forecasting.

On the other hand statistical precipitation forecasting models may be better for very short lead times (<2–3 h) but they tend to diverge when the required lead time increases.

Figure 22 shows for example the bias and the standard deviation of a statistical precipitation forecast provided by the Nearest Neighbour technique (Yakowitz 1987; Yakowitz & Karlsson 1987). One can see that although unbiased, the standard deviation of errors, initially of 0.5 mm/h, rapidly reaches values of over 4 mm/h.

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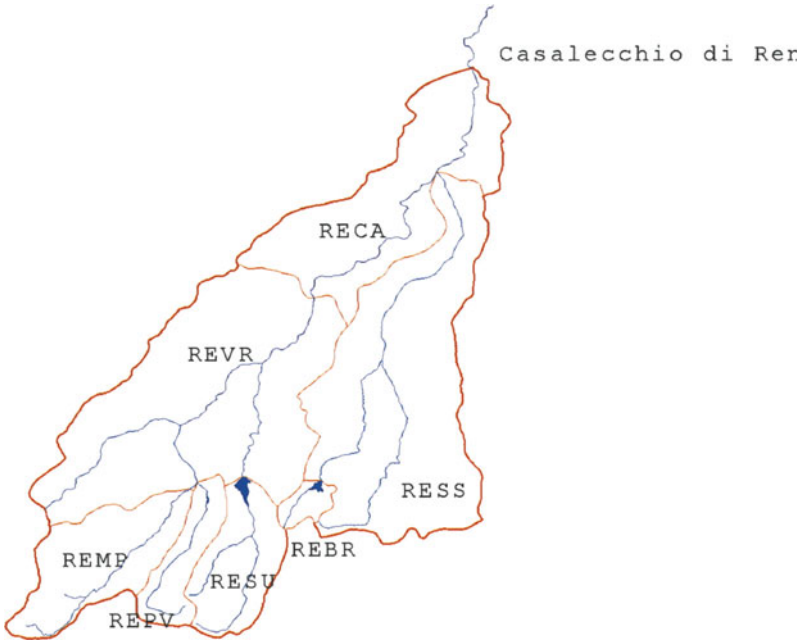


Fig. 20. Sub-catchments identified in the Reno river at Casalecchio

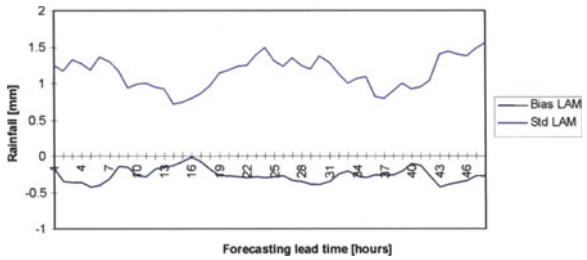


Fig. 21. Bias and standard deviation of LAM areal precipitation forecast as compared to rain gauge measurements

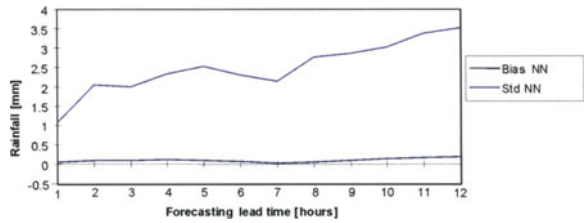


Fig. 22. Bias and standard deviation of the Nearest Neighbour areal precipitation forecast as compared to rain gauge measurements

The technique set up under the PRIMAVERA project uses a Bayesian combination of a set of twenty Nearest Neighbour precipitation traces, conditional to the latest ground measurements, with the LAM forecasts taken as biased and noise corrupted measurements of future precipitation. The obtained results are definitely encouraging: as one can see in Fig. 23, the combined forecast is totally unbiased and shows a standard deviation varying form 0.5 to 1.1 mm/h (150 to 350 m^3/s). Figures 24 and 25 clarify the increase in forecasting reliability obtained which is due to the mutual independence of the stochastic and the deterministic model errors. In Fig. 24 the LAM forecast is good, while the stochastic forecast, initially good, rapidly degenerates; Fig. 25 shows the opposite situation in which the LAM totally misses the event. In both examples, the combination of the two forecasts provides a less erratic forecast, which was the objective for the development of the post-processor.

Finally the technique insures not only an average forecast, but a full set of corrected precipitation traces to be transferred to the outlet using the rainfall-runoff model and the routing model, in order to estimate the uncertainty in terms of flood and to be used within the frame of stochastic decision frameworks.

5 The Need for a Flood Planning and Management DSS

The EU is extremely sensitive to the flood problem. In a recent message to a workshop organised by the RIBAMOD (RIver BAsin MODelling, management and flood mitigation) Concerted Action, Mme E. Cresson, the European Commissioner for Research, Innovation, Educa-

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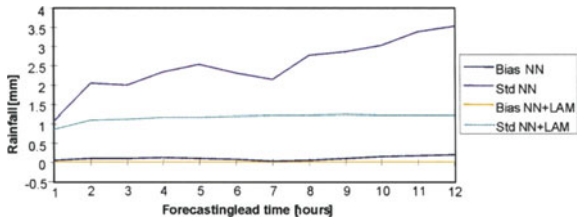


Fig. 23. Bias and standard deviation of the Nearest Neighbour precipitation forecast (NN) and of its Bayesian combination with the LAM forecast (NN+LAM)

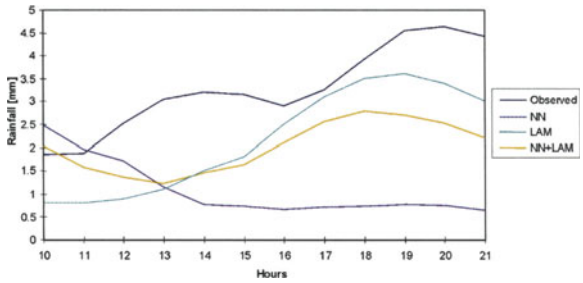


Fig. 24. Observed precipitation compared to the average stochastic forecast, (NN) the LAMs forecast (LAM) and their Bayesian combination (NN+LAM) for Reno at Casalecchio on June 11, 1994

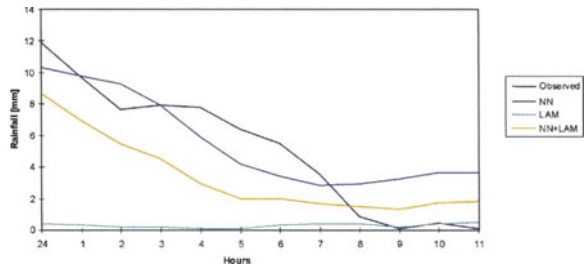


Fig. 25. Observed precipitation compared to the average stochastic forecast (NN), the LAMs forecast (LAM) and their Bayesian combination (NN+LAM) for Reno a Casalecchio on September 21, 1994

tion, Training and Youth, expressed her concern for the economic and human tragedy of flooding for the citizens of Europe and the vulnerability of our sophisticated society to natural hazards and risks. She thanked the European scientific community for its response to her initiative of establishing RIBAMOD Concerted Action on flooding and for the results already available. Mme Cresson identified natural and technological risk as an area which the Commission proposes for action under the forthcoming Fifth Framework Programme.

Moreover, several research projects have already been funded on the subject and more specifically, after the report of an Expert Meeting, held in Padua in September 1997, states:

The need for holistic flood management

The mitigation of flood damage and loss does not only depend upon the actions during floods but is a combination of flood preparedness, operational flood management and post-flood reconstruction and review.

Pre-flood activities include:

- Flood risk management for all cause of flooding and disaster contingency planning;
- construction of physical flood defence infrastructure and implementation of forecasting and warning systems;
- land-use planning and management within the whole catchment;
- discouragement of inappropriate development within the flood plains, and
- public communication and education of flood risk and actions to take in a flood emergency.

Operational flood management can be considered as a sequence of four activities:

- Detection of the likelihood of a flood forming (hydro-meteorology);
- forecasting of future river flow conditions for the hydro-meteorological observations;
- warning issued to the appropriate authorities and the public regarding, severity and timing of the flood, and;
- response by the public and the authorities.

Depending upon the severity of the event, the post-flood activities may include:

- Relief for the immediate needs of those affected by the disaster;
- reconstruction of damaged buildings, infrastructure and flood defences;
- recovery and regeneration of the environment and the economic activities in the flooded area, and

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- review of the flood management activities to improve the process and planning for future events in the area affected and more generally, elsewhere.

Given the large number of high risk situations as well as the extremely high costs in terms of casualties and damages involved in flooding the implementation of all the structural and non-structural measures aimed at its reduction, becomes essential in this holistic view of the problem.

While structural measures can be implemented with a sufficient degree of reliability in areas where the anthropic pressure is low, when dealing with heavily anthropised areas, and in particular in urban areas, the need for non-structural measures becomes extremely high. There are essentially four different non-structural measures to be realised for flood control. The first one is the identification of the areas of high flood hazard and the development of flood risk maps. The second is the setting up of reliable real-time flood forecasting and warning systems that allow for an operational forecasting lead time (not less than 6 hours possibly 12). The third one is the definition of flood risk emergency plans, with the preparation and the distribution to the Authorities in charge of a sort of unified Manual of Procedures describing, for each area at risk, the delineation of the flood threaten area, the risk thresholds, the Authorities in charge, the action to be taken, who to alert, etc. etc. The last non-structural measure is the development of an integrated Decision Support System aimed on the one hand at centralising the information in an Operational Emergency Unit, and on the other hand at monitoring and coordinating the activity of all the groups involved on the basis of the Manual of Procedures, given that the main problem during flood events has been identified as the lack of coordination among the plethora of Authorities and organisations operating for flood damage alleviation.

6 Aims and Structure of FLOODSS

Following the non-structural measures requirements, a FLOODSS (FLOod Operational Decision Support System) project was recently started in Italy, with the objective of implementing a Decision Support System (DSS) for Inundation Risk Evaluation and Emergencies Management aimed at analysing and anticipating catastrophic flood events and at preventing and mitigating their effects on the economical, social, environmental and cultural heritage. FLOODSS responds to the need of an integrated tool that, taking advantage of available High Performance Computer platforms allows, for planning purposes, (1) to locate areas at risk and to estimate expected damages; (2) to forecast floods and inundation phenomena on the basis of real-time analysis of the present meteorological situation and of forecasts available at different time and space scales; (3) to evaluate the effects of decisions aimed at reducing social, economical and environmental damages on the basis of planned or real-time forecasted scenarios; (4) to allow continuous training of personnel.

FLOODSS, presently under development within the frame of the project DESIREE, recently funded by the EU, is based upon the experience gained in national and international R&D projects such as EFFORTS (European Flood Forecasting Operational Real Time System; 1988–1991) (ET&P 1992, Todini et al. 1997a), which produced a real time flood forecasting package already operationally installed on several rivers in Italy, in Germany and China; AFORISM (A comprehensive FOrecasting system for flood RISk Mitigation and control; 1990–1993) (University of Bologna 1996) which produced a feasibility study for what is being proposed under the FLOODSS project; ODESSEI – Open architecture DEcision Support System for Environmental Impact assessment, planning and management (EUREKA-EU487; 1994–1997), which allowed for the development of an open architecture framework under which FLOODSS will be structured; TELFLOOD (Forecasting Floods in Urban Areas Downstream of Steep Catchments; 1996–1998) and PRIMAVERA (Previsione Regionale Idro-Meteorologica Accoppiata per la Valutazione delle Emergenze e del Rischio di Alluvione; 1997–1998) that are studying the link between Limited Area Meteorological Models quantitative rainfall forecasts and flood forecasting models.

Following the findings of AFORISM, FLOODSS will allow quantitative impact analyses on the basis of environmental, social, economical criteria by combining flood maps (generated by simulation or real-time forecast-

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ing models) with geo-referenced data (land use maps, cadaster maps, road maps, traffic information, etc.) using several tools developed in the ODESSEI project FLOODSS will also allow for the link to real-time hydro-meteorological data acquisition systems and to real-time flood forecasting systems.

Figure 26 shows the overall schematic diagram of FLOODSS, that will include at full development:

- a set of relational and mathematical models;
- a statistical model of rainfall extremes (GEV–Generalised Extreme Values distribution);
- a hydrological semi-distributed rainfall-runoff model (ARNO);
- a one-dimensional flood routing model (PAB);
- a combined one-dimensional/two-dimensional flood plain inundation model (CVFE);
- a socio-economic and environmental impact assessment model.

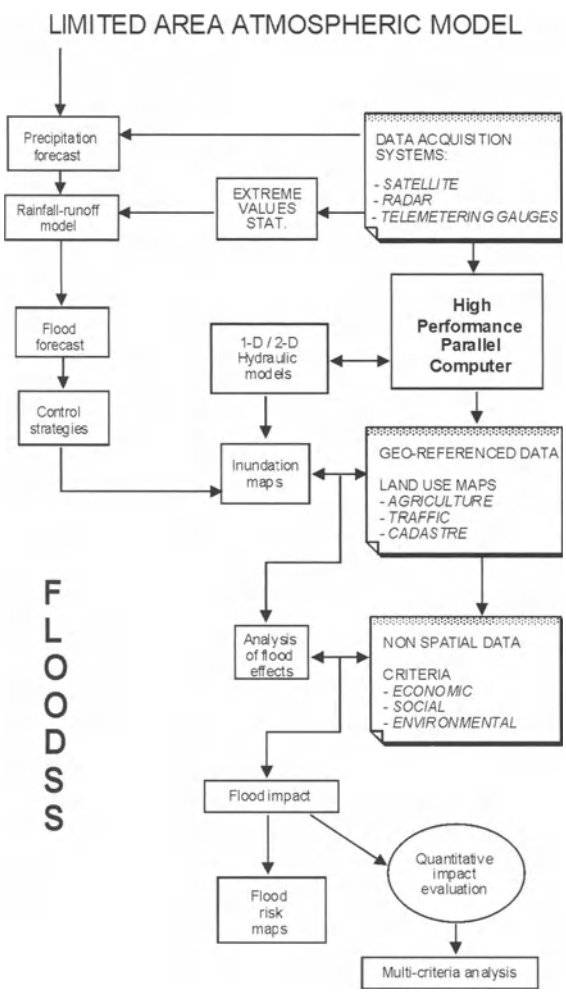


Fig. 26. Schematic representation of FLOODSS

A knowledge-based system which manages data flows to and from the database; executes the mathematical models in a supervised sequence; organises and compares the performed scenarios; guides the user in making decisions regarding a particular issue or problem.

A database management system, which includes a series of primary and secondary data treatment procedures, designed to optimally manage the historical series of meteo-climatic measures (rainfall, temperature, etc.), information concerning watershed entities (rivers, sub-basins, etc.) and the socio-economical and environmental data.

A geographical information system or GIS which allows the management of geo-referenced data, with the typical recent GIS spatial analysis tools, while the data interchange between the GIS and the models is optimised by knowledge-based system procedures.

An user interface which is extremely advanced and, at the same time, easy-to-use; it allows an extensive visualisation of complex information, in order to support qualitative analysis and interpretation of results.

6.1 Requirements of the Operational Real Time Forecasting Component

To return to the central question of the factors involved in the forecasting and management of flood events, it was seen that there are three forecasting levels, comprising firstly two meteorological forecasts (A and B) and then one flood forecast (C). In operational terms, it therefore follows that a flood monitoring, forecasting and management system is required which provides for different degrees of detail and which must therefore be structured around several modules: from the monitoring of the data and the meteorological forecasting to the automatic flood forecasting and advance warning of risk situations, and finally to a detailed analysis of the courses of action and decision-making support, as has been highlighted by the AFORISM project.

Downstream of the meteorological forecasting, the various levels at which it is necessary to organise the system comprising the monitor-

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ing, early warning, forecasting and decision-making support to the management of flood event emergencies, must adhere to the following scheme:

1. Real-time data acquisition.
2. Real-time analysis, verification and, if necessary, reconstruction of the missing data.
3. Automatic rainfall forecasts based on the latest measurements and on any forecasts that may have been generated by the Limited Area Models.
4. Automatic flood forecasts, based on the observed measurements and the rainfall forecasts, using continuous forecasting models, in which the saturation condition of the soil is constantly updated.
5. Automatic flood forecasts and routing along the river reaches using hydraulic models which provide for the identification of the key critical areas.
6. Implementation of possible intervention simulations and verification of their effects; in this last phase of analysis which corresponds to a declared state of emergency, all of the activities included in points 2., 3., 4. and 5. above, which represented the early warning phase and which necessarily had to be implemented in automatic form, can be reviewed and modified in assisted semi-automatic form, in order to verify the effects of possible alternative courses of action.

Note that point (2) above, which is frequently overlooked, is by contrast of paramount importance. In real time it is in fact essential that there are no breaks in the flow of input data to the forecasting model and the reconstruction of missing data, where necessary, must be performed using reliable procedures and in fully automated fashion: it is of course unthinkable that an operator should sit at the terminal around the clock and reconstruct the missing data using more or less manual procedures.

Another binding aspect for the successful application of real-time flood forecasting systems lies in the cooperation that can be established with the authorities operating the system. Due to the fact that floods do not occur very frequently, operational people tend to forget the use of the flood forecasting systems and this is why automatic forecasting and warning systems such as EFFORTS should always be present as part of an overall forecasting/simulation decision-support system with monthly procedures made available to the personnel in charge in order to constantly keep them fully operational.

6.2 The Flood Planning and Management DSS

An overall flood planning, warning and control DSS can be defined to meet the needs of the end-users. The three groups of people participating in the system are: meteorologists/hydrologists, operational managers and civil response managers (Fig. 27).

The communications links required between these three groups have been examined. The total planning and warning system consists of two parts: a technological part and a social part (Fig. 28).

The technological subsystem is run by meteorologists and hydrologists and consists of rain gauges, river gauges, and meteorological forecasting systems, which together provide data for hydrological and flood-forecasting models, and decision support tools.

These are, in turn, made available to the operations managers. The data, models and decision support tools are interrogated by the operations managers to meet both their own needs and other requests. Relying on this, the operations manager may issue warnings to the civil defence manager. The civil defence manager interacts with the media, the police, other officials and the public, both directly and indirectly. This forms the social subsystem of the overall total warning system. Acknowledging of the following lessons are important for the design and operational success of the technological subsystem of the DSS. In other words:

- Decisions must be clear;
- decisions must also specify what is the appropriate response;
- the source of the decisions must be credible;
- decisions must be reinforced locally;
- the medium used in issuing the decisions and the warnings must be suited to the circumstances of the specific case;

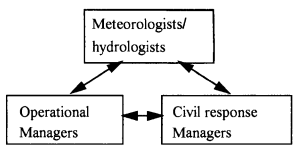


Fig. 27. The three groups participating in the system

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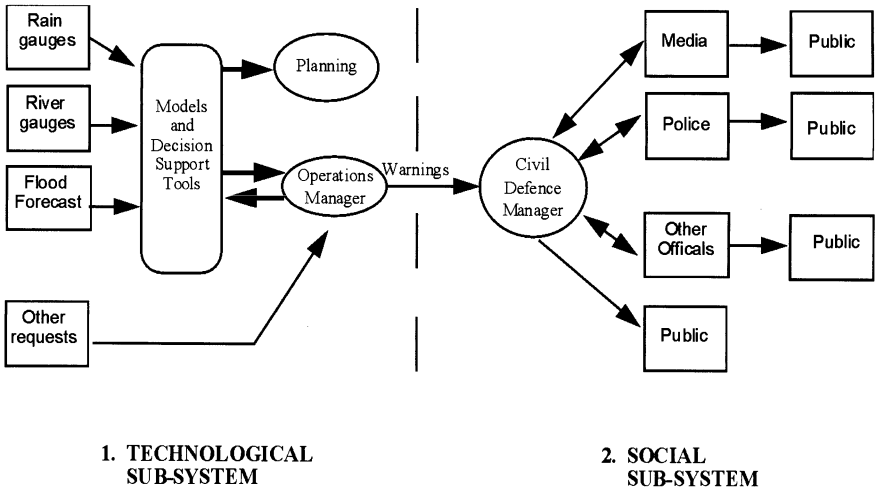


Fig. 28. The Technological and Social Sub-systems

- the type of appeal to the public must be tailored to the public audience.

The implications which derive from this for a decision support system are two-fold:

- Models, user-interfaces etc., must present clear, unambiguous predictions and courses of action;
- specific instructions on the appropriate response, must accompany all warnings.

On the basis of the above mentioned items it is possible to develop a DSS which directly responds to the needs of planners with the capability of answering questions such as:

- which areas are at risk of flooding?
- which areas are more vulnerable?
- is it possible to build in these areas?
- what is the social, environmental cost of flooding?
- which is the most appropriate intervention measure? etc.

To reach this objective the system must include an ensemble of tools all integrated and linked to a relational data bank, to a Geographical Information System (GIS), to a Knowledge Based System (KBS) and to an advanced and interactive Graphical Users Interface (GUI). At present ET&P has already developed a similar integrated package for environmental impact analysis at catchment scale, namely the ODESSEI (Open architecture Decision Support System for Environmental Impact analysis) system (Todini and Bottarelli 1997b), which already includes several tools which are essential for flood planning and flood warning, such as:

- A GIS which allows for automatic catchment identification, river identification, setting up and calibration of rainfall-runoff models as well as of one and two-dimensional hydraulic models.
- A KBS which helps the user at three different entry level ((1) decision level, (2) technical level, (3) model and data management) to navigate into the system and to find the answers to the queries.
- An advanced and interactive GUI which enables the user to obtain an immediate insight into the problem to be solved by setting up in an interactive mode all the necessary data and conditions and by looking at the results in a one, two, or three dimensional high definition graphics.
- A hydrologic model known as ARNO which has already been used for flood forecasting in several basins in different countries (Todini 1996);
- A hydraulic one-dimensional river routing model, the PAB (Todini and Bossi 1986);
- A combined one/two dimensional flood plain inundation model based on the control volume finite element approach (CVFE) (Di Giammarco et al. 1996).

The DSS allows high level graphic manipulation of data thanks to its 2D and 3D rendering modules based upon AVS (Advanced Visual System) - EXPRESS. It is possible to visualise these data geo-referencing them on the territory thanks to the GIS modules of the system (a modified version of GRASS where several vector routines have been corrected and extensively re-written at ET&P). The software supports typical GIS

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operations. These operations may help the user in using the data in order to:

- visualise maps,
- retrieve alphanumeric information regarding a specific graphic element (i.e. road, river, railway etc...),
- generate and print thematic maps,
- modify existing maps,
- graphically visualise the result of a query.

In addition the GIS capabilities are fully integrated with the models and can be used for instance to identify from the Digital Elevation Map a specific catchment boundary, its geomorphological characteristics, the drainage network, and to set-up a rainfall-runoff model) by linking the precipitation data at geo-referenced stations to the selected catchment area (Fig. 29). All objects are managed and integrated so as to create a logical sequence of operations to answer the user requirements and the user is guided in his choices by a set of expert system rules and controls which help him in solving the proposed problem.

The available tools and the structure of ODESSEI is kept in FLOODSS, where a flooding problem may be viewed as a cascade of the following operations:

- Estimation of the precipitation intensity for given duration and return period;
- estimation of peak flow and hydrograph shape (possibly using a rainfall-runoff model);
- 1-D routing and identification of over-banking areas;
- 1-D/2-D simulation and evaluation of the inundated areas, together with flow velocity and residence time, and production of a flood hazard map;
- assessment of vulnerability of the area and production of flood risk maps.

6.3 Flood Planning Tools

The study and evaluation of flood risk are generally based on a two-stage procedure. During the first stage (Rossi & Villani 1992), the statistical probabilities of exceeding (propensity for over-banking) is evaluated on the basis of the combination of statistical models of extremes, hydrological models and hydraulic models. During the second stage, the surrounding territory's greater or lesser capacity to eliminate water (propensity for flooding) is evaluated based on two-dimensional hydraulic models.

In other words, on the one hand, the level of danger of the watercourse must be evaluated, and this depends essentially on three elements:

1. Probability of rainfall in the upstream basin;
2. the geo-morphological features and land-use of the upstream basin;
3. the hydraulic features of the river section in question.

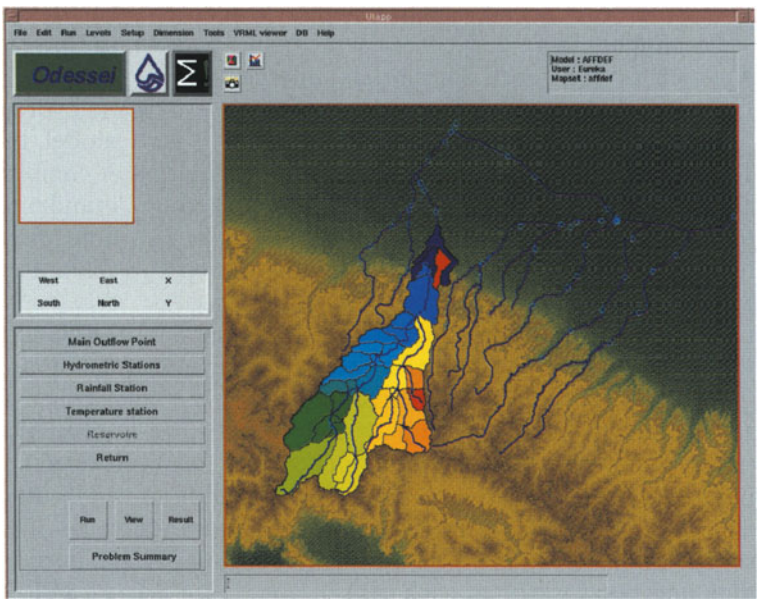


Fig. 29. Automatic identification of catchments and drainage network in the Reno river

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Once it has overflowed its embankments, the water may be discharged downstream and re-enter the riverbed without causing excessive damage, or it may spill into the surrounding territory with no possibility of draining away, thereby rising to levels capable of causing damage to people and property. This drainage capacity is analysed using hydraulic two-dimensional mathematical models to identify the three elements essential to evaluating possible damage: the maximum water level reached, the velocity of the water, and the amount of time it remains in a given area (Di Giammarco et al. 1994).

Guidelines and examples of overflow risk evaluation can be found in several reports (US Water Resources Council 1972), but estimation of the extent of the surface area being flooded as well as of its socio-economical consequences requires a considerable amount of work (detailed surveys, hydraulic modelling, land-use assessment, socio-economical damage evaluation, etc.), and in most countries is only carried out for particular risk areas and not extensively throughout the territory.

6.4 Flood Plain Inundation Models

Unless the water overtops dikes and spreads over the flood plain, rendering the one-dimensional description inadequate, the one-dimensional channel flow is reasonably accurate. The literature contains a large number of one-dimensional numerical models suitable for describing channel routing. They differ according to the accuracy required and the degree of approximation of the complete equations, the solution methods and the particular discontinuities in the propagation which they are able to handle (sudden geometrical changes; presence of dams, bridges, etc.). FLOODSS makes use of the PAB (Parabolilc And Backwater) approximation of the full De Saint Venant equations (Todini & Bossi 1986), fully integrated into the GIS and the relational Data Bank where the river cross sections are stored in vector form and the historical data are geo-referenced. This allows for an automatic and guided setting up of a 1-D problem, by identifying the river reach with the mouse (Fig. 30), selecting the appropriate boundary conditions (upstream incoming flood and downstream level or rating curve condition) (Fig. 31 & 32) and analysing the areas where over-banking may occur (Fig. 33). Quasi-two-dimensional models have also found application in the study of flood events; in these the flooded area is described by a series of reservoirs and channels whose position may correspond more or less to their exact spatial arrangement in the area in question (Di Giammarco et al. 1994).

The main advantage of a two-dimensional model is the possibility of handling the whole domain in the same way, without necessarily

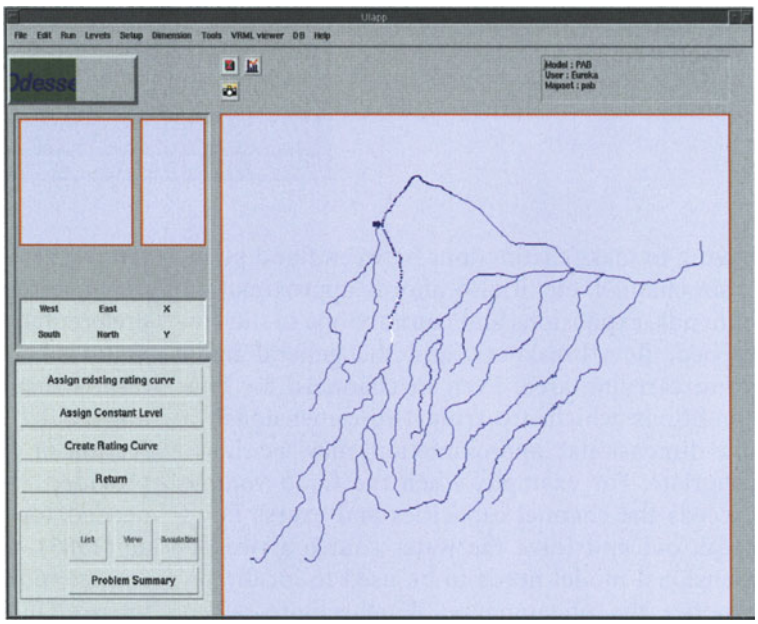


Fig. 30. Selection of a specific river reach for 1-D flood routing

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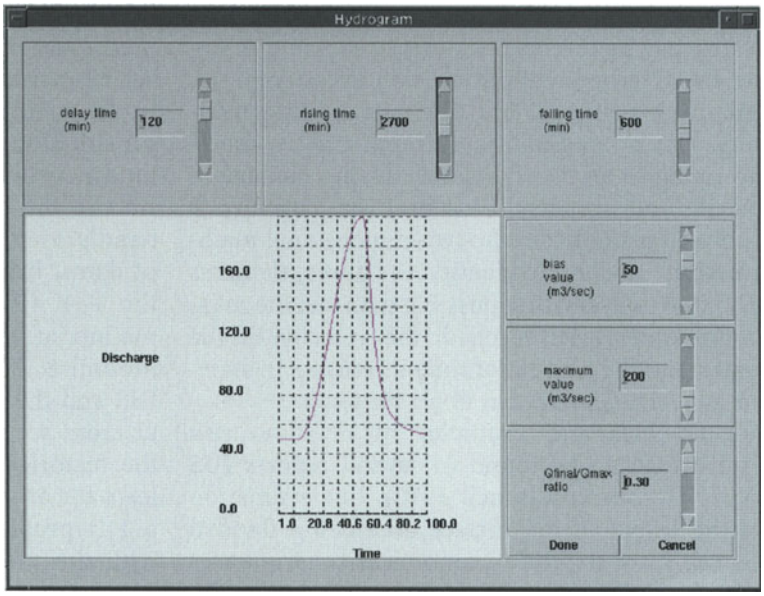


Fig. 31. Selection of an upstream hydrograph

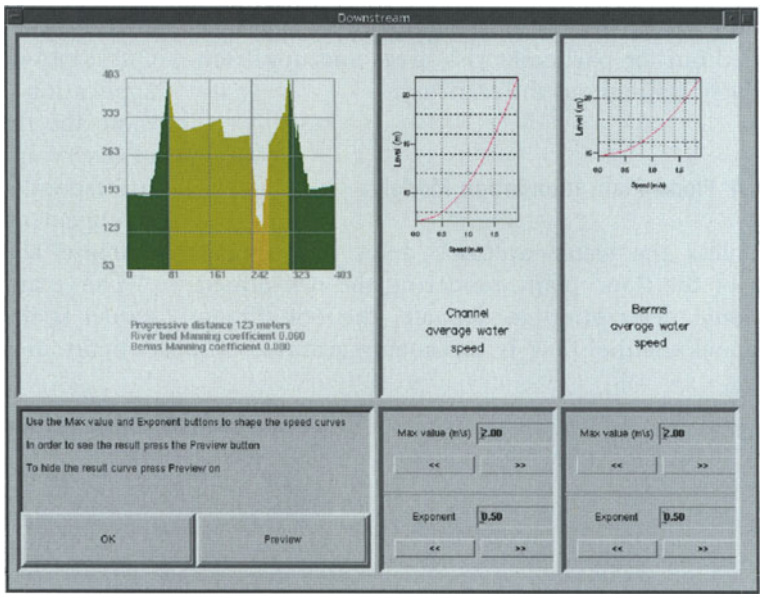


Fig. 32. A simplified procedure for setting up a downstream boundary when a rating curve is not available

having to make distinctions between flood plain, main channel, etc. it also affords approximation of bends, expansions and contractions of the river bed, flow breakouts, and the general main flood carrying area. Even in channels, for flow conditions which are truly two-dimensional, a one-dimensional approximation may be inappropriate. For example, when the flood volume exceeds the channel capacities and excess flows break out and leave the water course a two-dimensional model needs to be used to locally reproduce the phenomenon. Furthermore, when rivers present accentuated meandering, a flood may overtop the bends and change the original preferential flow direction. As a consequence, a major advantage of a two-dimensional description is that the construction of the model does not require "a priori" knowledge of the main direction of propagation which may vary in time, provided that the model is supplied with the needed topographic information. Hromadka et al. (1985), among others, developed a finite difference model based on an integrated finite difference (IFD) version of the nodal domain inte-

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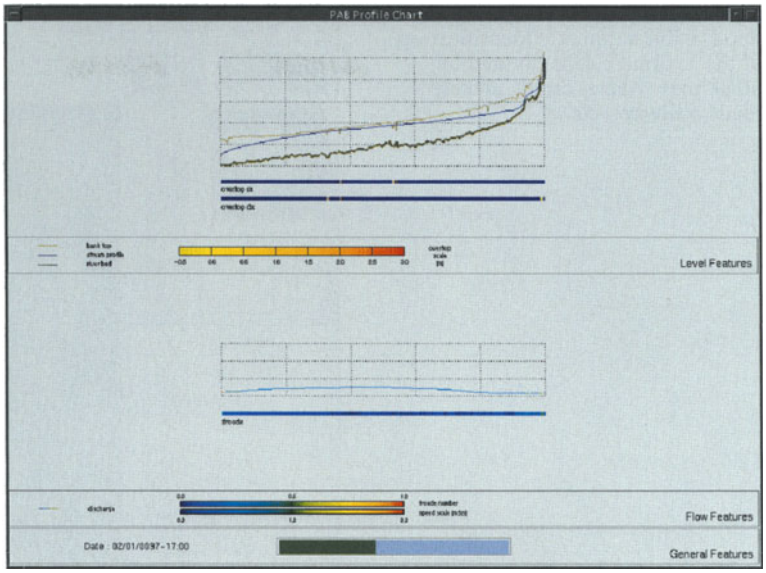


Fig. 33. Analysis of 1-D flood routing results

gration model (NDI) in which the discretisation in polygons (control volumes) is based on an irregular triangular discretisation. A comparison of the results of the two-dimensional diffusive approach and the results obtained from a one-dimensional approach based on the use of complete equations in the case of two-dimensional dam-break flood plain over a broad, flat plain shows that the former is able to furnish a valid representation of the problem, especially when the flow can break-out of the main channel and then return to the channel at other downstream reaches. One solution of the two-dimensional overland flow problem using FE method can be found in Galland et al. (1991) and Katopodes (1980 & 1984).

Given the lack of capability for the standard Finite Element (FE) approach to locally preserve the mass balance equation, as demonstrated by several authors, but in particular by Patankar (1980), which generally results in heavy oscillations of the solution, a new approach was introduced for flood plain modelling, which combines the advantages of the control volume approaches to the FE capability of describing the two-dimensional gradient and flow, namely the Control Volume Finite Element method (CVFE) (Di Giammarco et al. 1996). The CVFE, like any other control volume based method and, hence, like the IFD method, is based on assigning the conservation of mass to each control volume, the shape and position of which is known with precision. In this case attention is focused on a defined volume, fixed in space – the control volume – whose shape and position is chosen arbitrarily but is invariable in time, and the balance equations are written for each such volume.

The spatial discretisation of the domain can be obtained by making use of triangular elements. In particular, the choice of linear triangular elements turns out in a linear approximation of the soil altitude inside each triangle as well as in constant values of the Manning's coefficients in each triangle.

The flexibility of the triangular element discretisation structure permits the accurate spatial reproduction of the domain, even in the case of complex geometry. This feature turns out to be of particular interest for convergent hill-slope area faces and to represent sharp gradients near streams. The dual definition of the polygons (control volumes) which act as the basis for determining the exchanges between adjoining nodes (and on which the balance equations are set) ensures the immediate physical interpretation of the quantities present in the discretisation equation.

FLOODSS fully integrates the CVFE model with the Expert System and the GIS so that all operations required to set up the model of a particular area are simplified and can make full use of the available geo-referenced data such as river cross sections; digital terrain model; land use maps; dykes, roads, railways position and elevation, etc..

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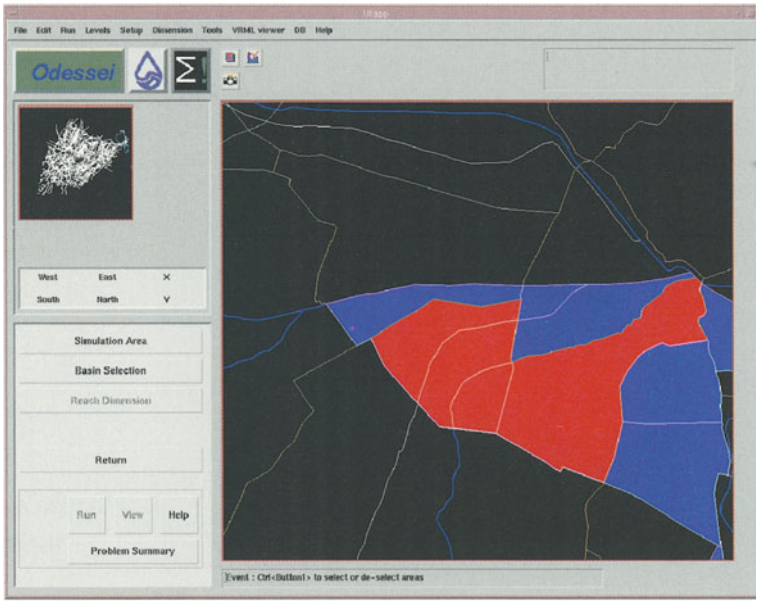


Fig. 34. Selection of an area in the flood plain: automatic identification of the hydraulic cells divided by breaklines (rivers, canals, dykes, roads, railways, etc.)

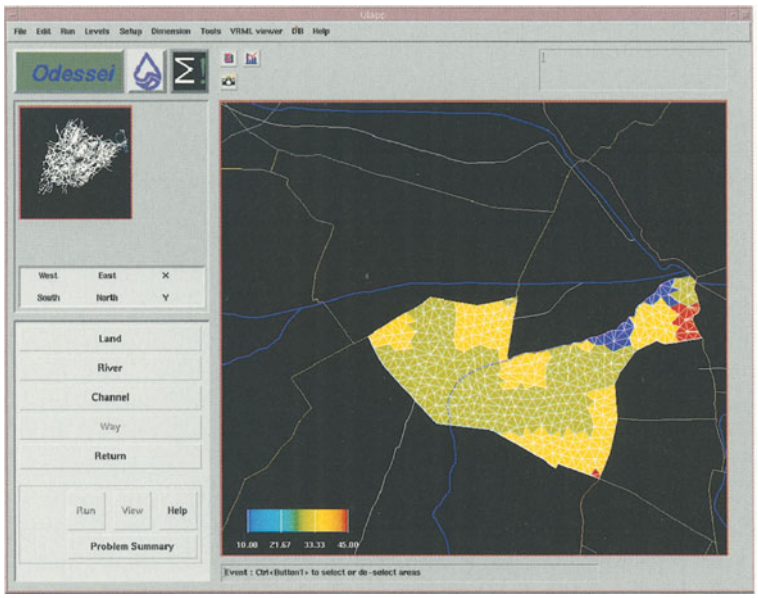


Fig. 35. Generation of the triangular irregular mesh for the CVFE and friction coefficient estimation from land-use maps

The GIS automatically searches for the closed cells in the selected area (Fig. 34) and the generation of the FE mesh, conditional upon the break lines, is also automatic while land use maps are used to determine a first guess of the friction coefficients to be used in the flood plain model (Fig. 35). After simulation, the results can be displayed in a technical 2-D mode (Fig. 36) or in a more realistic 3-D Virtual Reality mode through AVS-Express. Finally the simulation results, in terms of water elevation, water flow velocity and residence time may be intersected with the vulnerability maps and possible costs to produce the risk maps as described in area Di Giammarco et al. (1994).

FLOODSS can also handle typical urban flooding problems, with the possibility of isolating the buildings from the hydraulic computation. Figures 37 to 39 show an example of application in the city of La Spezia in Italy.

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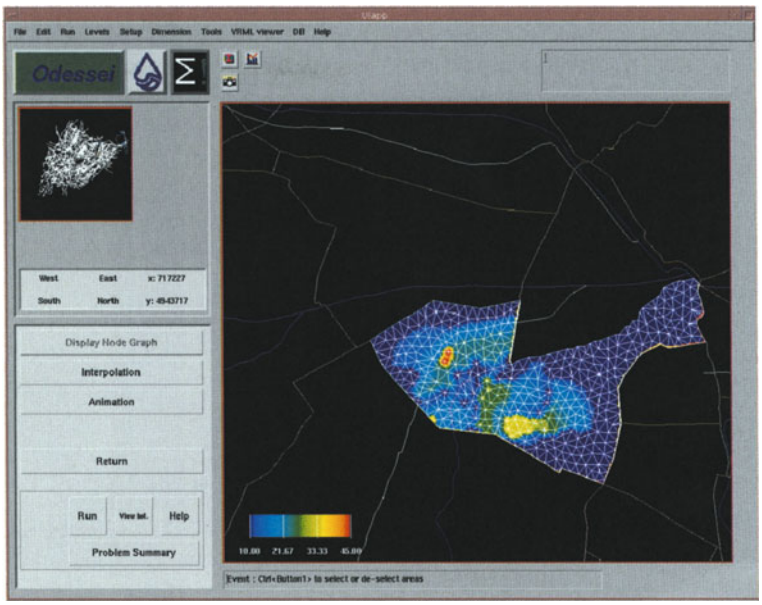


Fig. 36. 2-D analysis of simulation results in terms of water depth

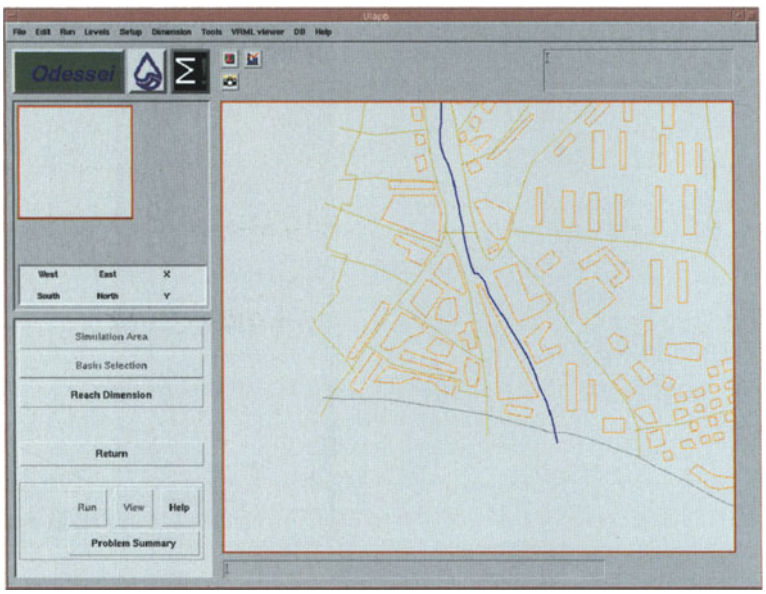


Fig. 37. A cadaster map of flood prone area in the city of La Spezia in Italy

7 Conclusions

As has been described, today it is possible to create systems which furnish, in operational terms and in automatic form, flood forecasts characterised by a high degree of precision for a time horizon of twelve hours on medium and large basins (>1 000 km^2), while research efforts aimed at achieving the same degree of accuracy and advance warning in forecasts on small basins are now at an advanced stage of development. However, one frequently feels that the Public Administration has still not come to terms with and does not fully appreciate the very real possibilities offered by the flood forecasts performed, albeit with the uncertainty inherent in every forecast, with an advance prediction time sufficient to organise emergency action and assistance, and that it persists in limiting itself merely to the monitoring of the events in progress.

In this connection it should be reiterated once again that flood forecasting can today be performed with a substantial margin of reliabil-

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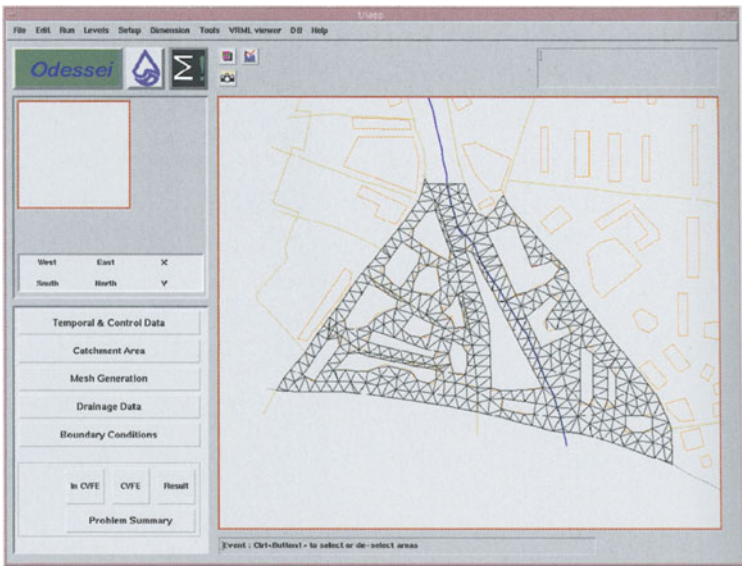


Fig. 38. The identification of the flooding domain and the automatic generation of the triangular irregular network

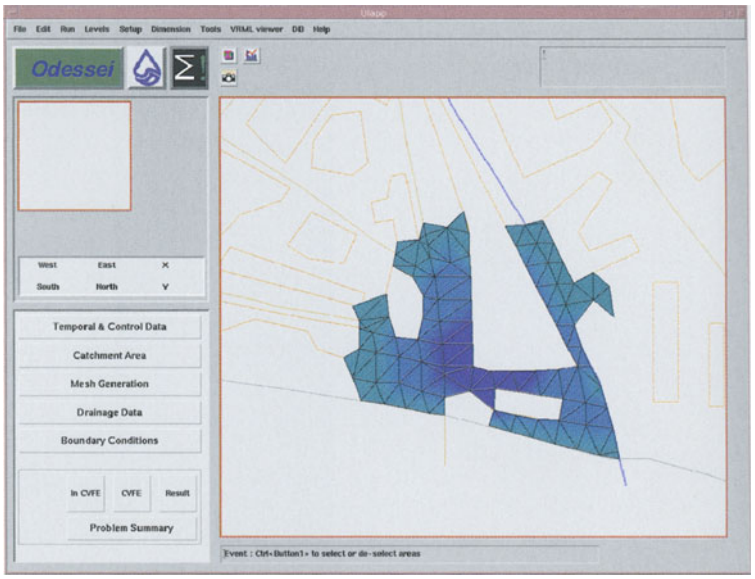


Fig. 39. Analysis of the maximum water depth

ity, for time horizons of twelve hours, in both large and intermediate-sized basins, while experimentation is well under way aimed at using the precipitation forecasts generated by LAMs directly as input in flood forecasting models.

Downstream of the meteorological and flood forecasting, however, the question of the planning and coordination of emergency situations is still unresolved: in fact it would be essential to have the on-line availability of a system of definite and unified procedures allowing all the parties responsible for the management of flood events to be aware of the situation, of what the other parties have done up until that point, and of the possible operational options that are available to them. This is probably the most critical and frequently overlooked aspect of real-time flood forecasting and control, given the multiplicity of different Institutions and Authorities involved in the decision making processes during flood emergencies.

This problem can probably be solved within the frame of a holistic approach to flood management, which requires the study and the development of decision supporting tools such as FLOODSS, where the integration of the GIS

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capabilities in the system together with the parallelisation of the flood plain inundation model will allow for extensive risk analyses and the preparation of flood risk maps. In addition, the link of the real time flood forecasting module with the precipitation forecasts produced by the atmospheric LAMs will allow operational forecasting lead times of 12 hours even on small-medium size catchments.

For all these reasons, it is the belief of the authors that the availability of a system allowing for the hydrological and hydraulic analyses; the evaluation and the preparation of the flood risk maps; the planning of structural and non structural measures; the real time flood forecasting with the possibility of analysing the advantages of the different intervention scenarios, will constitute a major breakthrough in the four areas related to flooding: planning, real time management, dissemination and training of personnel.

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CHAPTER 4.10

Satellite Monitoring of Floods as a Part of the Early Warning System

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Abstract

Floods are short-term, unexpected and frequently unpredictable. Floods are not just local phenomenon but can happen everywhere. Coincidence plays an important role in the size and frequency of flood formation. High floods are usually a result of a combination of several factors, and call for the theory of catastrophes to come into effect. All this complicates forecasting and increases the risk factor. Numerous attempts to use satellite surveys for mapping of inundation have not brought about sufficient reliable material for an estimation of the danger of occurrence and the development of floods. The reason for this lies in features of investigated process and used information, which should be used in an optimum combination. In Russia there we have twenty years of experience in the thematic analysis of satellite images; and have developed a technique for the estimation of river flood-plain submersion. The operative satellite information on the average resolution, aerial and satellite photographs are used. The reference data (volume of water and inundated area at any water stage) on zones of flood-plains of the Ob and Volga rivers are prepared. The typical layouts of flooding are revealed.

1 Introduction

Albert Einstein once said[1] that for observation a theory is necessary: the theory to decide what we contrive to observe. Unfortunately, there is no universally recognised theory of floods, even the definition of this term is ambiguous. Therefore, all flood observations proceeded from empirical requirements of prediction methods and from the particular economic needs.

Floods are a catastrophic natural phenomena often resulting in significant damage to property and the loss of human life. The adverse effect of floods is caused by growing intensive development of floodplains for agricultural purposes, for the expansion of urban buildings, as well as for the extraction of minerals (oil, sand etc). The prevention of floods or a decrease in their negative consequences is possible only by the construction of protective structures. However for many inundated territories the protective structures are missing, and sometimes even the available structures are incapable of protecting from extreme catastrophic floods. Therefore the most urgent three basic functions of hydrology in relation to floods include forecasting, monitoring (observation & control) and estimation of consequences.

2 Methods

Remote sensing (aerial & satellite) methods have a history of about fifty years. For these years various remote sensing equipment were used for estimation of floods. Aerial and satel-

[1] [Editor's comment:] Einstein is cited in Heisenberg, W (1971): Physics and Beyond: Encounters and Conversations. Translated from the German by Arnold J. Pomerans. New York: Harper and Row.

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lite methods have been used either as an independent approach (in the process of their opportunities range exposure) or often together with other approaches to obtain an estimation of parameters for the forecasting and diagnostic projects (Usachev et al. 1985). Aeromethods included a basic remote sensing approach of flood observation before occurrence of the artificial satellites of the Earth. The aerovisual inspection of the flooded areas was carried out as usual. For some projects both aerosurveying and aerohydrometrical investigations of the particular rivers were carried out, with the purpose of mapping the various stages of floods and of studying the water streams on the overflowed floodplain. With the occurrence of satellite surveys the aerophotography for flood observations played an auxiliary role and are now used now for small-scale objects and for the inspection of key sites (Gidrometeoizdat 1982).

Nevertheless, these flood assessment procedures are quite episodically, sporadic and incoherent. There is no multipurpose and regular system of flood monitoring. In any case, it is still worthwhile to review the case studies of remote sensing methods for flood observations (Fig. 1).

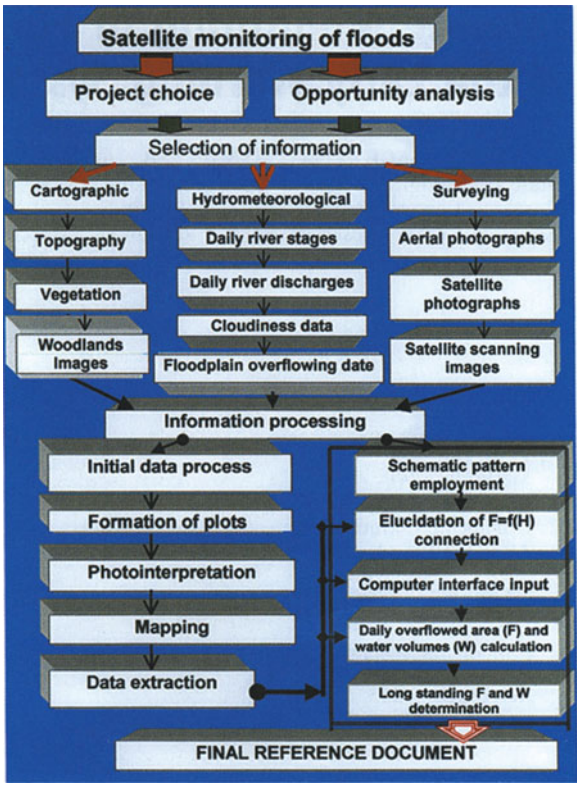


Fig. 1. The technological circuit of definition of the characteristics of floods

2.1 Before a Flood

Before water overflows to the floodplain, some preparatory work is carried out, such as: cartography and classification of lands, development of prediction methods, formation of the observation network, preparation of a forecast and of storm warnings. In this case remote sensing methods may be widely applied. These methods first provide a cartography of the flooded land as it is very important to classify the lands. Sometimes, a classification is made not only for the floodplain areas but also for the whole watershed. The implemented action of remote sensing facilities regarding prediction methods depends on the necessity to observe the leading factor, which is used in the forecast.

Satellites are, however, very useful for communication and rapid data transmission to the forecast centre and to the users and, thus, to provide a network operation.

2.2 During the Flood

It is very important to provide for the stability of the land network operation, to transmit the information to the managing authorities and to provide an operational cartography of the flood boundaries and of the rate of floodplain overflow. Satellite facilities demonstrate their indispensable operational capacity in this case. Satellite systems for land data collection have been developed and tested.

Flood dynamics may be estimated from the changes in flood boundaries and the rate of floodplain overflow. It is very important to define the actual situation in time and to process the results (in the form of the map) as quickly as possible. However, cloud often interferes with the situation; therefore, even daily satellite surveys in an optic range often provide only fragments of floods (in time and space). In this case, we hope that satellite radar will be beneficial. For example, a long wave range of L-band has been tested for these purposes and has been accepted as satisfactory. Regarding the rate of data processing, we expect some pro-

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gress from digital data transformation and GIS-technologies.

2.3 After the Flood

When water disappears from the floodplain, it is desirable to make final surveys and to analyse all cartographic and survey materials. Consequences are then estimated, the damage is determined, and measures are outlined to prevent as far as possible similar damage during future flooding periods. Satellite images may prove to be very useful during this stage. They may be applied to classify areas damaged by the flood (according to the damage rate and nature of damage). These images are essential for an indirect estimation of crop damage.

3 Technique of Data Processing and Some Results

Flood observation facilities may be arranged into the following three groups:

- Land facilities – observations at hydrological network, topographic surveys, surveys of high-water marks, selection of maps and archive data;
- Aircraft facilities – survey air photographs of large floodplain areas, detailed air photographs of floodplains at different stages of flooding, aerial hydrometric surveys of surface flow velocities on specified floodplain areas, aerial visual observations;
- Satellite facilities – multi-spectral photography and multizonal scanner TV surveys.

Air photography is the oldest and most reliable method of getting information on floods over large river reaches. This method, however, is very costly; films processing and photoschemes preparations are complicated.

The quality of satellite photographs of the overflow floodplain is also good. In some cases, they are even more suitable. Small scale high-resolution surveys (for flooded area cartography the scale of 1:200 000 is usually applied) makes it possible to show a long river reach with a floodplain in one picture. This simplifies image processing when the boundaries of the overflow floodplain are interpreted and the flooding parameters are determined.

The major portion of input for flood cartography is provided by multi-band scanner surveys from Earth resources satellites which transmit information by radio in the operational mode. Information from scanners of high and middle resolutions in the infrared wave band of 0.7–1.1 μm is used for flood cartography. High-resolution information (45 m) covers a stripe of land about 80 km wide. The scanner information of mid-resolution comes from satellites "Resurs-0" (resolution of 175 m) and "Ocean-0" (resolution of 345 m) at the frequency of once every 4 days and once every 3 days, respectively. Information from "Resurs-0" is more preferable for interpretation and mapping of floods. Photographs of mid-resolution differ from those of high-resolution in that they are detailed but have a greater scope.

Information obtained in one of the above ways is processed in a laboratory. Which is necessary for cartography of floods, i.e. a schematic map of flooded and not flooded lands (Fig. 2). There are two basic methods for flood data processing, i.e. visual-instrumental and digital based using a PC. Air and satellite photo-

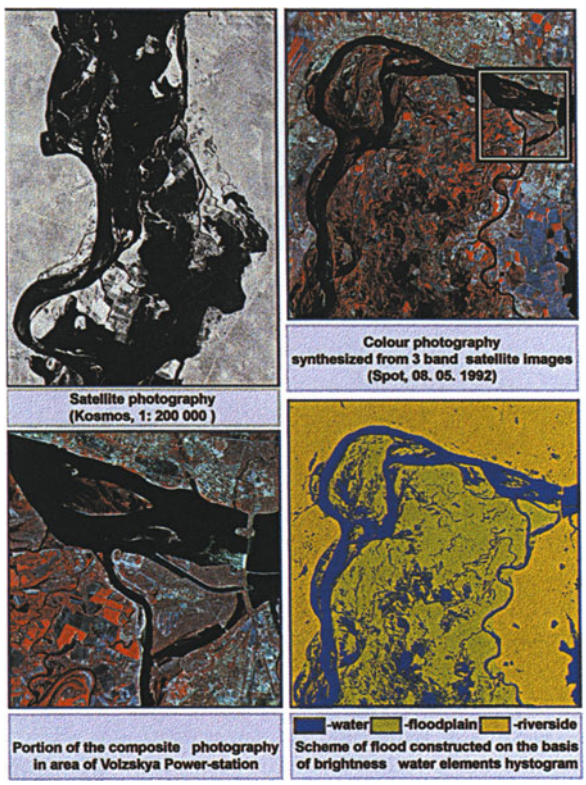


Fig. 2. Photointerpretation and mapping floods on Volga-Achtuba flood-plain

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graphs are usually processed in a visual and instrumental manner. Both of these methods are used for satellite scanner data processing, although the digital method is preferable.

Airborne and satellite photographs have a high resolution; therefore, the water edge is well interpreted in the photographs, which makes it possible to see the completely flooded areas in the floodplain. However, processing of this information by PC brings certain difficulties as it is necessary to transform the photographs (a great number of different photos) into digital form (Shcherbenko et al. 1990). When the visual-instrumental method is used, the water area on the river reach is determined by planimetering of the marked completely flooded zones. The rate of flooding is calculated as a ratio of the water area on the studied reach to the total area of the reach within the floodplain boundaries. A schematic map of floods is prepared from the results of the edge line interpretation. The accuracy of the flooded area determination for some floodplain is 2–3%, if airborne and satellite photographs are applied.

When satellite scanner information is used, a different situation can be observed. Firstly, most of the scanner information transmitted is digital, thus, it does not require transformation which is usually related with a decrease in the quality of the material. Secondly, when mid-resolution scanner information is used, we have generalised images where the edge line looks smeared and minor details are not seen at all (Asmus 1987). In this case flood interpretation by the visual-instrumental method is difficult because the configuration of the edge line becomes uncertain due to vague details in the image. Processing of mid-resolution scanner information by PC does not suffer from this uncertainty because quite a different approach is applied in this case. The flooding rate of each elementary area of the floodplain is determined, which corresponds to the image element, therefore, the vagueness of the image is of no importance. When the information is processed by PC, the flooded rate of the floodplain area is computed on the basis of data on the mean image brightness of the study area and the mean brightness of the water image and the non-overflow floodplain (Usachev 1991).

Resulting from this interpretation and cartography, the following parameters of flooding are determined for each of the selected river reach for every survey date:

- total boundary of the flooded land (floodplain boundaries);
- size of the area covered by water;
- the flooding rate of the floodplain on the reach.

In addition to the above parameters, the analysis of the material makes it possible to determine more accurately the level of the water overflow to the floodplain for each river reach. On the basis of the data obtained, dependence's of the flooded areas in the floodplain (the flooding rate of the reaches) upon water levels are plotted. The nature of every dependence is mainly determined by hydraulic and morphometric parameters of the floodplain on river reaches.

Investigations show that survey data on the same floodplain area obtained during different years but at similar water levels show a similar picture of the floodplain overflow. It gives ground to use survey data obtained during different years, which is very important, as we can, thus, use all available high quality and reliable information, mainly photographs made from aircrafts and satellite images.

4 Conclusion

On the basis of these regional dependence it is possible to calculate for each day of any year the area of flooding, the share of inundated areas, and also the volumes of water on the floodplain. The informational-forecasting system may then be prepared for warning of catastrophic floods on the rivers. This system is intended for the decision of the following tasks:

- mapping of territory with regard to danger and frequency of catastrophic flood occurrences;
- mapping of territory with regard to probable damage from catastrophic floods;
- operative estimation and forecast of future catastrophic floods for the period from several days to several months;
- perspective estimation of change in spatial distribution of catastrophic floods in connection with the future influence of economic activity and global climate change;
- elaboration of measures for operative and long-term prevention of adverse influences of catastrophic floods.

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On the basis of long-term hydrometeorological observations the system will allow determination of the following characteristics for each river:

- Average and extreme (maximal and minimal) values of water stages and discharges.
- Critical meanings of water levels and discharges, at which flooding of territories begin. Short range forecast of the daily flood characteristics with earliness in some days.
- The time intervals within a year, in which catastrophic floods occur and type of flood (spring flood, rainfall flood, etc.).
- Repeatability (frequency, in years) of catastrophic floods causing overflowing of territories.
- Assessment of possible future catastrophic floods for the basic regions with earliness from several months to 1–2 years.
- Submerged areas according to a repeatability of flooding.
- Information on inundated territories for an estimation of damage (population, basic industrial and municipal objects, areas and kinds of agricultural lands etc.).
- Generalised indexes for a type of flood danger, taking into account the frequency and damage of catastrophic floods.

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Snowmelt Forecasting as a Contribution to Operational Flood Warning: A System Integrating Remote Sensing Data and Meteorological Model Output

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Abstract

A system for operational snowmelt runoff prediction is described as it is presently being implemented for the Rhein-Felsberg basin of the river Rhein in Switzerland. It incorporates a hydrological snow melt model driven by remote sensing data, synoptic measurements and output of a meteorological forecast model. The system components are discussed and first test results are demonstrated.

1 Introduction

In regions of temperate and humid climate, a considerable amount of snow can accumulate during winter, which in turn will contribute a significant part to the springtime runoff. In many alpine countries, this melt water is used for energy production as well as water supply, and is, therefore, a valuable natural resource. However, certain conditions such as heavy rainfall in conjunction with intense snowmelt sometimes turns this resource into a threat to human activities by causing severe floods. For these reasons it is necessary to develop tools to predict timing and amount of melt water generation. Such predictions are not only important for water management issues, but can also contribute to an operational flood warning system.

One possibility of achieving such snowmelt runoff predictions is to apply a hydrological model driven by real-time input data. Karpack & Leiytham (1995) have tested several simple approaches for river flow forecast and have shown that especially information on the snow covered area improves predictions. In the system presented here the Snowmelt Runoff Model (SRM), introduced by Martinec (1975), is applied. The SRM is a conceptual degree-day model, based on daily input of air temperature, precipitation and snow cover extent. The latter is derived from satellite data, which enables near real-time assessment of the snow covered area (Baumgartner et al. 1994).

This paper describes the concept and first tests of an operational snowmelt forecast system as it is presently being implemented for the Swiss test basin Rhein-Felsberg within the frame-work of HydAlp (Hydrology of Alpine and High Latitude Basins). This European research project aims at the development and implementation of methods for operational snowmelt forecast, integrating remote sensing and hydrological modelling.

2 Test Area

The Rhein-Felsberg basin has been selected for developing and testing of the forecast system. It is located in the central Alps in Eastern

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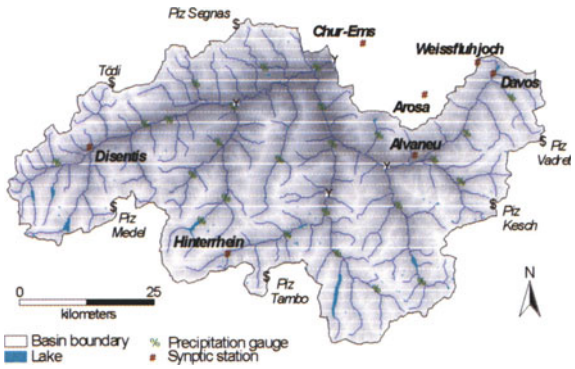


Fig. 1. Overview of the Rhein-Felsberg Basin

Switzerland, with its outlet close to Chur. While the basin size is 3242 km^2 and the elevation ranges from 571 m up to 3614 m a.s.l., only 1.9% of the basin area are covered by glaciers (Ehrler 1998). As it is typical for an alpine basin, snowmelt is a major part of the annual water balance and induces a specific runoff peak in May and June.

The main contributory rivers are Vorderrhein, Hinterrhein, Juila, Albula and Landwasser. The fact that various reservoir-based hydro power plants are operated in the basin leads to a remarkable artificial influence on the discharge at the basin outlet. During night-time, at weekends and in spring, water is held back to enable electricity production during periods of increased demand.

3 Data Basis

In order to run the snowmelt model as part of an operational forecast system, all data, measured as well as forecasted, must be provided in real time. Reliable links to the various data providers such as hydro-meteorological services, hydropower companies and research institutes have to be established.

3.1 Satellite Data

For frequent observations of the snow cover NOAA/AVHRR data are used in the present work. Raw imagery are recorded daily at the receiving station of the University of Bern and are further processed to snow cover maps if cloud conditions allow. The AVHRR instrument has a spatial resolution of 1.1km at Nadir and five spectral bands, which measure radiation in the visible, near infrared and thermal infrared part of the electromagnetic spectrum. Concerning spatial and temporal resolution, the NOAA/AVHRR system operates close to the optimum for snow cover monitoring in basins as large as the Rhein-Felsberg area. For operational applications a high repetition rate of satellite data is essential since cloud cover reduces the number of usable overpasses. Typically, every 5 to 10 days a complete snow cover map is available for the Rhein-Felsberg area if the AVHRR is utilised. A higher spatial resolution would remarkably increase the lag time between two overpasses.

3.2 Meteorological, Hydrological Data

Meteorological data, provided by the Swiss Meteorological Institute (SMA) are taken from seven meteorological stations, which are part of the automated synoptic station network. The stations are located at elevations between 555m and 2540 m a.s.l. They provide a number of meteorological parameters, of which only precipitation, air temperature and snow depth are used. The data are received once per hour with a delay of about 5 h after measurement.

Hydrological data are provided by the Swiss Hydrological Office (LHG) on a daily basis. The influence of the reservoir water management on the measured stream flow is taken into account by reconstructing the natural runoff based on the water balance data of each individual reservoir.

3.3 Meteo Forecast Data

Meteorological forecast data are taken from the Swiss Model (SM), a hydrostatic meso-scale numerical weather prediction model operated at the SMA (see Majewski 1991). It is based on a grid with a mesh size of 14km and provides hourly prediction of a number of meteorological parameters. Among these, precipitation, separated in snowfall and rain, and air temperature at 30m above ground are applied for snowmelt prediction. The forecast model computes up to 48 hours in advance, however, for the test period 1996, only 30 h of prediction were available.

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4 Processing

All required data described above need to be processed in order to generate the necessary model input. Spatially distributed data such as snow maps have to be combined with point measurements of meteorological parameters and also different temporal resolutions have to be taken into account.

Therefore, the forecast system combines several processing segments for the different data types. These segments operate independently in a modular structure as displayed in Fig. 2. The mainly PC based system comprises the segments image processing, data fusion, snowmelt simulation and data distribution. The interfaces between the different components are keyword based ASCII files. A messaging system for operation and quality control is used to synchronise the individual segments, monitor the performance of each module and carry out quality checks. It is planned to archive most of the modules outputs in a database, however, these links have yet to be established.

4.1 Image Processing Segment

The snowmelt model SRM relies on frequent observations of the snow covered area (SCA). Therefore, it is crucial to get as many snow cover maps as possible. The Image Processing Segment displayed in Fig. 3 is used to convert the raw AVHRR data into geo-coded snow cover maps, from which the elevation dependent

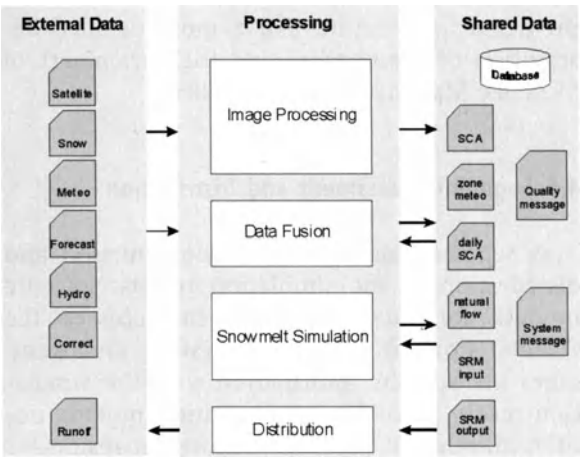


Fig. 2. Data flow and processing segments of the overall forecast scheme

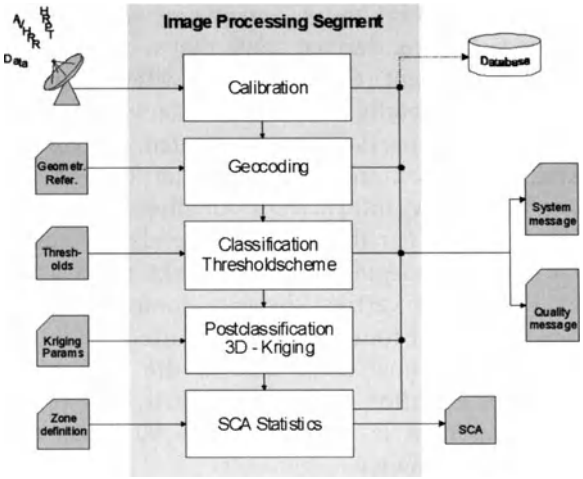


Fig. 3. Design of the Image Processing Segment

SCA statistics can be derived. The reception of the raw satellite data is not considered as part of this segment since the data can be acquired from commercial data suppliers at low cost.

In a first step the 10bit AVHRR raw data are calibrated to top-of-atmosphere reflectance in the reflective channels (1&2) and brightness temperature in the thermal channels (3,4&5) (Rao&Chen 1995). AVHRR channel 3 is located at 3.7 μm and therefore measures reflective and emissive (thermal) radiation. The reflective part carries valuable information on cloud cover and is therefore extracted into a synthetic 6^{th} channel (Gesell 1989). In addition, the Normalised Differential Vegetation Index (NDVI) is derived as a 7^{th} channel to aid the snow classification.

Since today's methods for automatic geocoding of AVHRR data only reach an accuracy of about 4 to 5 km it is necessary to interactively correct the image using ground control points. This is one of the few interactive steps in the processing chain and takes about 30 minutes per image, but in turn enables geo-referencing of the data to sub-pixel accuracy.

A threshold scheme, optimised for snow detection, is then applied, carrying out six tests on the five AVHRR and two synthetic channels (Saunders & Kriebel 1988; Gesell 1989 and Derrien et al. 1993). The tests check brightness temperature and reflectance thresholds at different wavelengths as well as the NDVI. A pixel is declared as "snow" only if all tests are passed. A plausibility check based on a large

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number of point measurements of snow depth helps validating derived snow maps.

It is evident that only very few satellite images are totally cloud free. Many data sets are at least partially contaminated by clouds and, therefore, require an interpolation of snow/no-snow information for these areas. A 3D *Kriging* algorithm, which extends the regular isotropic *Kriging* method (Isaaks & Srivastava 1989) by a vertical distance component was developed and found to be well suited for interpolation of snow data. Due to the high relevancy of elevation for snow analysis, this vertical component is weighted 60 to 90 times the horizontal distance.

As a last step, statistics on the snow covered area are derived from the snow maps by intersecting them with the different elevation zones, which were predefined in a GIS environment.

4.2 Segment Data Fusion

The purpose of the Data Fusion segment is to combine all data required as input into the SRM, whenever new data is available. The segment consists of three conversion modules, which transform the incoming data so that they match the SRM input standards.

The module for spatial interpolation of meteorological data processes the hourly data of the synoptic climate stations, as well as the meteorological forecast data. Precipitation and temperature data are interpolated to compute representative values for each elevation zone following a predefined weighting pattern and are compiled to daily values.

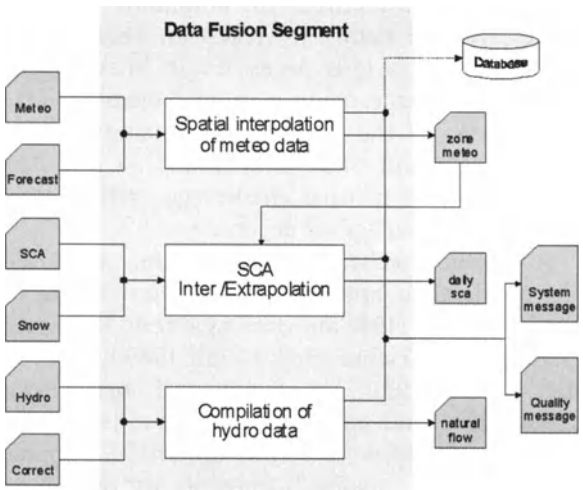


Fig. 4. Design of the Data Fusion Segment

The SCA module interpolates the snow coverage for all elevation zones on a daily basis. It uses the two adjacent SCA data sets, which were derived from observations, and computes the values using a degree-day approach. Assuming a linear relationship between SCA and accumulated snow melt, a gradient of SCA over accumulated melt can be derived and applied not only to interpolate, but also to extrapolate the snow coverage from the last observed SCA into the future. However, it has been shown that a plausibility check by the system operator and a manual, adaptation of the gradient based on experience is recommended.

The third module for compilation of hydrological data basically combines the stream flow corrections derived from reservoir management data with the measured stream flow in order to reconstruct the natural runoff.

4.3 Segment Simulation

This is the central segment concerning snowmelt prediction containing the simulation model SRM. For the purpose of operational snowmelt forecast, a Java version of SRM was developed and is applied within the system described here. It can be operated in an automated batch-controlled mode and also provides a more flexible way of data handling. In order to keep the SRM input as up-to-date as possible, an update module continuously replaces outdated data with more recent measured or predicted information. For a more detailed description of the concept and the parameters of SRM see Martinec & Rango (1985).

4.4 Segment Assessment and Distribution

This segment manages the documentation and distribution of the simulation results. Its core module for quality assessment accesses the Quality Control messaging system and combines the specific information with the simulation results of SRM. A distribution module notifies all relevant users of the forecast results.

In order to catch uncertainties in the runoff prediction the concept of a Critical Situation

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Observer (CSO) is introduced. This quality-based expert system monitors a number of sensitive parameters of the overall system and graphically displays their behaviour. System parameters, which indicate an increased risk of flooding are, runoff (measured and predicted), accumulated snowmelt (predicted) and rainfall (measured and predicted). A worst-case prediction assuming an underestimation of precipitation and temperature forecasts would be an additional parameter. Thresholds define critical ranges of each single parameter and separate three states: harmless, dangerous (critical only in combination with other parameters in dangerous state) and critical.

The CSO is not designed to run as an automated warning system, but as an aid to the operator to judge the present snowmelt situation and flooding risk. If the parameters indicate a critical situation, the operator must investigate the conditions in more detail and take the necessary warning measures.

5 Results

First tests of the system described above have been carried out for the snowmelt period 1996. A real time situation was simulated by using measured meteorological input data prior to each day of simulation and meteorological forecast data for the actual day. Hydrological data was assumed to be available for the previous day and was used to update the model on a daily basis. The SRM parameters were not optimised for the simulated period but were calibrated within physically reasonable limits.

Figure 5 shows the results of the simulation and the simulated forecast in combination with the corrected stream flow. The dotted line represents the conventional simulation based on measured meteorological data without stream flow updating, the triangles mark the forecast for each day based on the data which were available the day before.

The daily differences between the forecast and the observed stream flow are used to assess the accuracy of the prediction. On seven days of the test period (May 1st through 20th) the deviation was larger than 10% of the observed discharge, however, six of these can be explained by the aberration of forecast and measured precipitation.

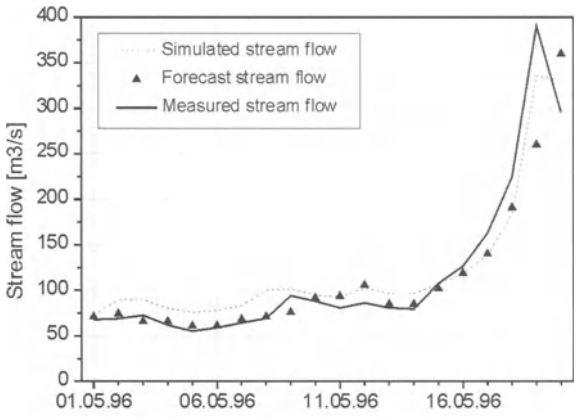


Fig. 5. Simulation results for the river Rhine at the stream gauge Domat-Ems during the test period of 1996. Both conventional simulations as well as forecast stream flow are plotted together with the observed stream flow (reconstructed)

As already mentioned, the snow coverage has to be extrapolated for the period within which no new snow map is available. Based on the method described above an accuracy between 2% and 10% on the last day of the test period could be achieved.

6 Conclusion

Although the concept of the forecast system presented here was applied for only a short test period, it could be shown that it is possible to predict stream flow, which mainly results from snowmelt, within reasonable limits. It also became clear that the quality of the stream flow forecast depends highly on the available input data, especially the meteorological forecast. Experiences with the data processing chain and especially the analysis of the NOAA-AVHRR data showed, that it is possible to assess the extent of the snow covered area in near real-time at low cost. Finally, the Java version of SRM proved to work well in an automated environment and could be integrated easily in the overall system.

After the final implementation phase and further testing, the forecast system as it is presented here will be operated during the snowmelt period in Spring 1999. Further quality assessments, comparisons with other forecast systems and a cost effectiveness analysis of the whole concept are subject to be investigated in the near future.

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Acknowledgements

We would like to thank the data providers SMA, LHG and SLF as well as the hydropower companies NOK and EWZ for their kind cooperation. We also very much appreciate the support by the other members of Remote Sensing Research Group at Bern University. The HydAlp project is funded by the European Centre of Earth Observation (CEO).

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CHAPTER 4.12

Short-Time Flood Forecast Methodology Using a Hydro-Meteorological Risk Concept for Flood Plains

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1 Introduction

Mountain relief and the extreme precipitation regime within the Russian Far East are reasons for enormous area flooding and high intensity of water erosion in the valleys during floods. The summer–autumn floods cause a major part of the damages from natural disasters to the region's economy. Stability and safe execution of economic activity in monsoon zone river valleys is impossible without flood protection actions. These actions must take into account the whole complex of disadvantage events, in accordance with floods, – a flooding of territory (repeatability, depth, length), river bed deformations, erosion-accumulative processes on the flood plain. The creation of an automatic technology for short-term hydrological forecasting with on information support system of decision making to help reduce the damages is one of the most important of such actions.

2 Automation of Hydrological Operative Work

However, as a result of only minor attention to particularities of hydrological methods in the Russian Hydro-meteorological Service, traditional priority given to weather forecast and the insufficient financing during the past years there is a sharp backlog in the degree of automation of hydrological operative work in contrast with meteorological departments. To tackle this problem a programme complex has been designed and introduced in two regional departments, allowing the automation of a main volume of work with operative hydrological information. The programme complex is intended for use in operative hydrological forecasts and allows execution of the following main functions: acceptance, decryption, sorting, checking, correction, conservation and inverse sending of information telegrams; analysis of the operative data and completing a hydrological bulletin clean forms (daily, for ten days, monthly, more than 10 forms); accumulation of operative and information databases of the hydrological, snow and precipitation measurements. Tables 1 and 2 demonstrate samples of printed products of the programme complex.

3 Flood Cycle of Small River Basin

For territory with the prevalence of summer-autumn rain floods in the river regime a flood-cycle model have been developed, which must satisfy the following conditions: parameters must have a physical sense and be defined independently, without digital optimisation; mathematical adaptation to the real basins on the base of standard observation be available for operative forecast work, be undemanding to the accuracy of observation data and be acceptable to technical requirements.

A model of flood cycles of small river basins (SRB) is based on the description of two main runoff formation modes – intercapacity and surface. It covers a dynamic SRB near the point of full moisture-holding capacity (FC). Before reaching this point, a basin is in the mode of intercapacity runoff. At saturation levels greatly above FC, surface runoff occurs. This means

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Table 1. A fragment of a daily hydrological bulletin (originally in Russian)

River, lake	Gaugestation	Water levels 17.08.98 (cm)						Discharges (m^3/s)	Precipitation (mm)	Notes
		at 8^{00}	daily change	date beginning of trend	change from initial date	output on flood plain	month average perennial			
Ussuri	Koksharovka	67	–1	17.08	–1	240	104	39.7		
Ussuri	Kirovski	164	9	15.08	25	425	238	114	1	
Malinovka	Ariadnoe	348	3	17.08	3	430	351	9.34		Qmeas.: 356/ 10.6/22.8/141
Malinovka	Rakitnoe	387	8	15.08	78	500	336	86.3	2	
Hanka lake	Astrahanka	264	–1	17.08	–1		293		4	Wind SW, 2 m/s, waves not

Table 2. A fragment of daily hydrological database (translated from Russian)

August 1998

River, lake: Razdolnaya
Gauge station: Terehovka
Height "0": 2.01

Factors of danger of hydrological phenomena

Perennial parameters

Date	Water levels (cm)		Dayly change	Precipitation (mm)	Temperature (°C)		Thickness (cm)		Ice phenomena	Discharges (m^3/s)	Notes
	8^{oo}	20^{oo}			water	air	ice	snow			
07/08	37	40	0	2.0	25					19.9	
08/08	42	101	5	0.4	24					23.1	
09/08	110	102	68		21					97.0	
10/08	96	84	–14		18					79.1	Qmeas.: 84/ 88.1/214/300

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that the volume and dynamics of all different genetic types of runoff are thereby be checked by the presence of surface runoff, in that it is indistinguishable from the surface runoff in the water balance model.

The transition process through the FC is considered the lock-and-key for catastrophic flood formation, and is largely non-linear, i.e. complex, possible chaotic system dynamics are likely to occur. It is fixed by particular "critical" discharge levels (Q_{cr}). Q_{cr} is the integral characteristic of small river basins. It correspond to the moment of runoff coefficient change rapid from the values 0.25–0.35 to 1.0. Q_{cr} is determined by the position of the probability density minimum separating the basic and the complementary modes of rain flood maximum distribution histograms. A specific value of Q_{cr} in the Primorie region changes negligibly near the 100 litres per second per square kilometre mark, and appears to be the regional constant. If one chooses two consequent floods with $Q_{max}>Q_{cr}$ during one season, and selects on both recession hydrographs the points of Q_{cr} transition, assuming that at the initial and end point of this period the basin water capacity is FC, and free capacity is absent. If the flood period, is slit into two parts at any point, it is possible to write the following two equations

$$V + Z' = X' - Y' \quad (1)$$

$$Z'' - V = X'' + Y'' \quad (2)$$

where X = precipitation, Y = runoff, Z = evaporation (prime symbols indicate the parts of the flood period), V = free capacity of the basin for a chosen moment. Solving equation (2) at a point before minimum flood discharge permits a free capacity of the basin to be defined, since the evaporation for the period of flood passing is not significant.

Using calculated values, the dependency graph of water discharge and the free capacity of the basin is constructed, and can be considered as a pseudo-phase system diagram (Fig. 1). The upper dotted curve describes the maximum possible values of free capacity depending on discharge, and cuts off the axis at a value FC. The lower dotted curve describes the minimum possible values of free capacity depending on discharge, and cuts the axis at a maximum gravity capacity value (MGC). The difference between FC and MGC is maximum ungravity (capillary) capacity (CC).

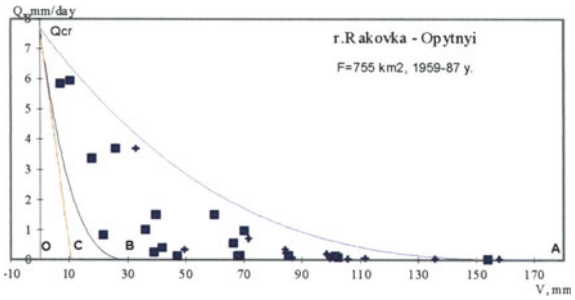


Fig. 1. Relationship between free basin capacity and discharge. OA is equivalent to the full capacity of the basin; OB is equivalent to the maximum gravity capacity of the basin; OC is equivalent to the critical channel capacity of the basin; BA is equivalent to the soil capillary capacity of the basin; CB is equivalent to the ground capacity of the basin

It has been possible to create a method of detailed water balance calculation to SRB capacities (channel, ground and soil capillary capacity, runoff, inflows to channels and to ground capacity, precipitation and evaporation) with daily time lags based on standard hydro-meteorological observations (Table 3). The calculations can be carried out using regression whereby gravitational capacity, the normative evaporation and the preceding precipitation index, are used as the predictors, and soil capillary capacity is used as the predictant.

The method of basin capacity diagnosis is, at the same time, the forecast method for determining the probability of transition to surface runoff formation and surface flood features. Checking of the forecast method, as applicable to maximum flood discharges on small rivers, has show that all 34 basins received satisfactory results and good enough quality without using the optimisation procedures in the model (Table 4). The results show that it is possible to create a good forecast model of the river flood hydrograph for use in hydro-meteorological services operating in monsoon regions.

4 Risk Concept in Support of Decision-making

Hydro-meteorological risk is understood as the probability of a complex event, culminating in the observed combination of elementary hydro-

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Table 3. The example of basins capacity diagnosis (translated from Russian)

Gauge station, F km^2	Date	Preceding precipitation index	Discharge (mm/day)	Channel capacity (mm)	Channel inflow (mm/day)	Ground capacity (mm)	Ground inflow (mm/day)	Soil capillary capacity (mm)	Evaporation (mm/day)	Free capacity (mm)	Precipitation (mm/day)
Partizanskaya river near Molchanovka 549	8-08	35.4	0.86	1.2	0.0	16.6	0.0	135.9	3.1	64.0	
	9-08	31.9	0.64	0.9	0.3	15.2	−1.0	131.0	3.1	70.5	
	10-08	28.7	0.58	0.8	0.5	14.8	0.0	128.4	3.1	73.6	
	11-08	25.8	0.49	0.7	0.4	14.1	−0.4	125.0	3.1	77.9	
	12-08	29.2	0.49	0.7	0.5	14.1	0.5	126.7	3.1	76.3	6
	13-08	27.3	0.46	0.7	0.4	13.8	0.1	125.0	3.1	78.3	1
	14-08	25.6	0.46	0.7	0.5	13.8	0.5	124.1	3.1	79.1	1
	15-08	23.0	0.44	0.6	0.4	13.6	0.3	122.3	3.1	81.1	
	16-08	20.7	0.43	0.6	0.4	13.5	0.3	120.5	3.1	83.1	0
	17-08	23.6	0.49	0.7	0.6	14.1	1.1	123.8	3.1	79.1	5

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Table 4. The amount of basins with different forecast quality

Number of estimated basins	Ratio of forecast standard error to forecasted value standard deviation
7	<0.50
13	0.50–0.60
9	0.60–0.70
5	0.70–0.80
34	0.37–0.78

meteorological events within a certain territory and time cell, which is calculated based on absolute and conditional probability of elementary events. When analysing the problem of floods, the priority is to separate a zone of low, average and high risk based on qualitative signs of risk. The lower end of the low risk zone is defined by specific or non-specific nature of risk from floods, here risk is low enough, such that it is not specific for the given territory and must be taken into account in the general complexity of protective actions against natural hazards. The lower boundary of average risk zone is defined by controlled or uncontrolled risk from floods, here risk is sufficiently great, however, separate local managers are able to efficiently evaluate and control the situation. In the high risk zone, the risk is high enough, such that it cannot always be safely evaluated, and efficient risk control is only possible from the whole social-economic system.

In river valleys, morphologically uniform stretches are separate from uniform hydrological regimes, uniform conditions of riverbed deformations development and flood plain forming processes and one type of channel process. In each stretch based on the analysis, a riverbed and flood plain developed separate processes during the different flood categories: the low, average and high risk zones, as well as zone of constant danger, manifested by the riverbed with rolling near channel relief forms. Differences between zones (repeatability, nature and intensity of flooding processes and water erosion during floods) define the conditions of the economic activity and restrictions on flood plains, as well as the degree of efficiency of the different categories of defensive actions: engineering preparing a territory; dams; channel regulations; runoff regulations. Risk maps of disadvantageous and dangerous events related to floods, available on three scales: regional overview maps on the scale 1:1 000 000–1:500 000; district (basin) river valley maps on the scale 1:200 000–1:100 000; and on the scale of construction, land and forest plans – from 1:50 000 and greater.

The analysis of spatial combinations of elementary events during a flood is possible based on of modelling by the Monte Carlo-method. The problem of modelling the multivariate flow of correlated hydrological events is solved by normalisation of the primary asymmetrically correlated hydrological sequences by the optimum functional transformation and through the transition, by changing the coordinates, to the system of non-correlated normally distributed random quantities. As a result, the solution of two problems becomes possible: during the, using a sensor of the independent normally distributed random quantities, the model hydrological sequences with prototype features of any length can be obtained; and during the direct transformation of a given vector for any separate year, an evaluation frequency of this year's flood can be obtained as a product of probability of independent random quantities.

By modelling hydrological sequences at a group of stations under investigation and by converting them to damage sequences we will obtain the direct risk assessment of one or other damage magnitude based on their relationship with the relatively stationary and controlled natural processes. This allows us to analyse probable scenarios of flood development and to better plan the emergency-rescue actions.

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CHAPTER 4.13

Hydro-Meteorological Tools for Flood Protection in River Basins

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1 Introduction

Meteorological causes of floods include storm rainfalls in small catchment areas, persistent rainfall in large catchment areas or sudden melting of snow, which is often linked with heavy rainfall. Considering the increase of meteorological extremes in recent years, there is a pressing need for well-timed and applicable hydro-meteorological information. The Deutscher Wetterdienst (DWD) has made every effort to meet these demands.

Supplementary to the automation of data acquisition, in particular in the precipitation network of the DWD, and the use of radar data, the hydrometeorologists of the DWD have several tools at their disposal for improving flood protection. On the one hand, these tools can be used operationally, on the other hand, they can be used to improve the design of dams and storage ponds. The Business Unit Hydrometeorology of the DWD is attempting to increase the accuracy of areal precipitation and water release of the melting snow cover. Consequently the model systems BONIE and SNOW-D have been developed. Evaluations of extreme rainfalls have been carried out to estimate probable maximum precipitation and design depth of precipitation.

2 Model System BONIE – Estimation of Areal Precipitation in Real Time

An operational use of precipitation data has, to date, not been successful as required values were not available within the necessary time limits or only for a very inadequate number of precipitation gauging stations. In addition methods for an areal generalisation of the measured precipitation data were lacking. The installation of a dense automated precipitation gauging network (ombrometer network) in Germany, especially in flood prone areas, enables the application of the model *bonieop* – a special version of the model system BONIE.

BONIE is a procedure used to estimate areal precipitation by means of ground-based measurements. Irregular distributed rain gauge data are interpolated to a regular grid (mesh width about 7 km×7 km). The areal precipitation amount is calculated as the arithmetic mean of grid-point values. BONIE consists of two major steps: The actual data are classified into one of a small number of characteristic patterns of spatial precipitation distribution, the so-called background field. After that the statistical interpolation – a procedure similar to "Kriging" – is carried out by means of statistical features derived from the selected background field, above all the spatial correlation function. With the help of a multidimensional variance measure BONIE can recognise the best background field and current precipitation data. The selected background field represents the peculiarities of the certain area, especially the differing influence of the current weather situation and the structure of the terrain. BONIE calculates the deviations of the current measured values from the data of the selected background field and adds this interpolated "anomaly field" to the background field at every single grid-point (Reich 1998).

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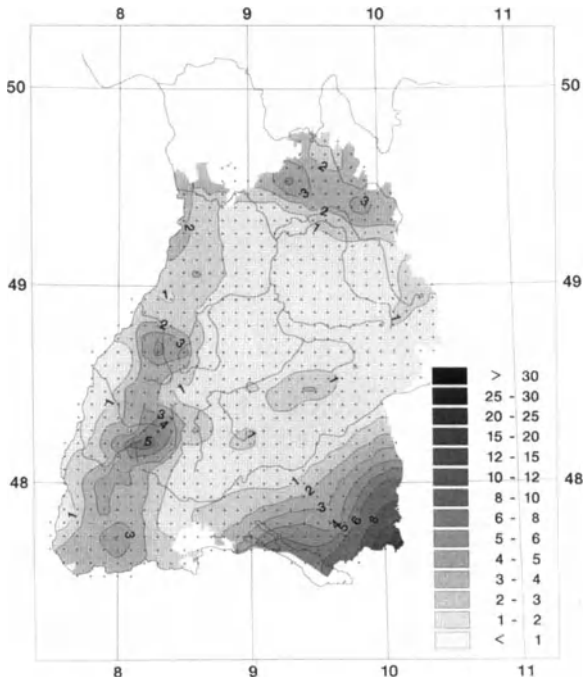


Fig. 1. Example of calculation by means of *bonieop*: Precipitation (in mm) on 24 August 1998, 12.00 to 18.00 GMT.

At present the types of the background field do not yet cover the whole area of Germany. The model *bonieop* is already operationally used in the province of Baden-Württemberg. With the help of *bonieop*, more than 700 grid-point values are operationally computed for 6-h intervals. These data can be processed in the latest precipitation maps (Fig. 1). Input data are provided by the joint automated precipitation measuring network, which was established in cooperation between the Authority for Environmental Protection of Baden-Württemberg and DWD; output data are available in real time. The other parts of Germany will follow during the next few years.

3 Model System SNOW-D – Estimation and Forecast of Snow Cover Development and Areal Melt Water Release

In the Federal States Thuringia, Saxony and Saxony-Anhalt of Germany, special hydrometeorological observing and reporting programmes were established more than two decades ago, for the information on the water management of areal values of snow depth and snow density as well as the water equivalent of the snow cover. The water managers' demands for additional information on the development of the snow cover and especially on the prospective water release led to the creation of the computer-aided project SNOW (Rachner & Matthäus 1986). This project was further developed over the last few years. The model system SNOW-D enables a daily calculation and forecast of grid-point values of the water equivalent of the snow cover and its meltwater release. The snow cover development is computed with the help of physically-based model components which describe accumulation, metamorphosis, ablation, and meltwater release.

The model input consists of:

- 6-hour interval averages of air temperature and vapour pressure,
- global radiation (or duration of sunshine) and precipitation totals of the last 24 h,
- additional data from a part-time network three times a week (snow cover, water equivalent of snow cover),
- output data of the regional NWP model (Deutschland model) of the DWD (used as input for the forecast calculations).

As model output the following information is available:

1. current values of the snow cover (reference point 06.00 GMT)
   - snow depth (in cm)
   - water equivalent (in mm)
   - specific water equivalent (in mm/cm)
2. forecast values of snow cover development (forecast interval maximum 48 h, forecasting for 6-h intervals)
   - water equivalent (in mm)
   - precipitation supply, defined as the sum of meltwater release and rain (in mm).

The calculations are grid-oriented and provide blanket coverage for Germany. A summary of the grid values can be made for any area required (Rachner et al. 1997). At present SNOW-D is used in certain regions of Thuringia, Saxony, Saxony-Anhalt and Baden-Württemberg (Fig. 2).

In order to achieve high reliability in the results, a regional division was first carried out, which was oriented to hydrological and snow cover climatological criteria. The differentiation of areas with similar hydro-climatological behaviour reduces the spatial variability of the

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Fig. 2. Provision of the SNOW-D advisory service for dark-coloured regions in operation.

model input and the model parameters important for the simulation.

The SNOW-D advises are focussed in the first place on mountainous regions and their direct foothills, as there the influence of the snow cover is particularly important to the development of floods.

4 Estimation of Design Depths of Precipitation and Probable Maximum Precipitation

Although non-meteorological factors also contribute to the consequences of disastrous floods, extreme precipitation is first to blame for causing floods. That is why in the Business Unit Hydrometeorology a large amount of needs-based investigations have been carried out to provide the expertise on extreme precipitation for the planners of drainage systems as well as for those responsible for long-term view on floodplain management and on building defences to reduce the risk of flooding, with emphasis on prevention of flooding problems, rather than on remedy.

Regionalised depths of storm rainfall in terms of duration (5 minutes, ..., 72 hours), return period (twice a year, ..., once in 100 years), and time of the year (whole year, summerly part and winterly part of the year) in Germany were published by the Deutscher Wetterdienst (Bartels et al. 1997) in the *KOSTRA atlas*. The results base on daily rainfall measurements and breakpoint data derived from the manual digitisation of pluviographs for the 30-yr period 1951–1980. The breakpoints, recording changes of intensity from one steady value to another, were digitised and processed into partial-duration series. In these series all values above a threshold are used regardless of how many occur in the same year. The only restriction is the independence of individual events. Annual series contending the largest single event that occurred within each year of record were also considered. Both Gumbel and exponential distribution functions were fitted by regression. With the help of a complex regionalisation method, the results for individual stations were spread to areas without precipitation gauges and pluviographs. KOSTRA methodology enables blanket coverage and grid-oriented depths of heavy rainfall to be provided for Germany (Fig. 3).

Even tremendous areal rainfall of more than 400 mm within 72 h is possible in Germany. Investigations on probable maximum precipitation led to this conclusion. Precipitation associated with the uppermost limits is known as the probable maximum precipitation (PMP) which is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year. The procedure used for estimating PMP by the Deutscher Wetterdienst is the estimation of maximised areal precipitation. This approach consists essentially of moisture maximisation and transposition of observed storms. The spatial distribution of maximised areal precipitation is determined by using different arrays of PMP depth–area–duration data for specific regions in Germany.

Estimates of maximised areal precipitation were made with the help of a hydrometeorological technique that has been often used (Svensson & Rakhecha 1998). The main assumption in this method is that the maximised areal precipitation will result from a storm in which there is the optimum combination of

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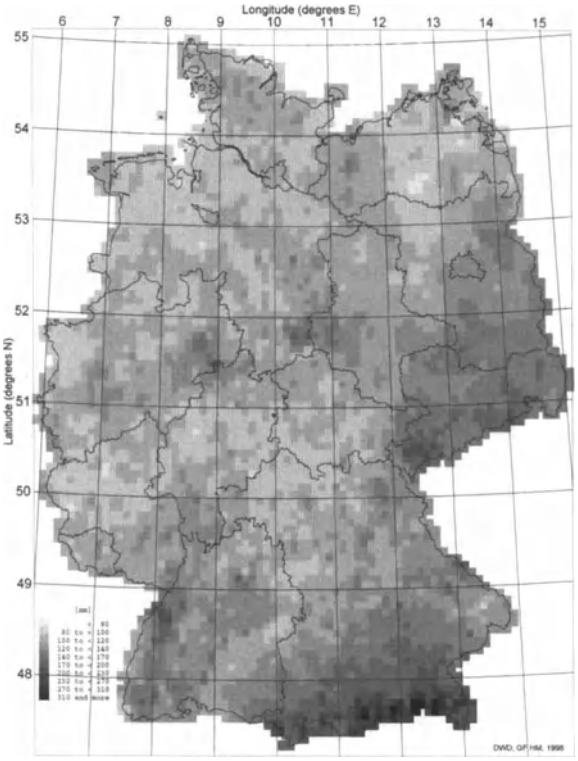


Fig. 3. Regionalised storm rainfall of a duration of 72 hours and a return period of 100 years in Germany (May to September).

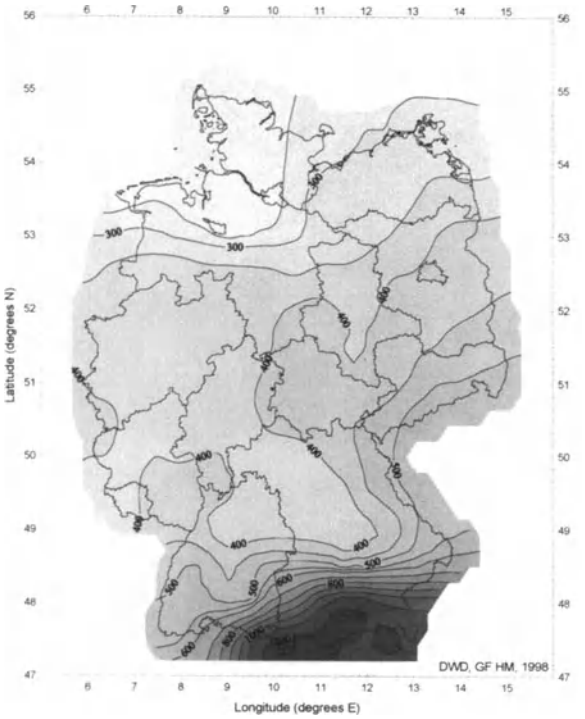


Fig. 4. Regionalised maximised areal precipitation in Germany (area: 1 000 km^2, duration: 72 hours, June to August).

available moisture in the atmosphere and efficiency of the storm mechanism. It is not possible to evaluate the factors influencing the storm efficiency separately, and therefore the observed highest rainfall is used as an indirect measure of storm efficiency. The highest areal rainfall is multiplied by moisture maximisation factor, i. e., the ratio of the maximum amount of precipitable water in a column of air (W_1) to the amount of precipitable water recorded during the storm period (W_2)

$$h_{P,max} = h_{P,obs} W_1 / W_2$$

where $h_{P,obs}$ is the highest observed storm rainfall for a particular duration, and $h_{P,max}$ is the maximised areal precipitation. The amount of precipitable water in an air mass, from which heavy rainfall occurs, can be estimated by the sea level dew points following the saturated pseudoadiabatic lapse rate. The maximum moisture content of a saturated air mass in a given region is then limited by the extreme sea surface temperature in the source region (WMO 1986).

Long period rainfalls of different duration, dew point temperatures (for example the maximum 12-h persisting dew point) and other meteorological data for several stations in Germany were required for estimating the maximisation factors and for regionalising the results obtained for particular areas (Schmidt 1997). For durations of 30 minutes to 72 h, four sizes of area from 25 km^2 to 1000 km^2, and for the four seasons, the values of maximised areal precipitation are given for all regions in Germany (Fig. 4).

5 Conclusions

Considering the increase in meteorological extremes in recent years, there is a need for the use of available future-oriented and applicable hydrometeorological information and services. The conception of the DWD – modernisation of the precipitation measuring and reporting systems, quantitative forecasts of precipitation, the use of the radar network, development and application of special hydrometeorological

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models (SNOW-D, BONIE), and evaluation of extreme values and maximised areal precipitation – could provide an important contribution to the improvement of flood forecasting and planning bases for the dimensioning of retention basins and for the design of storage ponds. It is necessary to support communication between all stakeholders in these special fields of application. Balancing required actions against economic costs and climatological uncertainties, a policy of flexibility in a pro-active manner is recommended. It is likely that in the future additional measures will be required to cope with the impacts of climate change in relation to flood protection. Therefore it is important that the measures taken today are flexible with regard to the future.

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Extreme Runoff Events in Small Catchments – the Need for a Proper Modelling Strategy for Early Warning Systems

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1 Introduction

Extreme runoff events in small catchments are characterised by their individual character, their random occurrence, and their short-lived nature. These characteristics make it extremely difficult to forecast such events. Several aspects contribute to these difficulties: (1) even when it is known that an extreme storm will hit somewhere in a region, it usually remains unknown exactly where and when it will hit and which size it will have; (2) observational data on such events are usually scarce due to the generally low network density of automatically recording raingauges, so local events are rarely recorded; (3) the rare occurrence of extreme events reduces the chances of observing the important processes to close to nil and renders it difficult to provide the information needed for a thorough model building; (4) detailed modelling of all the catchments of a region that are likely to be hit by a storm is not feasible, even taking into account the tremendous increase in information that has taken place with the advent of GIS and related techniques and instruments.

This paper proposes an alternative route to developing an appropriate modelling strategy. It is based on the use of radar data to specify the current situation and uses a catalogue of catchment runoff responses that allows to connect storm and catchment characteristics in order to derive the runoff response of the current event in real-time.

2 Early Warning System Approach – Runoff Modelling Part

Based on the rationale described above, the EWS (Early Warning System) approach proposed here follows a procedure as outlined in Fig. 1. In a first step, the current situation is characterised by defining the initial conditions, comprising information on the date, season, pre-event rainfall, and other parameters describing the pre-event state of the catchment. This information is drawn from general data bases. Parallel, online radar data information is used to define the nature, the location, and the time of occurrence of the storm event. Storms are further specified in terms of their type (i.e. single cell, multicell, imbedded in squall lines, etc.) and structure, and their movement. Based on the information on the storm location, the area to be hit by the storm can be delineated. Subsequently, reference is made to the physical characteristics of the specific location, such as geology, geomorphology, topography, soils and vegetation which allows to specify the catchment in terms of likely runoff response types.

To be able to do this, a classification scheme is necessary relating runoff responses to catchment characteristics. The rationale behind this draws from the general evidence that storms of different types and magnitudes produce runoff hydrographs with distinct features and that these features closely correspond to the runoff mechanisms occurring during the event. Since the runoff mechanism becoming operative in

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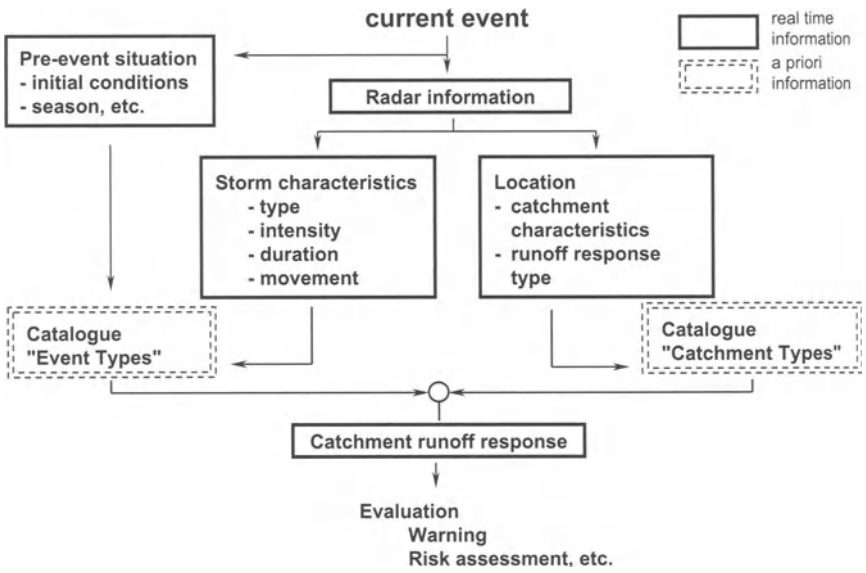


Fig. 1. Early warning system approach – runoff modelling part

response to a certain storm depends on the catchment characteristics, it is possible to establish a link between catchment characteristics and runoff responses via the dominant runoff generation mechanisms.

In a second step, the information contained in the catalogue of storm types is used for a more refined specification of the current event. Additional storm type information builds around elements such as the temporal distribution of the rainfall intensity and the depth-area-reduction factor. The latter may be estimated from global storm characteristics such as storm type and duration as derived from the radar data.

By combining the so gained information on the current storm with the information contained in the catalogue of catchment response types, the runoff response specific to the current event can be derived and used within the warning system.

Central to the approach described above is the concept of "catalogues". They actually act as a knowledge base that relates specific features of the storm and the runoff response to the factors that control their occurrence and development. In the case of storm characteristics, it is the meteorological situation that dictates which storm features develop. As an indicator for the meteorological factors, the global storm specification as outlined above can be used. The derivation of appropriate indicators to define the dominating runoff response is discussed below.

3 Characteristic Features of Extreme Runoff Events

What dominates the runoff process during extreme events has to be inferred from various detectable traces of these events, such as marks of overland flow, flow channelisation, planar and rill erosion, sediment deposits and vegetal debris, as well as traces of uncommon outbursts of subsurface flow. These outbursts have been described by some observers as "fountain-effects". All of these phenomena give a special character to these extreme events and to their runoff responses.

The evidence obtained both from these field observations and from the reconstruction of three extreme events that occurred in small catchments in Austria in recent years (Simlinger 1995; Wild 1997) suggests that the runoff process is highly dynamic and non-linear. There is also evidence for the occurrence of "new" processes not to be observed under common conditions and evidence for a "change over" of processes when a new runoff phenomenon becomes operative and starts to dominate the whole runoff process. For example, this is the case when wide-spread overland flow starts in a major part of the catchment.

Figure 2 (Gutknecht 1994) shows an idealised sketch of the dynamic effects inherent in extreme events. The emphasis is on the "extreme" reaction that becomes operative in the fully developed phase of an extreme event

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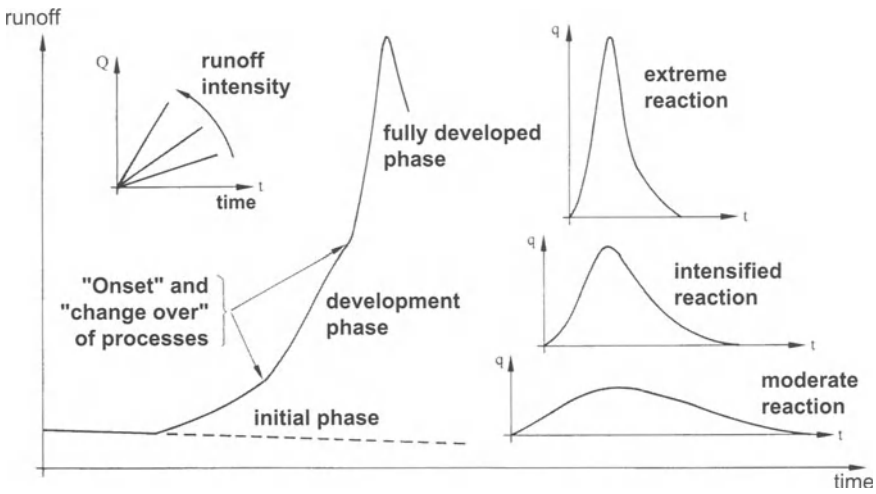


Fig. 2. The dynamics of runoff production in extreme events

whereas it does not occur during events that can be observed more frequently. Figure 2 depicts one of the major obstacles to modelling the runoff response of such events by the traditional modelling approach. The figure suggests that an appropriate modelling strategy can only be found when the runoff mechanisms that lead to such a dynamic behaviour and the conditions under which they occur are properly understood.

The conceptualisation presented here draws heavily from work that has helped to clarify the factors that control the runoff process in a catchment through field and experimental investigations and through mathematical simulation studies. Particularly influential have been the results of studies on runoff generation mechanisms (e.g. Whipkey 1965; Beven & Kirkby 1979; Sklash & Farvolden 1979; Dunne 1983; Zuidema 1985; Kölla 1986; more recently, Kirnbauer et al. 1996; Faeh 1997; Scherrer 1997) and of studies directed at the role of the spatial variability of hydrologic parameters in the runoff process (e.g. Blöschl 1996; Merz & Plate 1997). In recent years also the search for hydrologically similar units (HSUs) (e.g. Schumann & Schultz 1995), hydrological response units (HRUs) (e.g. Flügel 1995) and hydrotopes has stimulated research into a runoff-response related differentiation of catchment areas.

4 A Runoff Response-oriented Catchment Model

A possible starting point of a process-based catchment model can be found in the comparison of runoff generation mechanisms (Fig. 3). Some of them, such as infiltration-excess and saturation-excess overland flow, produce fast runoff responses from the respective areas. On the other hand, certain soils tend to produce subsurface storm flow, particularly in cases where macropore flow and other types of flow through preferred flow paths become operative. Other sites with deep soils and well-developed root-zones hardly produce any runoff under usual conditions. However, even at these sites the situation may change when prolonged wet periods precede a storm event and subsurface storm flow may develop. This indicates that the occurrence of a specific runoff mechanism and an either quick or delayed runoff response associated with it, is the result of the interactions of both the event and storm properties and the soil and underground properties. Based on this, it appears reasonable to differentiate the catchment areas according to the runoff mechanisms with particular emphasis on the time delay associated with each mechanism. Obviously, this classification of the catchment areas may vary with the initial conditions which depend on pre-event rainfall and on seasonal variations. The classification will also change with the magnitude of the storm event proper.

Taking into account these dependencies, a strategy for modelling the runoff response of extreme events may be developed by defining

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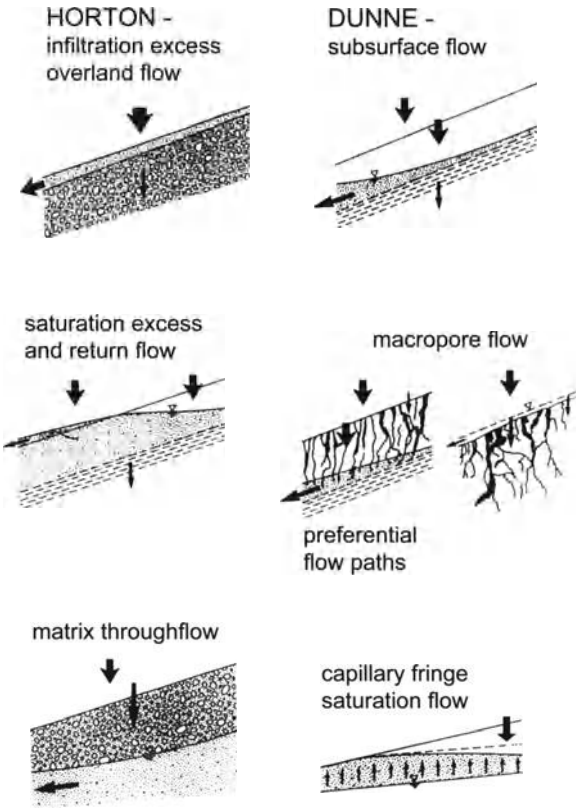


Fig. 3. Runoff generation mechanisms at the site scale

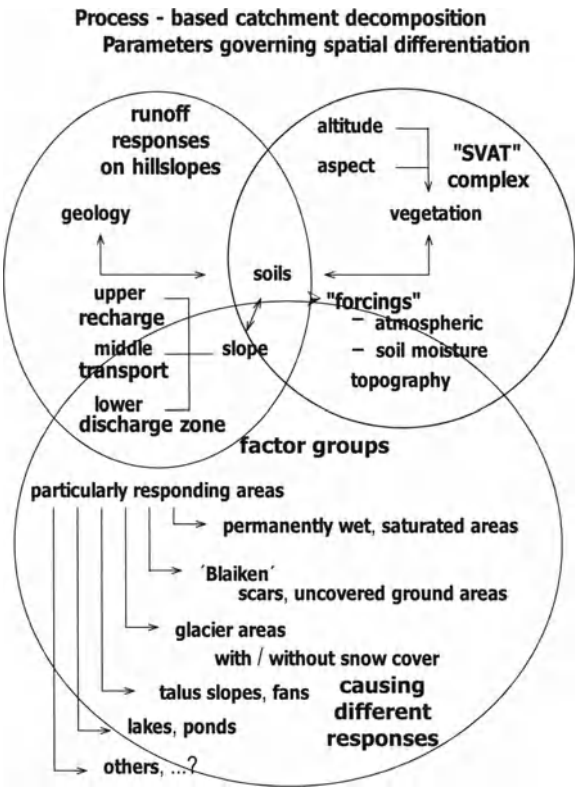


Fig. 4. Factors controlling runoff response generation

the specific conditions that characterise these events. Out of the whole multitude of situations that are possible in general, only those are chosen that match the envisaged situation. The runoff response derived (computed) for this situation may be termed a "catchment response type", each "type" mirroring a specific situation. It is in this sense that the catchment (response) types have been introduced above.

The main task in adopting this modelling concept is the appropriate delineation of catchment areas related to particular runoff mechanism. In principle, this task is similar to the derivation (definition) of "hydrologically similar or homogeneous areas" which are frequently the basis for a quasi-distributed model building. Most of these approaches focus on the simulation of the water balance in the soil-vegetation-atmosphere (SVAT) complex. As the analysis of extreme events in catchments with more complex geologic and geomorphic conditions has shown (Gutknecht 1996) not only the processes within the soil zone but also all the processes related to the structure of the hillslopes are important. Figure 4 groups the various factors that influence the spatial differentiation in the light of runoff generation processes.

5 Conclusions

The approach proposed in this paper rests on the assumption that the overall complexity of the runoff process can suitably be dealt with by decomposing it into runoff response types. First attempts to use this concept in the reconstruction of extreme events in the context of the necessarily broad information base of a regional early warning system have been made. A more comprehensive investigation including data from a variety of events and a variety of catchments seems to be necessary.

Acknowledgement

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Using Real Time Data and a Flow Prediction Model to Assist in the Operation of the Orange River

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Abstract

A hydraulic model is being used to simulate 1400 km of the Orange River, the largest river in southern Africa, south of the Zambezi and one of South Africa's most important water resources. The system will be used as a decision support tool in the operation of the river so that the supply of water to the lower Orange River can be optimised. By incorporating real time telemetry flow and stage data into the model the forecast flows in the river are improved.

1 Introduction

The Orange River is the longest river in South Africa. Originating in the Maluti Mountains in Lesotho, it flows 2300 km westward across South Africa to the Atlantic Coast (see Fig. 1). It is an important resource for Lesotho, Namibia and South Africa and it supports the demands in its own catchments as well as augmenting the water supply to other catchments by means of inter basin transfers.

Vanderkloof Dam is the last major storage structure on the Orange River and after water is released from the dam there is no controlling structure for the remaining 1400 km of river. In this river reach the gross annual average evaporation of 2900 mm far exceeds the annual average rainfall of only 150 mm with the result that the runoff from the catchment is usually insignificant. Therefore, under normal hydrological conditions, the users in this reach of river are dependent on the releases made from Vanderkloof Dam.

An additional complication to the system is that it can take several weeks for water released from Vanderkloof Dam to reach the river mouth where certain domestic, industrial and environmental demands must be supplied. The time taken for the releases to reach the mouth depends on conditions in the river. At low summer flows releases of 100 m^3/s from Vanderkloof Dam take approximately 4 weeks to reach the river mouth. In winter when both demands and evaporation are lower, releases of approximately 40 m^3/s take over 6 weeks to travel the length of the river. It is therefore evident that there can be no immediate relief for any shortages that might be experienced. Due to the nature of these demands any water shortages have a major impact, both economic and environmental.

In the past water was released from Vanderkloof Dam primarily for hydro-power generation and these releases were generally in excess of the requirements of the downstream users. As the demand for water in the industrialised Gauteng area continues to grow, further transfers from the Orange River will be needed and the resources of the river will eventually be fully utilised. The releases will then have to be reduced to correspond to the demands of the downstream users. It is therefore becoming increasingly important to optimise the operation of the Orange River system below

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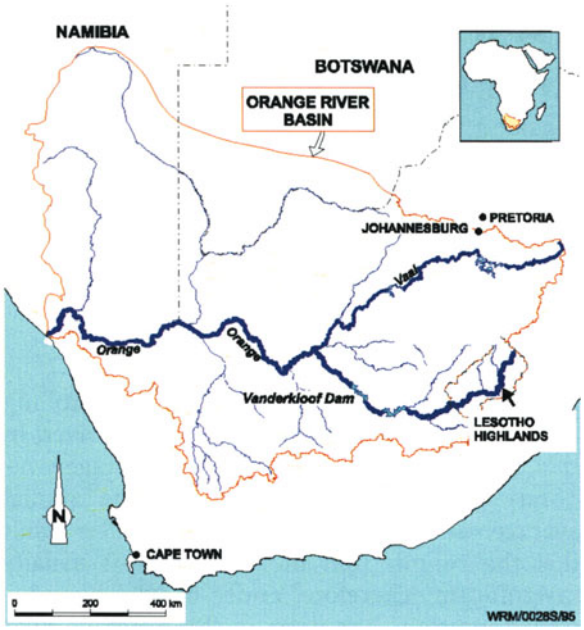


Fig. 1. Location map of the Orange River

Vanderkloof Dam in order to supply the users with their requirements in terms of both magnitude and timing.

1.1 The Objective

In order to manage the Orange River during low flow conditions, the Water Research Commission of South Africa, in association with the South African Department of Water Affairs and Forestry, are supporting a research project on the Orange River. The principle aim of the study is to provide a tool to the operational staff of Vanderkloof Dam to rationalise their decision making process regarding release volumes and patterns.

Water released from the dam supplies numerous requirements including irrigation (1000 million m^3/annum), urban, industrial and mining (40 million m^3/annum) demands, hydro-electric power generation by ESKOM, monthly instream flow requirements (from 35 million m^3/month in summer to 13 million m^3/month in winter) and natural groundwater and evaporation losses.

Any decision taken regarding releases from Vanderkloof Dam will have to satisfy all of the downstream requirements whilst limiting the spillage from the river mouth in excess of the estuarine demands and adhering to any operational policies dictated by the relevant authorities.

2 Conceptual Application of the Model

The World Meteorological Organisation (WMO), in association with the World Bank, is promoting a World Hydrological Cycle Observing System (WHYCOS). This system is based on a global network of reference stations with real-time satellite-based data transmission to enable the development of continuously updated data bases of various hydrological parameters, one of which is river flow. South Africa is included in this system with the Department of Water Affairs and Forestry (DWAF) being in control of all hydrological data collected in South Africa. Several stations on the Orange River are included in the agreement.

The use of cell phone technology has provided another means of data transmission and DWAF has implemented this technology at several sites on the Orange River. Combining the two technologies has resulted in a database of real-time flow conditions at the DWAF head offices in Pretoria. The stations on the Orange River downstream of Vanderkloof Dam included in the real-time network are indicated in Fig. 2.

The real time data recorded at these stations are incorporated into a real time hydraulic model of the Orange River at regular time intervals so that the simulated results at any time are a best estimate of the actual conditions of the river. These results are then used as the initial conditions for the forecasting runs. Each forecasting run therefore starts from an accurate estimate of the current river conditions.

The method used to model the Orange River involves one model operating in real time mode and another, or several others, performing the forecasting runs to test the release patterns from Vanderkloof Dam. Data are exchanged between the real time and predictive models. There is no requirement for the real time and forecasting models to run on the same machine or Local Area Network. They need only be connected intermittently via any Internet service provider. The real time and forecasting models are essentially the same model, utilising identical hydrodynamic infor-

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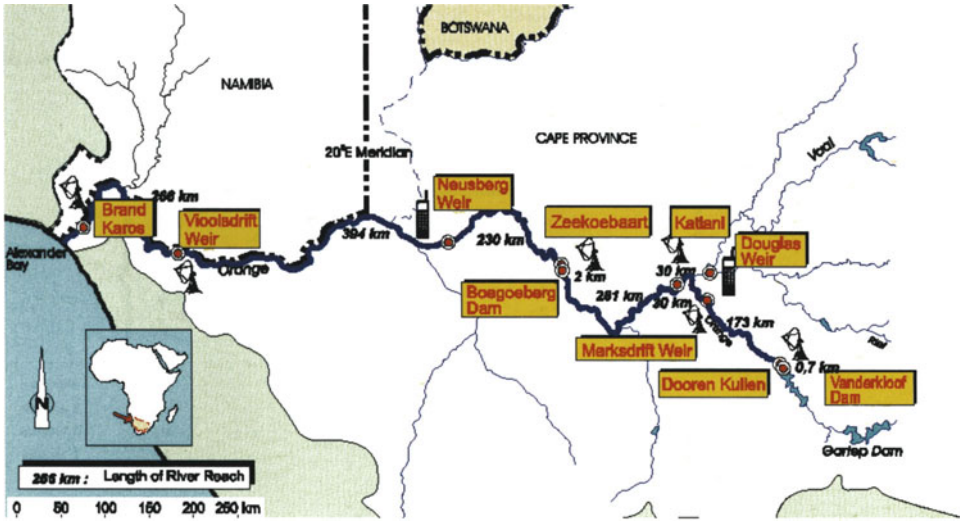


Fig. 2. Location of telemetry stations

mation. They differ only in their use of either real time or predicted data.

It should also be noted that the software consists of two parts, the hydraulic model and the Graphical User Interface. The hydraulic modelling component simulates the hydraulic conditions of the river and is common to both the real time and forecasting models. The United Kingdom based ISIS program was chosen as the basic software for the hydraulic model as the project team has close connections to the software developers and the source code could therefore be customised for the project. In order for ISIS to model conditions in the river certain data are required. These include (inter alia):

Initial conditions for the simulation describing the flow and stage at all computational nodes of the model. The initial conditions are continuously determined and updated by the real time model as it uses the incoming real-time telemetry data. The forecasting simulations utilise these results spawned by the real time simulation.

An inflow hydrograph at the upstream boundary of the model covering the full period of the simulation. For the real time model the upstream hydrographs are the actual releases from Vanderkloof Dam, relayed to the ISIS model via the real time telemetry network and the Internet. Once the real time model has simulated the period up to the latest available data, it pauses until more data becomes available. For the predictive model the hydrographs are the proposed releases from the dam.

Changes to the ISIS source code included incorporating the ability to update, at random intervals, internal boundary conditions using externally obtained real time data. The software was also amended to allow for gaps in the data when measurements were not received at the usual frequency. The possibility exists that incorrect data or a period of no data is recorded and transmitted to the model via the telemetry network. It was therefore necessary to develop error trapping routines to prevent unrealistic real time data from being incorporated into the model.

The Graphical User Interface collects and collates the remote real time data, manipulating it into the format required by the hydraulic modelling component. The GUI also facilitates the exchange of data between the real time and forecasting models and the FTP server or LAN. This data includes the results of the simulations, the pre-determined release scenarios and information regarding downstream demands that have to be modelled.

3 Real Time Hydraulic Modelling

The real-time telemetry data are only available for those nodes in the model which correspond to the real-time flow gauging stations. The purpose of the real-time modelling is to incorporate the incoming data into the hydraulic model so that the modelled results, at all computational nodes, are a best estimate of the flow conditions in the river. The results of the simu-

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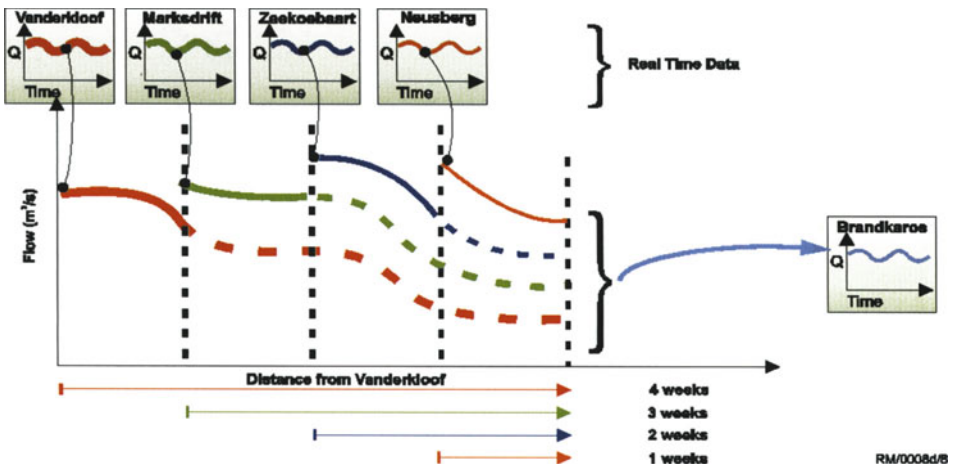


Fig. 3. Methodology for estimating flows

lation are "forced" to the recorded conditions where they are available and the hydrodynamic model then performs the necessary hydraulic calculations to determine the subsequent conditions at all the other computational nodes where no real-time data exists.

There are various unforeseen, and therefore unmodelled, factors that can alter the flow conditions, such as localised rainfall events, incremental inflows and unexpected losses and abstractions from the river. The effect of these occurrences are minimised in the real-time simulations as the modelled results are corrected to the recorded values at numerous places along the river.

Consider for example Fig. 3 in which a hypothetical long section of the Orange River is depicted. Real time data are recorded at the gauges as indicated in Fig. 3 and the simulated conditions at these points are adjusted to the recorded values. The discontinuities at the real-time stations indicate the differences between the simulated results and the recorded conditions. These differences are due to both the effects of unmodelled events which can affect the flow conditions and which are recorded at the real-time gauging stations and by calibration errors. The systematic differences between the recorded and modelled flows could be used for the automatic calibration of the model.

During the subsequent simulations the real time flows are propagated down the reach which extends only as far as the next real-time station, where the recorded data for that station, if available, replace the simulated values. The simulated conditions at any point on a reach are therefore dependent on the recorded data at the closest upstream telemetry station. If for some reason the flows are not recorded at a real time station, the model then uses the simulated flows at the station to estimate the flows further downstream as indicated by the broken lines. The time for the effect of the recorded data to propagate downstream to Brandkaros increases with increasing distance from the real-time station with the result that the accuracy of the predicted flows may decrease due to any unmodelled events that may occur.

In summary, the simulation of river conditions are improved as subsequent real-time data become available. The effect of the releases from Vanderkloof Dam can be monitored using the real-time data and the data at upstream stations can be used to improve the prediction of downstream flow conditions. The closer the real-time station is to the point under consideration, the better the predicted flows.

3.1 Determination of the Release Schedule

When a decision is to be made regarding the release schedule, the forecasting model obtains the most recent results from the real time simulation. The simulation therefore starts from the best available initial conditions. The operator of the forecasting model is able to define the hydrographs for the proposed releases from Vanderkloof Dam through each turbine in terms of quantities released and the timing of the releases. The hydrographs can be repeated for the duration of the simulation.

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As most of the demands to be satisfied are located a considerable distance from Vanderkloof Dam it takes several weeks for the releases to reach them depending on the flow conditions in the river. It is therefore necessary to simulate several weeks during the forecasting runs.

3.2 Effect of Real Time Data on Forecast Results

The inclusion of real-time data improves the simulated results. In Fig. 4 three sets of long section plots of part of the river are shown for two different time slices. The dashed vertical line represents Zeekoebaart Weir which is a real time station. The real time data are included into the model at this point. The reductions in streamflow are due to major abstractions from the river.

Three simulations were conducted to produce the results in Fig. 4. The first simulation (thin line) started on 11 June at 22h00 using the results of the real time simulation available at that time, and simulated the period up to 17 June at 16h00. The real time simulation also continued, incorporating the data recorded at Zeekoebaart Weir into the model. The thicker line in the first plot represents the best estimate of the conditions of the river on 13 June at 17h00. The differences between this line and the results of the forecasting simulation (thin line) indicate that the abstractions upstream of Zeekoebaart Weir were approximately 10 m^3/s more than expected and included in the forecasting model.

Using the results of the real time simulation on 13 June at 17h00 as the initial conditions, a second forecasting simulation was conducted. In the second plot of Fig. 4 the two sets of forecast results for 17 June at 16h00 are compared to the conditions given by the real time simulation at that time (thickest line). It is evident that the abstraction upstream of Zeekoebaart Weir continued to be 10 m^3/s greater than that included in the forecasting simulations. Comparing the conditions given by the real time simulation (thickest line) to those given by the two previous simulations it is evident that the second simulation (medium thickness), which included more real-time data than the first simulation, provided a better estimate of the actual river conditions.

3.3 Project Challenges

In order to successfully model the Orange River using real time data there were several challenges which the project team had to overcome.

A mathematical model, which solves the full St Venant equations, was adapted to utilise the real time data. Due to the rapid changes in the flows released from Vanderkloof Dam an adaptive time stepping routine was utilised.

An external Graphical User Interface (GUI) was developed to present the visualisation of the data and to control the manual and automatic download of remote data from the Internet using FTP or from a network connection. Data files for different release scenarios can also be produced so that their effects can be evaluated.

The Department of Water Affairs and Forestry is a government institution and there are considerable security protocols and firewalls protecting their Internet Servers. For this reason, at the time of writing this paper, the real time data could not be automatically down-

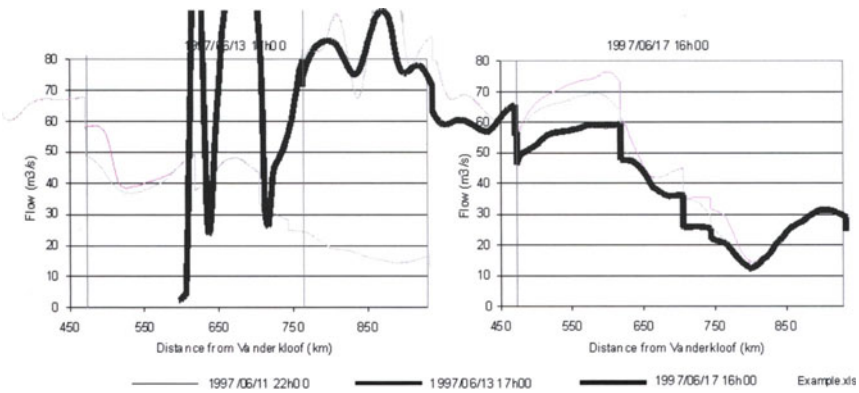


Fig. 4. Effect of real time data on forecast results

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loaded from DWAF at predetermined intervals using File Transfer Protocols (FTP). This problem is being addressed and as an interim measure the data is transferred when requested on a daily, or more frequent basis.

Evaporation losses from the Orange River are highly significant (McKenzie & Craig 1997a) and it was necessary to include a component in the hydrodynamic model to simulate these losses. (McKenzie & Craig 1997b).

4 Conclusions

The strategy described in this paper gives a rational basis for the operators of Vanderkloof Dam to determine a discharge release pattern to ensure that the various demands downstream of Vanderkloof Dam are satisfied. Since the model is based on sound hydraulic principles rather than simplified routing methods the users can be confident in the simulated results. The use of real time data further improves the simulation as unmodelled events such as localised inflows can be taken into account. A logical development is to allow the flow predictions at various locations along the Orange River to be accessed directly through the Internet.

This model was developed primarily to manage the river at low flow conditions. The software can be adapted for flood management and flood warning purposes. Rainfall runoff models have been developed and there is currently much research being conducted on rainfall prediction using satellite and radar technology and real-time rainfall data is becoming more readily available. It is therefore clear that the next step in research is to link the technology developed in these studies to form a real-time catchment model that includes rainfall, runoff and hydraulics. Such a model could be used for general catchment management purposes and more importantly for flood forecasting and management.

Acknowledgements

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GISELE: A New Capability for Flash Flood Early Warnings Over Garonne River Sub-Basins

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1 Introduction: an Overview of the Flood Warning Organisation in France

The French Ministry of Environment is responsible for the management of the early warning systems for floods in France. Météo-France is in charge of the general weather prediction, and more specifically the observations and prediction of precipitation. This situation implies increasing connections between the two organisations, and this paper describes and presents the most advanced real time application.

First of all, we need to describe the general picture of the current formal process used in France for the early warning of floods, including the technical and administrative organisation, regardless of the specific application.

1.1 The Measurement Networks and Data Processing

Since 1983, an upgrade in hydrological measurements has made possible real-time observations of the limnimetric data. Today, 53 SAC (French acronym for Flood Warning Services) use more than 800 automatic measurements. Conversely, Météo-France operates an automatic network of more than 1000 rain gauges, and currently 15 weather radars. Three more radar will be installed in the next few years in the highly sensitive area of the south-east of France. The improved coverage in this area has been partly funded by the Ministry of Environment for hydrological purposes.

Software for collecting, analysis and data processing has been developed accordingly. Since the second purpose of the network is to accumulate knowledge for future studies, radar, rain gauge and limnimetric data are archived in specific databases and therefore can easily be used in post-processing mode.

1.2 The Real-time Management of Early Warning (Fig. 1)

The EWS operates 3 different modes:

- The monitoring mode, which is the normal mode. This mode can be changed into a pre-warning mode when limnimetric measurements exceed a certain threshold, or when important precipitation is forecasted in the daily precipitation forecast from Météo-France; a specific message is then delivered to the EWS.
- When the "first warning" mode is activated, the civil protection services are warned, and are ready to intervene.

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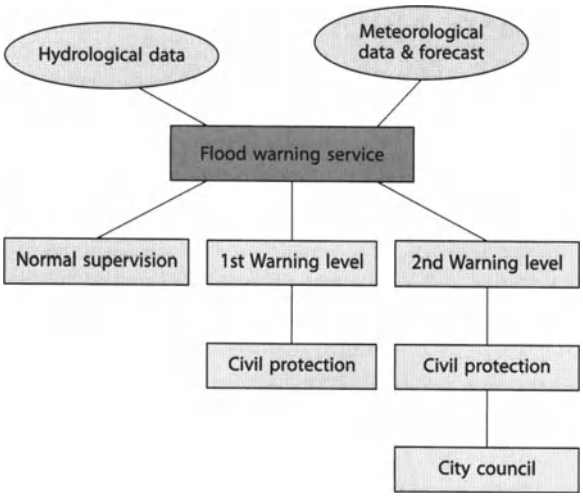


Fig. 1. The Flood Warning Scheme

- If the critical threshold is reached, the second warning, i.e. the complete alert, is developed. The mayor of every village or city threatened by the flood is warned. He (or she) is in charge of the population alert, and has the legal responsibility to decide, if necessary, the evacuation process, in conjunction with the civil protection services. The mayor is permanently informed by mean of a data server. Meanwhile, Météo-France regularly communicates with the EWS by formal specific messages.

The EWS is revised according to the specific hydrologic situations. Where classical flood warnings may be sufficient for the largest basins, with concentration time exceeding 24 h, a specific warning system has to be adapted for flash floods. This is the purpose of the GISELE project described hereafter.

2 The Need for the Flood Warning Service of the Upper Garonne Basin

According to the meteorological conditions resulting in rain events, 3 types of flooding can be generally distinguished for the Garonne river basin:

- The oceanic pyrenean floods, the strongest ones, which can occur at any time of the year but appear more frequently, and stronger, in May, June and July.
- The classical oceanic floods, which occur mainly in winter and spring, and influence especially the middle part of the Tarn and Lot rivers. For the Garonne river such events affect only the part of the river situated downstream converging with the Lot river.
- The mediterranean floods, due to heavy rain on the eastern part of the basin (Tarn, Aveyron and Lot rivers).

2.1 The Upper Garonne River Basin

The upper Garonne river basin covers an area of 10000 km^2, upstream Toulouse, and includes *3 main watersheds*: the sub-basin of the Ariege river (4160 km^2), the Salat river (1570 km^2) and the sub-basin of the "upstream Garonne" (2770 km^2).

The *intermediary watershed* located between Toulouse and the bottom of the 3 already-named sub-basins causes particular difficulties by delivering intermediary contributions quite variable according to the quantities of rain that fall on this area. The error due to a lack of knowledge on rainfall amounts for this intermediary watershed can reach 0.5 m for a level of 2 to 3 m (corresponding to a 10-year return period). To overcome this source of error, new methods of run-off forecasts for the intermediary part and for the downstream part of the upper Garonne river basin have been developed and implemented. A better knowledge of the rainfall event of the intermediary watershed would provide more reliable data.

2.2 Monitoring of Numerous Small Upstream Watersheds

Monitoring of upstream watersheds is much more difficult. As their superficies range between 170 and 1000 km^2, information on rain fall in these small watersheds is absolutely necessary to perform run-off forecasts. This is especially essential for the warning stations of the sub-basins of Arreau-sur-Louron (170 km^2), Arreau d'Aure (390 km^2), le Mas d'Azil (215 km^2) or Saint Béat sur Garonne (694 km^2), and Salat de Saint-Girons (1080 km^2). These small watersheds located at the foot of Pyrenees are responsible for strong floods observed in the upper Garonne river basin.

For the upper Garonne river basin, difficulties are enhanced by the topography and rainfall pattern that cause flash floods. The Saint-

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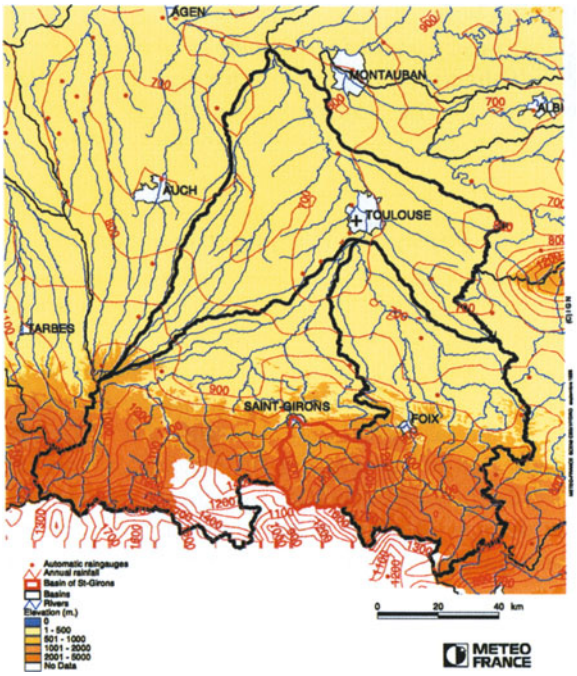


Fig. 2. Upper-Garonne basin

Girons basin includes both lowlands (elevations lower than 500 m) and high mountains (higher than 2900 m). The annual mean rainfall given in Fig. 2 varies from 800 mm to more than 1600 mm in the Saint-Girons basin. Individual events can easily produce a greater variability.

Slopes and shapes of basins allow a quick run-off of water and give sharp hydrograms. Therefore high speeds of propagation are observed and the forecast range cannot exceed 6 hours for Toulouse, 3 hours for the intermediary watersheds and 1 to 2 hours for small upstream watersheds. As the height of the rivers can grow by 0.5 to 1 meter per hour (and even more), it is obvious that a good knowledge of the rainfall is needed.

The upper Garonne river basin is, now, equipped with more than 30 automatic stations measuring rainfall and run-off. To obtain an acceptable coverage with rain gauges, this number ought to be multiplied at least by a factor 3. If such coverage is barely a minimum to perform rainfall-runoff modelling, uncertainties on the spatial variation of the rain field can partly explain the difficulties encountered by hydrologists in establishing rainfall-runoff relationships. Due to all the above-mentioned reasons, it is obvious that additional information on rainfall by radar imagery is indispensable.

Observation of rain by radar is however difficult in mountainous areas, due to possible problems of ground clutter (spurious echoes returned by the relief) and blocking of the radar beam. Radar-imaging with several elevation angles would reduce ground clutter and blocking effects, but on the other hand generates other problems related to the higher height of the radar beam leading to more frequent interceptions of the 0°Celsius isotherm. Accordingly the use of radar imagery for hydrological applications requires the development of regulation algorithms, in particular for clutter suppression, adjustment of shielding effects and rectification of the vertical profile of reflectivity (VPR).

To hasten advances in the operational use of radar imagery for flood warning application, a cooperative project started in 1995 by the Direction Régionale de l'Environnement Midi-Pyrénées, Météo-France and the Laboratoire d'Aérologie within the framework of GISELE (French acronym of Groupement Inter-organismes Scientifique pour l'Evaluation des Lames d'Eau).

The aim of this project is to test a real-time system devoted to runoff forecasts and flood warning for the upper Garonne river basin giving special attention to the small and intermediate basins using areal rainfall estimated by radar.

3 The GISELE Real Time Experimental System

This experimental system is described in Fig. 3. Radar data is acquired and processed on the radar site itself, and images of hourly rainfall amounts are transmitted to the Flood Warning Service where they enter the local network to be used as input for rainfall-runoff modelling. The transmission of images is performed in real time by NUMERIS, which is a public telecommunication network for numerical data.

3.1 Computation of Images of Hourly Rainfall Amounts

Many existing correction methods need to be applied to basic polar data (VPR identification, correction of attenuation by heavy rain, correction of shielding effects, etc.). For this reason,

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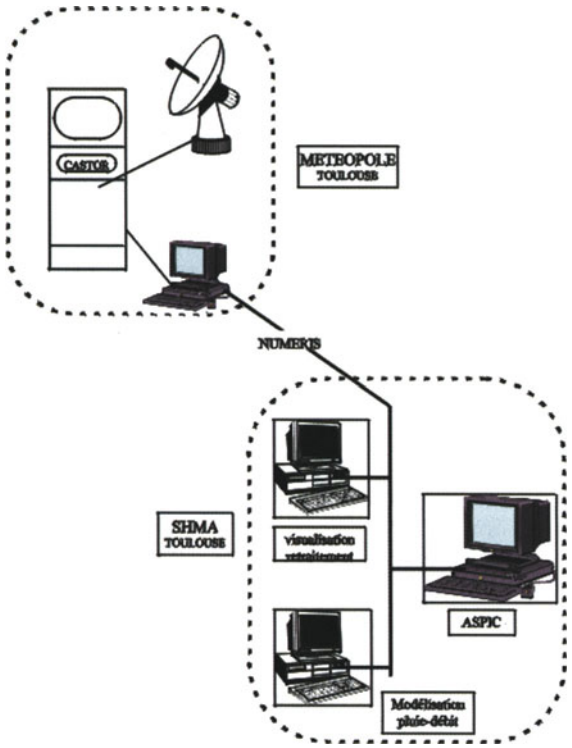


Fig. 3. Outline of the experimental system

we installed a dedicated workstation on the radar site which receives high resolution polar data for different elevation angles (0°8', 1°4', 2°2') from the radar computer CASTOR. For these 3 elevation angles, a polar image is generated every 5 minutes by the CASTOR computer and transmitted to the workstation for archiving and computations. These basic images contain 820 shots of 254 gates; the angular resolution is 0.45° and the radial resolution 1 km. Each pixel is encoded according to a scale of 180 levels of reflectivity.

Ground clutter is identified by computing the frequency of non-zero values of reflectivity for polar data during one month for each of the 3 elevation angles of the Toulouse radar. A pixel with a frequency above 30% is considered as a ground clutter. For the computation of the images in cartesian coordinates, we take into account the reflectivity of the polar pixels corresponding to the lowest elevation where ground clutter is not present. This allows a better detection of rain in mountainous areas.

The influence of the *vertical reflectivity profile* on radar measurements can be corrected by the analysis of the radar signal at successive elevations, assuming a constant vertical gradient of precipitation. We use for this a simplified version of the Andrieu and Creutin method (Andrieu & Creutin 1991; Chèze et al. 1998).

3.2 Data Display and Post-processing at SHMA

The device used to display images of rainfall accumulations on the workstation was developed at the beginning of the experiment in summer 1996 (VALERHY); the software computes the areal rainfall amounts for different sub-basins by integrating the images of rain accumulations. Additional functions concerning the display of other meteorological information (rain gauge, satellite imagery) has been added since the end of 1996.

3.3 Rainfall-runoff Modelling

Areal rainfall accumulations are computed for elementary watersheds. The results are issued from a runoff forecasting system based on a multi-model procedure (SOPHIE). This procedure allows the comparison of the results of forecasts from either rain gauge data, or radar data.

Several points of runoff measurements are available for the upper Garonne river basin. This is a "bulk" model, which relates the mean rainfall to the runoff observed at the outlet. The quality is better when applied to a small "shell-like" watershed, having a small concentration time. The physical characteristics of the watershed must be deduced from the analysis of several recorded events.

These methods are based on a multi-model procedure. A forecast is performed for a given station, using several models taking into account different input data. Each model contributes to the final result, called weighted forecast, with a weight that is a function of errors registered for the near past. So, the forecast fitting process takes into account errors due to bad estimates (Dupouyet et al. 1994).

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4 First Tests on Flooding Events of Autumn 1996

October, November and December 1996 were characterised by heavy rains that resulted in numerous floods on different tributaries of the upper Garonne river basin.

During these rain events, systematic comparisons were made between rainfall accumulations measured with the rain gauge network of SHMA and areal rainfall accumulations deduced from the images of the Toulouse radar. Both of them were competitively used in real time as an input for the runoff forecasting system.

The example presented here concerns a tributary of the upstream part of the Garonne river, namely "Salat de Saint-Girons". Recall that the corresponding watershed has an area of 1080 km^2; the altitude strongly varies from 380 meters to nearly 2900 meters (Mont-Rouch). At that time, the VPR correction was not implemented in realtime.

Figure 4 shows the hydrograms observed at the Saint-Girons station and 2 hydrograms forecast 2 hours earlier. One of the forecast hydrograms is computed using data from 3 rain gauges located in the watershed; the other is computed using radar derived areal rainfall. These curves have to be carefully analysed: because of the auto-correction process in the runoff model, the general shape has to be in a good agreement either with radar or rain gauge data. Only small-term fluctuations (about 2 or 3 hours) are relevant for our present discussion.

For the 26 November flood, the hydrogram forecast from the radar data is closer to the observed hydrogram during the most sensitive part of the flood (i.e. just before the maximum value of the hydrogram was reached), with less irregularities. The fact that radar data are representative of the mean rainfall on the watershed probably explains these better results. This is partly confirmed by the one hour accumulation picture taken just before the maximum runoff (Fig. 5). The maximum value can be observed in the northern part of the watershed, contrary to the usual pattern, and these irregularities are correctly sensed by the radar.

These encouraging results need to be confirmed for other events before a completely operational use of the hydrological method based on radar data. From now on, with this new tool, flood forecasters of the upper Garonne river basin have a better perception of the situation and, thus, of the risk.

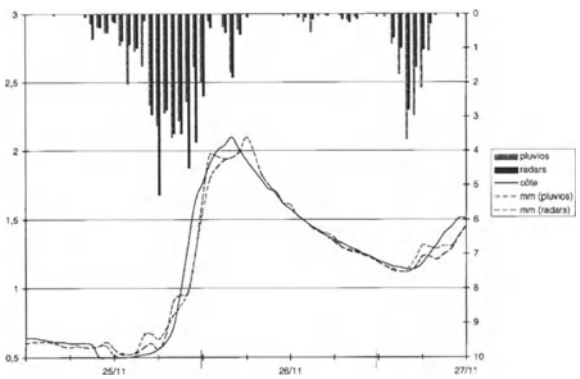


Fig. 4. Height vs time (St Girons)

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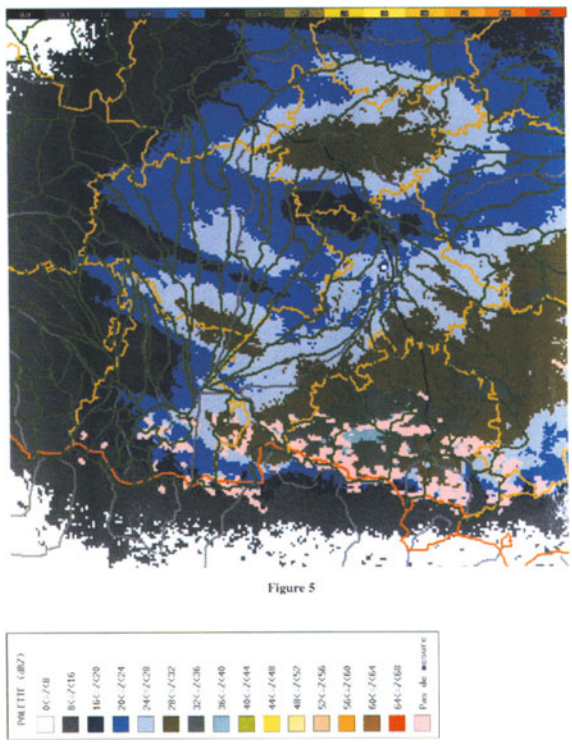


Figure 5

Fig. 5. 1 h radar rainfall accumulation (25/11/96 16h00–17h00 UT), Toulouse

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5 Concluding Remarks

In order to perform flood warnings on small river basins, operational services need estimates of rainfall amounts with very short delay. Considering the size of the areas observed it is difficult for the rain gauge network to provide realistic data. Radar imaging appears capable of solving this problem. However use of radar in mountainous areas implies coping with problems of ground clutter, shielding effects and vertical reflectivity profiles.

Strong flooding events of the upper Garonne river basin in the Autumn of 1996 provided an opportunity to first encourage testing of the complete hydrological application. With a limited set of corrections, radar seems to slightly improve the runoff forecast. We expect further improvements from the Vertical Profile Correction, as demonstrated by off-line corrections (Chèze et al. 1998). It opens the way to the generalisation of such systems.

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CHAPTER 4.17

The Passage of the '97 Flood Wave on the Lower Odra

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1 Introduction

The flood that occurred on the Odra river in July and August 1997 was one of the biggest for this river noted in history. The flood was less violent on the lower Odra than on the upper and middle stretches of the river. In this area, however the flood also imposed severe damages, especially on embankments, the river bed and hydrotechnical structures. Moreover, the water transported a large amount of potentially dangerous substances from the flooded areas and this load was eventually released in other flooded areas. To evaluate the forces that lead to damage and to prevent similar disasters in the future, a documentation of the discharges along different branches of the river is necessary.

In managing the water discharge, the German and the Polish administrations cooperated and informed each other as well as possible given the difficult circumstances. After the fact, however, it can be stated that improvements in cooperation could be made. In particular a lack of sufficient discharge measurements in the different branches of the river and along the flooded summer polders (areas protected by lower dikes, used for agricultural purposes during spring-summer periods, and prepared for inundation during autumn and winter) instigated long-lasting discussions regarding flow values in the culmination phase of the flood. Flood culmination flow values on the lower Odra river differed between 2000 m^3/s and 3000 m^3/s (Buchholz & Dybkowska 1998; Rosenthal et al. 1999; Pluta et al. 1998). These differences could not be explained by the usual sampling variability. They originated either from erroneous measurements, or from by-passing a part of the flow through flooded areas, with this consequently not being taken into account in the total discharge calculation. The following text presents an investigation into this second possibility. In the investigation, the downstream passage of the '97 flood wave on the lower Odra river, taking into account the by-pass of the Odra water through the German summer polders near Schwedt, has been simulated. The simulation has been performed using a numerical model of flows in the lower Odra river network, developed and utilised in the Maritime Research Institute, Szczecin Branch. The calculations were carried out based on data available in the early part of 1998, as provided by both Polish and German sides. Assuming that all water level and discharge measurements were done correctly, the most probable scenario for the downstream passage of the '97 flood wave on the lower Odra was constructed.

2 Data Used for the '97 Flood Wave Passage Simulation

The simulation of the '97 flood wave passage on the lower Odra was performed based on the following data:

- water stage observations carried out by the Meteorology and Water Management Institute (IMGW) and the District Water Management Board in Szczecin (ODGW),

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- water stage observations conducted in continuous mode by the monitoring network of the Maritime Research Institute, Szczecin Branch (MRI),
- discharge measurements at the Widuchowa cross-section, performed by Coriolis s.c. (Coriolis), Szczecin, instructed by ODGW,
- discharge measurements carried out by the GKSS Research Centre, Geesthacht (GKSS), during a campaign in 1997 at the Odra Lagoon,
- flows at the Hohensaaten-Finow cross-section published by Landesumweltamt Brandenburg (LUA),
- discharge measurements at the Schwedt's bridges cross-section, delivered by Landesumweltamt Brandenburg (LUA).

3 Tools Used for the '97 Flood Wave Passage Simulation

The '97 flood wave passage simulation was performed using a numerical model of unsteady flows in the lower Odra river network, bounded by Hohensaaten (664.9 km of Odra river) and Police (48.5 km of waterway Świnoujście–Szczecin) (Ewertowski, 1988).

In this model, the river network is presented schematically as a system of 52 sections and 38 nodes. Particular sections of the computational network either relate to natural sections, or are artificially separated from longer sections of the river. The nodes relate to the connections of particular sections. The computational network is composed of 376 cross-sections. The whole river network is considered as a planar digraph.

Flows in each section are treated as one-dimensional, and described by Saint-Venant's equations. At all nodes of the river internal balance conditions are used.

For the numerical realisation of the unsteady flows model, its equations are approximated in space and in time using a four-point difference scheme.

The boundary conditions of the model are at initial (lower) nodes and last (upper) nodes of a network are hydrographs of water stages, and hydrographs of flows or water stages, respectively.

The initial conditions of the model (i.e. water stage and flows in each computational cross-section of a network for the initial instant) are acquired directly from the output of the numerical model of steady flows calculated for the initial values of the unsteady boundary conditions.

In the model total area of each cross-section has been divided into three parts – the main river bed and the lateral flooded plains, each with different roughness coefficients. Bottom stresses are calculated accordingly to Manning's formula.

In the unsteady flows model concentrated inflows and outflows in any internal node of the network can be prescribed – as auxiliary conditions, changeable in time.

In the model the influence of the transient wind field on water stages and flows is taken into account. The transient wind field is given using spatial interpolation of temporally variable wind speed and direction from several measuring stations. Wind stresses are calculated according to Buchholz's formula.

In the model of unsteady flows in the lower Odra river network, a model of the Widuchowa weir is included – as a special section. The Widuchowa weir controls the distribution of the Odra flow to the eastern and western branches of the river. The model is based on currently valid *Instructions of the Weir Service*, which determine the way the gates are open (Pluta 1995).

The model of unsteady flows in the lower Odra river network is linked to the quasi-one-dimensional retention model of Międzyodrze. Międzyodrze belong to the land situated between the eastern and the western branches of the Odra, downstream from Widuchowa. In the past, this area has been utilised economically as summer polders. At present, Międzyodrze is classified as a flood plain. Its inundation takes place for Odra river stages insignificantly higher than mean values, and is not controlled in any way. As a result, there exists a permanent and free-flow exchange of water between the Eastern and Western Odra throughout this area. In the model, Międzyodrze is represented as system of reservoirs. The exchange of water between Międzyodrze and the Odra – represented by the lateral inflow/outflow to/from the river – takes place through the sluices present within the line of dikes surrounding this area. These sluices are considered to be either open or flooded (Dybkowska-Stefek 1989).

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The Manning's roughness coefficient, wind drag coefficient and empirical parameters in wind stress formula and coefficients of discharge for sluices of Międzyodrze represent the parameters for the unsteady flows model.

Verification and calibration of the model have been carried out based on hydrograms of water stages at internal cross-sections of the river network.

4 Simulation of the '97 Downstream Flood Wave Passage on the Lower Odra River

The passage of the '97 downstream flood wave on the lower Odra river for the period from 18 July to 15 August was simulated. In the simulation:

- the flows hydrogram at the Hohensaaten cross-section from LUA Brandenburg data (Fig. 1) were assumed to represent the upper boundary condition. Culmination of the flood at Hohensaaten was equal to 3000 m^3/s,
- the water stage hydrogram at the Police cross-section obtained from MRI measurements were assumed for the lower boundary condition (Fig. 2),
- the wind field over the area of the lower Odra – were based on measurements obtained at the Police MRI station (Fig. 3).

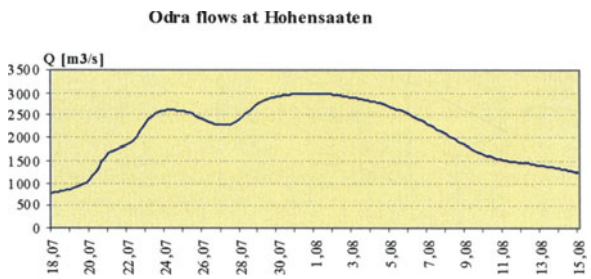


Fig. 1. Upper boundary condition



Fig. 2. Lower boundary condition

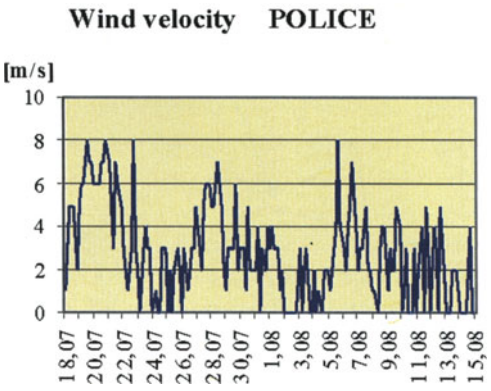


Fig. 3. Wind conditions



Fig. 4. Diagram of the lower Odra network

In the simulation, the by-pass of the Odra water through the German summer polders during the flood was taken into account. In the internal nodes of the model network three additional concentrated inflows/outflows – changeable in time – were therefore assumed. These related to:

- the outflow from the Odra to polder A,
- the outflow from polders A/B to the Odra,
- the outflow from polders A/B and C through Hohensaaten-Friedrichsthal-Canal to the Western Odra (Fig. 4).

Different hydrograms of inflows/outflows still within the estimated limits of the flow through the polders have been considered, and those most consistent with the measurements were finally chosen. For the estimation of the hydrograms the discharge measurements at the bridge in Schwedt and the water storage capacity of the German summer polders (kindly provided by LUA Brandenburg) were taken into account. The most consistent estimated hydrograms of inflows/outflows are presented in Fig. 5. In this figure, the discharge measured at the bridges in Schwedt are also shown.

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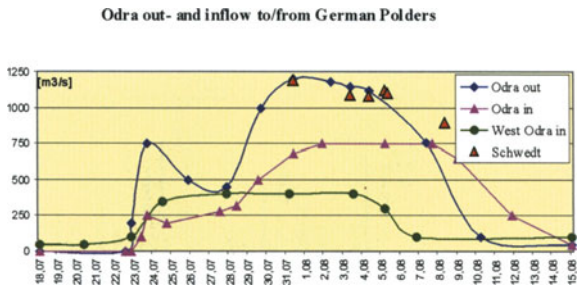


Fig. 5. Estimated hydrograms of the inflows/outflows to/from German summer polders

In the simulation, the Międzyodrze flood plain was taken into account.

Verification of the model was performed on the basis of:

- hydrograms of water stages at internal cross-sections of the river network, i.e. at Pomorzany, Parnica, Gryfino, Widuchowa and Bielinek,
- discharge measurements performed at the Odra Lagoon and at the Widuchowa cross-section.

In order to determine the influence of the by-pass of the Odra water through the German summer polders on the '97 downstream flood wave passage on the lower Odra, an additional simulation of flooding scenario has been carried out. In this simulation, outflow from the Odra onto German polders and inflows from these polders into the river network were switched off.

Simulations of the '97 downstream flood wave passage on the lower Odra river were performed with a time step of 4 hours, and parameters of the model were taken from previous calibration experiments.

The simulations produced the following:

- hydrograms of water stages, both calculated (with and without taking into account the by-pass of the Odra waters through the German polders) and observed (at Pomorzany, Parnica, Gryfino and Widuchowa cross-sections) – Fig. 6a and 6b,
- hydrograms of flows, calculated taking into account the by-pass of the Odra waters through the German polders, at Widuchowa cross-section (with discharge values measured by Coriolis) and at the Police cross-section (with discharge values measured by GKSS) – Fig. 7.

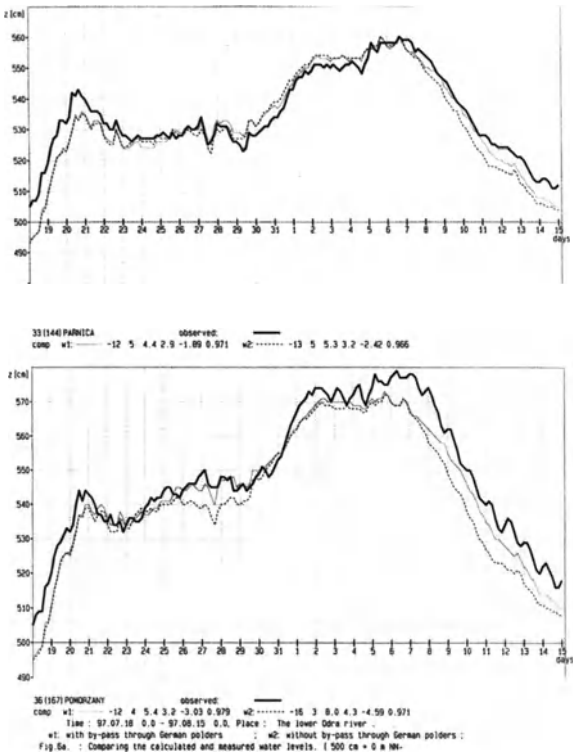


Fig. 6a. Hydrogram of water stages, both calculated and observed at Parnica and Pomorzany

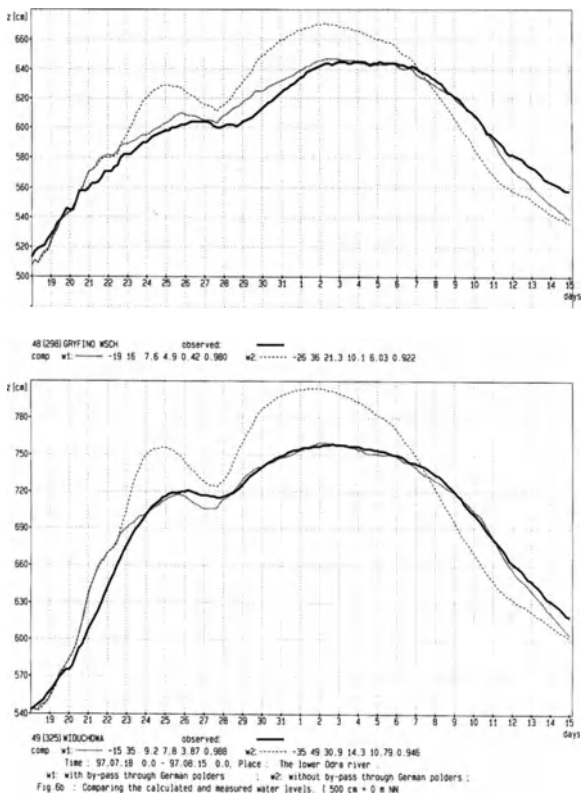


Fig. 6b. Hydrogram of water stages, both calculated and observed at Gryfino and Widuchowa

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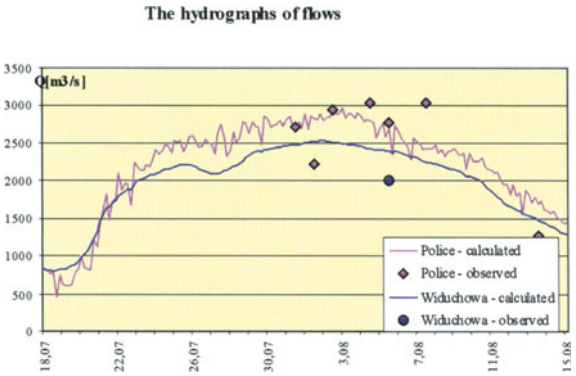


Fig. 7. Hydrograms of flows at Police and Widuchowa cross-sections

The analysis of results of the simulations indicates that:

- the opening of the German summer polders substantially influenced the downstream flood wave passage on the lower Odra river. The discharge measurements from LUA Brandenburg indicate that the biggest flows at the Schwedt bridges were equal to 1190 m^3/s. This means that water left the German polders returning in part to the Odra river bed in the region of Ognica, and in part through the Hohensaaten-Friedrichsthal-Canal to the Western Odra river bed. If the by-pass of the Odra waters through the German polders were not possible, the water levels in the river network of the lower Odra would increase. Maximum increase in water levels would take place at the cross-sections upstream from Widuchowa. The highest water level at the Bielinek cross-section (assuming that the shape of this cross-section is invariable during the flood wave passage) would be 130 cm higher than the flood culmination. Culmination of the flood would go up 45 cm in Widuchowa and about 25 cm in Gryfino. The exclusion of the by-pass of the Odra waters through the German polders would not have any practical influence on the highest stages noted in the Szczecin area during the flood,
- the opening of the German summer polders caused lowering of the water levels at cross-sections upstream (depression curve), and increased the water flow velocity. Results of measurements carried out during the flood indicate that, at Bielinek cross-section, flow velocities reached 2.5 m/s. They were very high, and substantially exceeded the washout velocities. They explain the bottom erosion at the Bielinek cross-section which caused deepenings of 1 m. In the area of spurs (at the concave bank) local deepenings reached values of 9–10 m relative to the average water level (Buchholz & Dybkowska 1998).

5 Conclusions and Suggestions for Future Activities

The good agreement of calculated and measured water stages and flows at given cross-sections indicates that the performed simulation has described the real distribution of the water transport in the '97 downstream flood wave passage on the lower Odra river. It can be therefore deduced that the culmination flow of this flood was indeed equal to 3000 m^3/s. The described investigation shows that, in the case of a severe flood, the knowledge of the river topography for normal flows is not enough. The inundation of flood plains and summer polders during the flood requires knowing the topography of these areas and their hydrodynamic parameters (e.g. bottom friction). In addition topography of areas potentially inundated in the case of a dike break should be known. For these areas a two-dimensional flow model allowing forecasts of flood development, should be available.

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The Oder River Flood in Summer 1997 from Brandenburg's Point of View

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1 Introduction

An analysis of world-wide experience regarding the damages caused by natural disasters in the course of ten years (1986 to 1995) shows that floodings and storms have each caused about one third of the total record of 5370 harmful events. The remaining number of harmful events is made up of earthquakes and other natural phenomena (winter damages, forest fires, volcanic eruptions etc.) whose shares are almost equal. 367000 people died between 1986 and 1995 in the natural disasters recorded and analysed. More than half of the deaths were caused by storm tides, river floods, tidal waves and torrents of water. Most of the casualties were registered in Asia where cataclysmic events recur. The floodings in Bangladesh (1991) took 140000 lives. In view of these statements, one has to face the questions of disaster control over and over again.

One year has already passed since the event. Its memory is starting to fade in the minds of many people then affected on the spot, of the helpers who did their best to prevent or minimise damages, or the people who followed the sequence of events in the media. Others have still today, and certainly for years to come, to fight the consequences of the flood. Their health, everything they owned, their economic existence, their family or their life's work may have been destroyed by the flood. 250 years after the drainage of the Oder valley the flood control works on the Oder River had to go through their hardest loading test so far.

The whole Oder region in Czechia, Poland and Brandenburg was struck by the heaviest flood since water level measurements became verifiable. The flood affected first our south-eastern neighbours: The disastrous flood took 48 lives in Czechia and 56 in Poland. About 40% of the Czech territory was directly or indirectly affected by the flood.

More than 160000 people had to be evacuated in Poland. Approximately 650000 hectares of land and 1362 localities were inundated, some of them are still uninhabitable to this day. Damages were particularly devastating in major towns like Wrocław (Breslau), Opole (Oppeln), Nova Sol (Neusalz) or Zielona Gora (Grünberg). Compared here with Germany and especially Brandenburg got off lightly. Every single personal drama, every house which turned uninhabitable is a tragedy, as is the destroyed harvest – but the flood did not take one life. After the dykes burst 150 houses in the low-lying area near Ziltendorf and others in the affected districts of Frankfurt/Oder, in Ratzdorf and in Lebus were inundated as well as some isolated farmsteads and agricultural works along the Oder River. Altogether 9300 inhabitants of imperilled areas had to be evacuated.

Although the "maximum credible accident" could be averted in the Oder valley, the direct

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flood damages amount to approximately 50 million DM for repairs on residential buildings, about 31.5 million DM for damages in agriculture, about 50 million DM for repairs on infrastructural works, and about 35 million DM for the first repair work on the dykes. On top of that there are costs for dyke defence which will come to a total of about 500 million DM, as shown by yet incomplete surveys.

2 The Oder River and its Catchment Area (Fig. 1)

With a length of 854 km the Oder is the sixth longest fresh water confluent to the Baltic Sea. Its catchment area comprises nearly 120000 square kilometres, with 89% situated in Poland, 6% in Czechia an 5% in Germany. Downstream between the localities of Ratzdorf and Mescherin the course of the Oder forms the border between Germany and Poland.



Fig. 1. Boundaries of the catchment area of the Oder River
1) Total catchment area of the Oder River, 2) German catchment area of the Oder River

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The Oder rises at an altitude of 634 metres above sea level in the Czech East Sudety Mountains. It passes the Moravian Gate near Ostrava and flows in a northwest direction from there up to the mouth of the Lusatian Neisse. Having passed the mouth of the Lusatian Neisse the Oder flows to the north. Downstream Frankfurt/Oder the river is tangent to the Oderbruch valley, a low-lying area of about 800 square kilometres which was given its actual shaping by extensive hydraulic engineering under Frederick II.

On the latitude of Fiddichow (Widuchowa) the river divides into East Oder which has to be regarded as the actual Oder Stream, and the West Oder. Eventually, the Oder flows into the Szczecin Lagoon (Stettiner Haff/Zalew Szczecinski) and from there through its three arms Peene Stream, Swine (Swina) and Dievenow (Dziwna) which meet the Baltic Sea.

The most important Oder confluents to the left are Glatzer Neisse (Nysa Klodzka), Katzbach (Kaszawa), Bober (Bobr) and Lusatian Neisse (Nysa Luzycka). To the right one has to point to the Warta River (Warthe) which meets the Oder near Küstrin.

3 River Engineering on the Oder

The riverbed of the Oder had been decisively changed by land reclamation work and measured the prevention of severe flood damages already during the 18th and 19th centuries. River regulations (through-cuts) upstream Glatzer Neisse, from Glatzer Neisse up to Dyhernfurt (Brzeg Dolny) and between Güstebiese and Hohensaaten brought about a shortening of the river course by 187 km during the period from 1740 until 1896. Flood protection dykes were built during the different stages of river regulations but could not hold out against decades of very heavy flood events (as for instance in 1736, 1755, 1838, 1947).

The most important works were:

1717 Construction of the dyke from Lebus to Zellin

1747–1753 Construction of the "New Oder" between Güstebiese and Hohensaaten; after that, almost the whole Oder valley was protected by dykes.

1832 Construction of the dyke near Güstebiese upon the left bank of the Oder separating the Old Oder. The dyke was then completely closed from Lebus up to Neuglietzen.

1840–1859 Construction of the dyke from Hohenwutzen to Stützkow; construction of the dyke on the right bank of the Oder from Niederwutzen to Bellinchen (polder of the low-lying area near Zehden).

1892–1896 Construction of the polders A and B near Schwedt.

1907–1932 Extension of the Oder Stream near Niedersaaten; extension of the draining canal in the Oder valley downstream Hohensaaten to the Hohensaaten-Friedrichsthal waterway; extension of the dyke Hohensaaten-Stützkow; construction of two connecting waterways, the Schwedt transverse canal and the Gartz transverse canal.

The Oder had an original natural flooding area of approx. 3709 km^2 between the mouth of River Oppa (Opava km 0) and the Oder lagoon. The construction of dykes up to 1896 reduced that area to 859.4 km^2 (23.17%).

4 Origin and Course of the Flood Event

Basically twice a year floods may occur on the Oder River.

1. Winter or spring flood (thaw, ice jam);
2. Summer flood (heavy rainfalls due to Vb-type weather conditions).

The latter was the cause of the flood in 1997.

In July 1997, two big-scale atmospheric situations of the "Vb-type", as meteorologists designate them, followed each other in rapid succession in Central Europe. With them, arctic cold air led south by a high-pressure area over Western Europe and the British Islands meets humid air masses which are guided north by a low-pressure area over Upper Italy. In July 1997 the limits of these air masses comprised the whole upper catchment area of the Oder River. Weather situations of that kind are relatively frequent in June and July. They had repeatedly generated floods in previous years and therefore, people speak of "St. John's flood".

The conflict of atmospheric pressures was especially intensive that year, and as a conse-

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Table 1. Amount of precipitation during the flood-relevant periods

Station	Country	Precipitation 4.7.97, 6:00– 8.7.97, 6:00 UTC	Precipitation 18.7.97, 6:00– 21.7.97, 6:00 UTC
Lysa Hora	CZ	415 mm	147 mm
Altvater (Praded	CZ	359 mm	–
Märkisch Ostrau (Ostrava)	CZ	186 mm	–
Svratha (Svratouch)	CZ	165 mm	108 mm
Hirschberg (Jelenia Gora)	PL	175 mm	133 mm
Lodz (odz)	PL	129 mm	–
Wielun (Wielun)	PL	131 mm	125 mm
Ratibor (Raciborz)	PL	197 mm	–
Schneekoppe (Sniezka)	PL	–	124 mm
Czestochowa	PL	–	115 mm
Oderberg	D	–	90 mm
Angermünde	D	–	77 mm

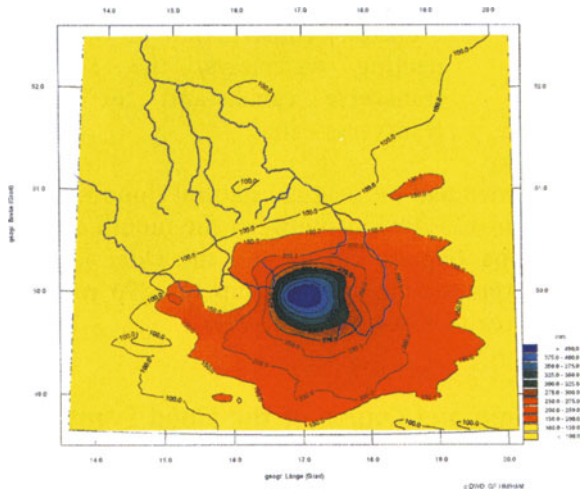


Fig. 2. Isohyet graph of the amount of precipitations in mm from 03/07/1997, 20.00 hours to 08/07/1997, 20.00 hours. (after: German Weather Service – DWD)

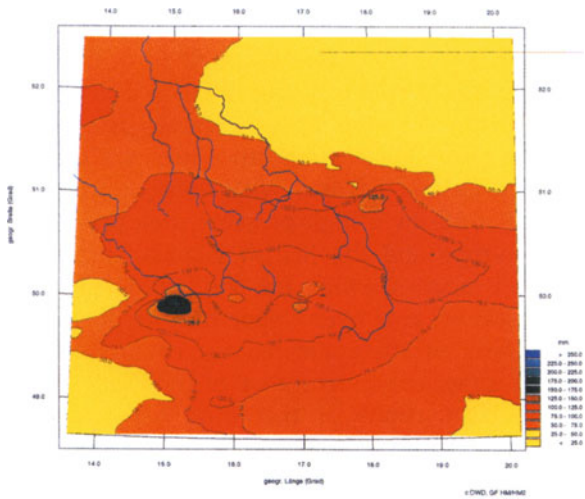


Fig. 3. Isohyet graph of the amount of precipitations in mm from 17/07/1997, 20.00 hours to 21/07/1997, 20.00 hours (after: German Weather Service – DWD)

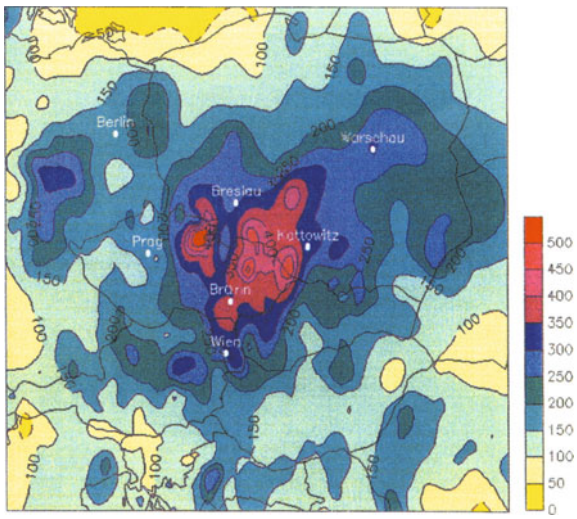


Fig. 4. Proportional distribution of precipitations in July 1997
Amount of precipitation in July 1997 in per cent of the monthly precipitation in the years 1961–1990

quence there were regional precipitations of more than 400 mm in the Sudety and Beskids Mountains, i.e. in the area between Wrocaw (Breslau), Katowice (Kattowitz) and Brno (Brünn), during the time period from 03/07/ to 09/07/1997. Maximum precipitations of 585 mm were measured at the Czech station of Lysa Hora (Altvater Mountains), LUA (1997) (Fig. 2).

Those first heavy precipitations were followed by a second bad weather area during the time period from 18/07/ to 22/07/, also resulting from a Vb-type weather situation. This time precipitations fell mainly on the mountains Iser- and Riesengebirge, i.e. in the upper catchment area of Bober, Lusatian Neisse and Oder (Fig. 3 and 4). Reaching values between

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108 and 144 mm, precipitations were not that intensive but flew off almost completely because the soils had already been water-saturated. Those precipitations did not generate new extreme water levels but they resulted in a considerable prolongation of the flood event. In the German catchment area of the Oder there were also precipitations of 77 to 90 mm on the weekend of July 19th and 20th. It can be estimated that the total amount of precipitation which fell and flowed off in the catchment area of the Oder River in July 1997 was approximately 10000 million cubic metres. Table 1 and Figure 5 illustrate the amount of precipitation in Czechia and Poland. As a consequence of the first heavy rainfalls from 04/07/ to 09/07/ water levels rose immensely and the upper Oder as well as its confluents overflowed their banks and inundated major areas, especially the rivers Weistritz, Glatzer Neisse and Katzbach.

On 09/07/ water levels of 1045 cm at gauge were measured at the water gauge of Miedonia (Oderfurt, km 55.5) when the flood flow was approximately 3340 m^3/s (corresponding to a

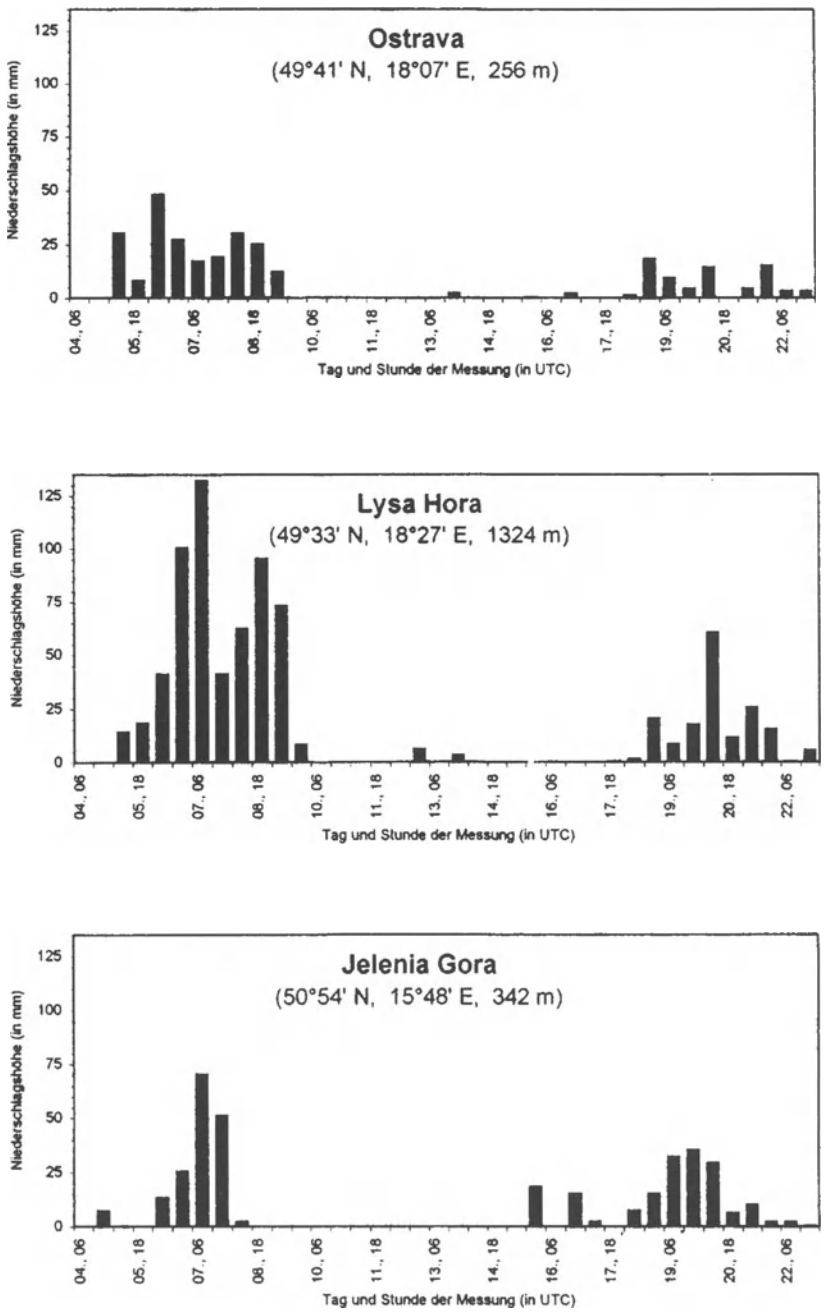


Fig. 5. Amount of precipitation within 12 hours in the time from July 4th to 22nd, 1997 at selected stations in the Czech Republic and in Poland

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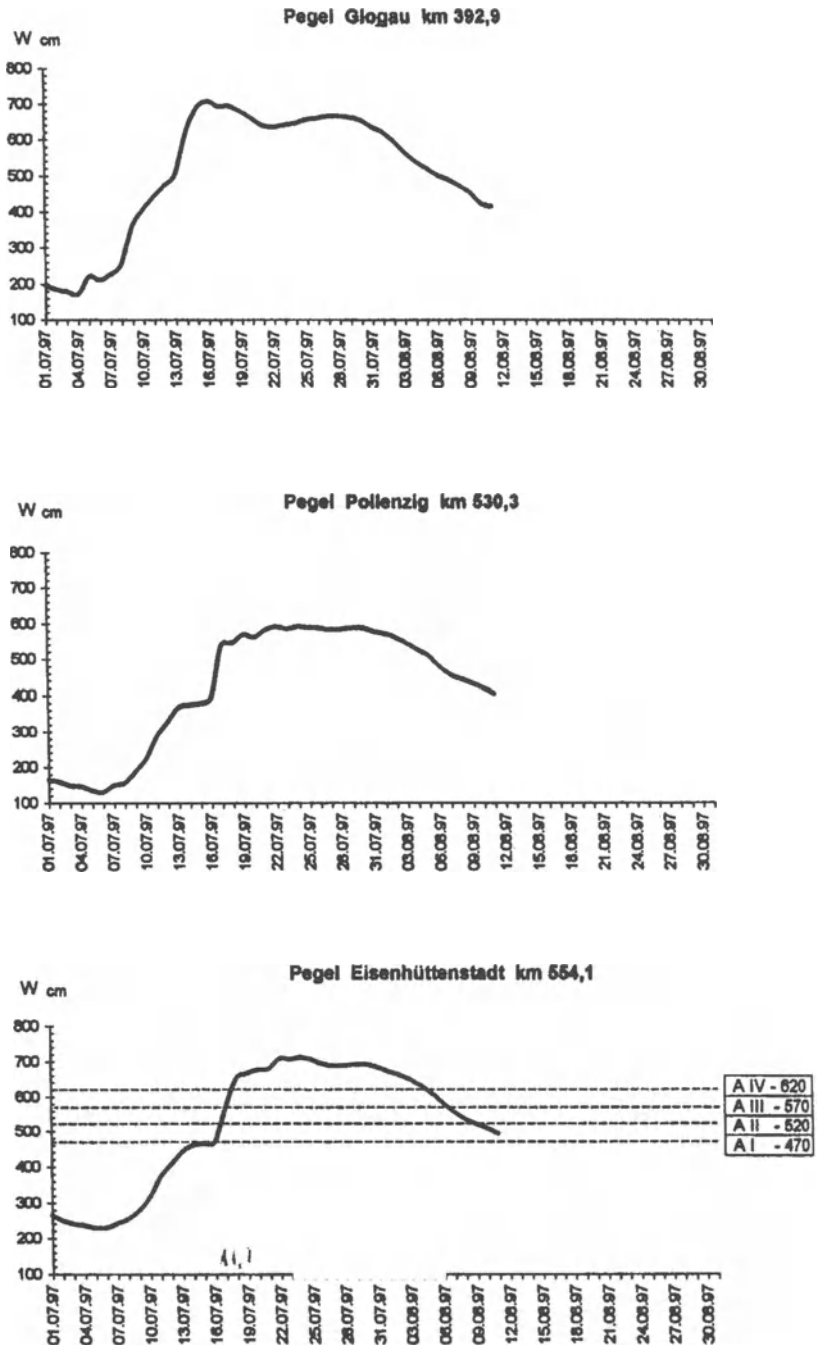


Fig. 6. Water level gauges of the Oder during the flood in summer 1997

yield sector of nearly 500 l/s*km^2) thus exceeding the maximum high-water levels recorded up to then by more than 2 m. After that, the water gauge station was washed away, which was also going to happen to other gauges downstream. An exact survey and forecast of water levels was no longer possible. At that time, a flood warning was already given for Brandenburg.

The flood wave arrived at Opole (Oppeln) on 11/07/, at Wrocaw (Breslau) on 13/07/, and at the town of Steinau on 15/07/, and it caused disastrous devastations in all these places. The dykes burst at several places. The inundation of large areas followed. The first obvious rise of the water level of the Oder in Brandenburg was noticed on 17/07/. On 19/07/, the high-water level at the gauge of Eisenhüttenstadt (Fig. 6) already exceeded the maximum levels recorded up to then (maximum high water level of 1854: 655 cm at gauge). Alert phase IV (red alert) was declared. In the further course of the event the water levels at the gauge of Eisenhüttenstadt reached the new

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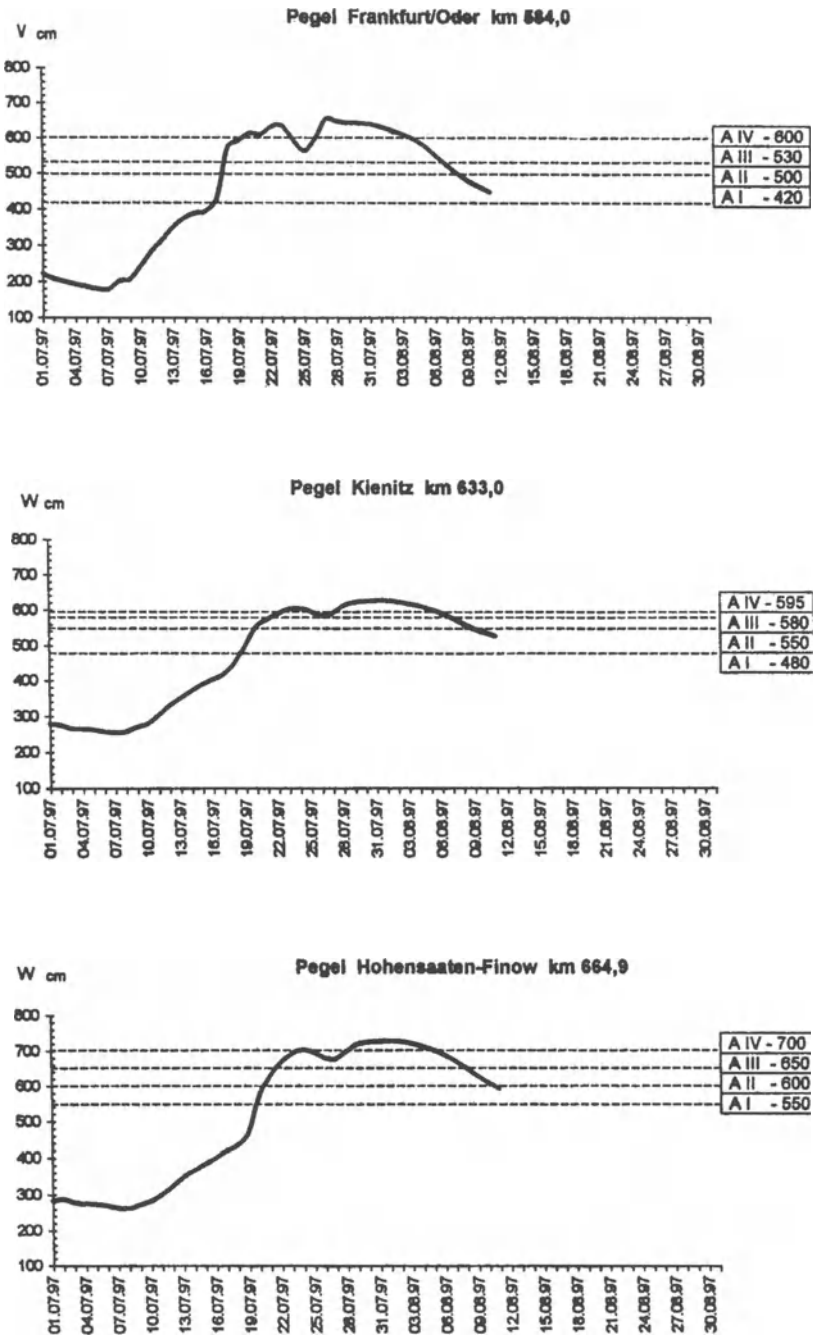


Fig. 7. Water level gauges of the Oder during the flood in summer 1997

record level of 717 cm at gauge, which is 62 cm above the previous high-water mark. An emergency dyke of sandbags had to be built in Ratzdorf in order to prevent the further flooding of the village. The safety of the dykes for the low-lying areas of Ziltendorf and Neuzelle could no longer be guaranteed and so, it was recommended to evacuate the low-lying areas – a decision which proved to be right as shown later when the dykes burst in the Ziltendorf valley at dyke kilometre 18.0 on 23/07/ and at dyke kilometre 8.7 on 24/07/ which inundated the village of Aurith and the Thälmann settlement.

For the town of Frankfurt/Oder, red alert had been declared on 18/07/. The Oder reached its old high-water mark of 1930 on 22/07/ with 634 cm at gauge (Fig. 7). The river overflowed its embankment and the southern districts of the town were inundated. On 25/07/ the dykes in the Ziltendorf valley burst and brought a short-time relief for Frankfurt – water levels fell 72 cm to the gauge mark of 562 cm. Two days later however, on

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Table 2. Summit levels of the Oder River in the border area

Oder gauge	Flood increase (m)	Summit level reached on (cm) (Date)	Previous maximum high water levels (ice-free) (cm) (Year)	Exceeds previous MHW by (ice-free) (cm)	Maximum high water level (ice-influenced) (cm) (Year)
Eisenhüttenstadt	4.90	717 (24.07.97)	655 (1854)	62	638 (1947)
Frankfurt/Oder	4.80	657 (27.07.97)	635 (1930)	22	610 (1947)
Kietz	4.00	653 (27.07.97)	587 (1854)	66	653 (1982)
Kienitz	3.75	628 (31.07.97)	614 (1917)	14	630 (1940)
Hohenstaaten-Finow	4.65	729 (31.07.97)	712 (1891)	17	778 (1940)
Stützkow	4.05	1009 (29.07.97)	945 (1891)	64	1085 (1892)
Gartz (Westoder)	Approx. 1.80	698 (02.08.97)	–	–	820 (1830)

27/07/, the breaches on the opposite side of the lake dyke at Brieskow-Finken-heerd lead to a new maximum high water level of 657 cm at gauge exceeding the old record mark of 1930 by 22 cm. Table 2 shows the comparison of the summit levels of the Oder River in the border area.

In the Oder valley north of Frankfurt alert phase III had already been declared and dyke watch had started on 18/07/. River Warta, which has the same stream as the Oder at medium water levels, appeared very calm and brought only relatively little water into the Oder. In the Warta valley there were, consequently, big retention capacities which absorbed the flood summits in the Oder but also prolonged the flood wave. The previously retention-free high-water marks were exceeded by 17 cm at Hohensaaten gauge where 729 cm were measured, and by 64 cm at Stützkow gauge with 1 009 cm. Especially the long-lasting water levels threaten the stability of the dykes in the Oder valley. Slope failures near Hohenwutzen and critical crackings which indicated beginning slope failures near Zollbrücke, Neuranft and Reitwein made it necessary to evacuate 4 500 inhabitants of the northern Oder valley (Glietzen polders). The breaches could be prevented with enormous efforts.

The summer polders near Schwedt had already been flooded on 15/07/ when the high water was expected. Still, the summer dykes were overflown along their whole length and did not hold out against these burdens. The dyke burst in 5 places over a total length of approximately 700 m. Only from 02/08/ on falling water levels were found on the Oder, the situation at the dykes became more stable. Alert phase II was declared on 07/08/ for the rural district of Oder-Spree and on 12/08/ for Märkisch-Oderland. The inhabitants of the imperilled areas began to recover bit by bit – the hydraulic engineering staff started clearing and repairing the flood control works.

5 The Dyke System

The 170 km long dyke system on the Oder River basically proved its quality in the summer flood of 1997. Built and constantly improved in the course of centuries, these dykes were calculated as a protection against a flood which occurs once in 100 years. This flood was higher and lasted longer than the hypothetical high water which was taken as a basis for assessment and for which the dykes were made. The dykes had to hold out during a longer period of time and against higher water levels. The dyke breaches and slidings have manifold reasons. These can be classified as follows.

- Break-up of local springs, most of them in combination with eluviations. In most cases springs broke up at or in the immediate neighbourhood of the outside (landside) slope foundation, seldom at a higher point of the slope (total number approx. 120).
- Sheet seepage boil at the outside slope foundation which destabilised the slopes and berms (to a total length of approx. 18 km).
- Outside slope failures at different stages:
  - Sheet slope slumpings some of which affected only the sod or remained flat, to a total length of approximately 800 m;
  - Crackings indicating a beginning failure, mostly at the berms or the dyke defence path, to a total length of about 1 000 m;

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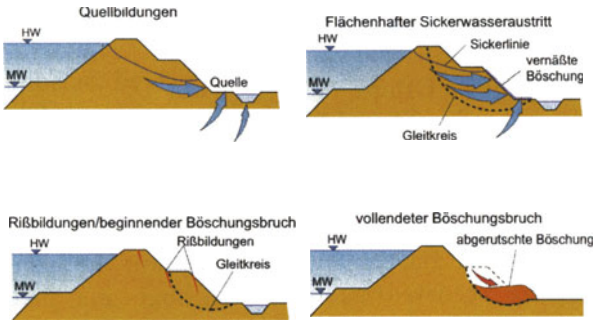


Fig. 8. Damages on the dykes.
1) Breaking-up of springs, 2) Spring, 3) Sheet seepage boil, 4) Seepage line, 5) Soggy slope sections, 6) Crackings/beginning slope failure, 7) Crackings, 8) Circle of rupture, 9) Total slope failure, 10) Slumped slope, 11) Circle of rupture

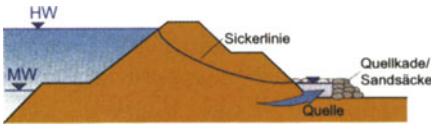


Fig. 9. Securing local water outflows by spring coffer-dams.
1) Seepage line, 2) Spring coffer-dam/sandbags, 3) Spring

  - Total slope failures with the slopes broken down, some of them several metres, forming the typical circles of rupture, to a total length of about 500 m.
- Damages by overflowing, especially at the summer dykes at the lower Oder which were overflown along their total length.
- Dyke breaches which included a total loss of the dyke body (altogether 10 breaches on an overall length of about 1.4 km) due either to overflowing or the failure in general stability.
- Damages by outer erosion at the inside slopes of the dykes due to excess flow rates were not found.

6 Measures of Dyke Defence

Up to 30000 Bundeswehr troops and up to 15000 helpers from the Technical Emergency Service (THW), the German Society for Lifesaving (DLRG), the police, the Federal Border Guard, voluntary fire brigades, civilians etc. took part in dyke defence and emergency repair works of the damaged sections. Only this tremendous number of people made it possible to transport defence material and build in the huge amount of the damaged sections of the dykes. The necessary material was:

- Sandbags of standard measure 30 x 60 cm and a filling weight of 10–20 kg. Where bigger sandbags were used, they were only partly filled. About 8.8 million sandbags with a total weight of about 130000 tons were used.
- Fascines, length approx. 3.50 m and diameter approx. 25 cm. Fascines of conifer brushwood were delivered in the first place, in some cases also willow fascines of greater length up to 12 m. About 200000 fascines were needed.
- Sands and filtering gravel.
- Geotextiles and filtering fleece to a total of about 66000 m^2.
- Plastic foils of different thicknesses to a total of about 20000 m^2.

A decisive criterion for the choice of defence material was not only the technical property but also immediate availability.

The material was transported to the damaged sections in the first line via the reinforced dyke defence paths. The penetration of moisture into the dykes, however, rendered them inappropriate for heavy vehicles. Therefore, mainly pickup vans with a total weight of up to 2 tons were used. Transport of material on cargo barges could be organised in a few cases only, for example at the Oder-Spree Canal. The Oder River itself is not navigable at high water. In particularly critical situations material was also transported by helicopters from the Bundeswehr and the Federal Border Guard (BGS). The engines used were HC 46 with a total carrying capacity of about 2 tons, and the army helicopter CR 53 capable of bearing 8 tons. Technical solutions of dyke defence were adopted according to the kind and presumed cause of the damages.

6.1 Heightening the Dykes

In the Eisenhüttenstadt area especially, water levels were markedly above previous high-water marks. In some dyke sections there was a risk of overflowing because the freeboard depth was no longer sufficient, and so the dykes had to be heightened. Sandbags were used to heighten the dyke crest. They were laid in a bond like a brick wall and could be sealed by foils if neces-

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sary. Heightening a dyke is only possible to a limited extent as soggy dykes are not capable of bearing any additional load and water pressure. Near the locality of Ratzdorf a protective wall of sandbags was piled up for a length of about 800 m and to a height of about 1 m.

6.2 Springs

The break-up of local springs was especially found in connection with an elevated seepage line and lack of drainage elements (filters) and with the ducts of burrowing animals and roots. The outflow of water is not a risk in itself; but cavities appear when springs wash out the earth, and those cavities increase rapidly and put the slope stability at risk. There is then a danger of hydraulic base failure. Springs breaking up directly in the foundation of the slope were secured by spring coffer-dams. A ring wall of sandbags was built around the spring in order to produce a counterpressure and reduce the flow rate and eluviation. Spring coffer-dams had a negative effect when built up very high: The water pressure generated that way produced an underseepage of the ring wall or the break-up of new springs besides the old coffer-dam.

6.3 Sheet Seepage Boil

Sheet seepage boil at the Oder dykes had to be considered as a critical factor because the local stability of the slope was at risk, especially in combination with the steep inclination of the slopes and the presence of silt which tends to "flow". Measures for draining and stabilising the dyke slopes had to be taken for a length of 18 km. Filtering prisms of gross pebblestone were scattered in some cases where only the base of the slope had to be protected. Packings of sandbags on a fascine bottoming were more effective when large surfaces had to be protected. Geotextiles generally did not prove their suitability as drainage elements and as a sandbag base. Another strategy is the reduction of dyke percolation by sealing the inside slope with a foil. The combination of the two methods – stabilisation and sealing – was also used in many cases.

6.4 Slope Failures

First signs of slope failures appeared in some cases, in the form of crackings on the dyke crest, the berm or on the inside slope (Reitwein, km 4.7 and 5.1; Zollbrücke, km 61, 61.2 and 62.0). In other cases (Hohenwutzen dyke km 70.4 and Oder-Spree Canal, km 1.8) the failures occurred suddenly without any previous warning signs. Immediate action was then absolutely necessary because a subsequent breach of the slopes above had to be expected and in that case, the bursting of the dyke could no longer be hindered.

The defence strategy has to be orientated to building a supporting wedge for the slumped slope ensuring drainage at the same time. First, a pressure bank has to be built at the foundation of the slope in order to support the new slope or the supporting wedge. It proved very efficient to start by building pillars of sandbags and subsequently filling in the fields between them by scattering pebblestone or also with sandbags. A substruction which ensures drainage, preferably a packing of fascines, is always necessary. It is also useful to combine these measures with for example an inside sealing.

6.5 Dyke Bursts

The total, sudden burst of a dyke generally has disastrous consequences for the low-lying area behind it. The high flow rates in the burst section make it very difficult to take defence measures and apply technical solutions. On top of that, there are logistic difficulties because paths are normally inundated. That was the reason why the five dyke bursts in the summer dykes of the Schwedt polder could not be defended.

As to the dyke bursts in the Ziltendorf valley efforts were concentrated on securing the breach heads. Helicopters were used to bring sandbags and net containers with quarrystones and concrete blocks and to lower them into the breach. The measures were not successful, however as flow rates were too high and the breaches broadened more quickly than material could be brought. Gaps in the dyke could only be sealed when water levels had fallen considerably.

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7 Causes of the Damages

The damages and the causes of the damages were studied very closely after the flood had flown off, also in order to determine the future call for action in hydraulic engineering. I should begin by mentioning that the flood level was notably above previous water levels which had been taken as a basis for assessment, and that the dykes had not been calculated for such water levels and such a time period of high water. In general it has to be stated that the safety reserves of the dykes were almost exhausted by those water levels and the degree of moisture penetration. The general (calculated) stability was near the critical equilibrium but did as a rule still prevail. Considerably bigger problems of local stability arose especially from the too steep slope inclinations, from the lack of drainage elements (filters) and from an unfavourable dyke structure. The dyke structure must be understood as the result of historical development. The dykes had been heightened and reinforced several times in previous centuries, and people always used the materials available at the time. The lack of a filter and the relatively steep slopes are another problem of the Oder dykes.

In many cases, a whole complex of unfavourable details was found as the cause of damages.

Here, I should also draw your attention to the fact that a correct analysis of such an inhomogeneous dyke structure involves much time and energy and that simple soundings, for example by only one single reconnaissance drill on the dyke crest, can lead to a complete misinterpretation of the stability. The knowledge gained from the flown-off flood event and from the defence of the dykes was, of course, considered when repairing the 13 damaged sections and breaches.

As to the measures for future improvement of flood control on the Oder River we do not think of comprehensively heightening the dykes but we will stabilise them. This means that the future dyke profile will have a different structure, already implemented at repaired sections. We are following the concept developed in the new German industrial standard "DIN River Dykes" for building a 3-zone dyke (Fig. 10):

- Supporting mass (of materials as used until now)
- Inside sealing

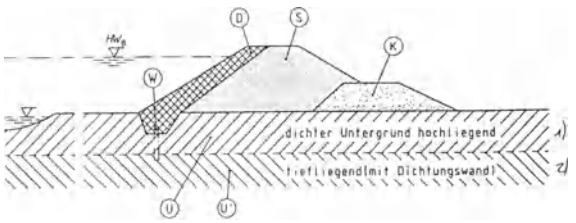


Fig. 10. Three-Zone Dyke
Generally binding standardized profiles for dykes cannot be determined.
Stability can be achieved by making a dyke of homogenous material. The better way is the use of less permeable material on the waterside and of more permeable material on the landsite. It is worthwhile building a dike in three zones (see Figure 4): The permeable supporting mass (S) gets an inside sealing layer (D) which should adjoin to a tight substructure (U), and an outside drainage mass (K) of higher permeability. The inside sealing layer (D) can be completed with a wall-like sealing (W) in a low-lying tight substructure (U). One has to consider, though, the influence of the general water table.
The advantages of such a three-zone dyke are:
- use of various kind of available earth and building materials;
- small quantity of seepage water;
- well drained outside slope.

1) tight substructure in upper position
2) in deep position (with sealing wall)
(after: DIN 19 712; Flußdeiche)

- Outside filter prism (to lower the seepage line).

As a rule, the boundary trench remains on the outer side and a dyke defence path remains on the berm. For the slope inclination the ratio shall generally be 1:3 on both sides.

8 Crisis Management

With regard to flooding the principle applies that it is easier to face a danger that was recognised in good time and against which preventions have been taken.

8.1 Flood Forecast on the Oder River

A successful flood control requires a functioning flood warning system. In Brandenburg, the institution responsible for publishing information on water levels, flood warnings and flood reports is the Flood Warning Centre in Frankfurt/Oder, an institution of the Environmental Protection Agency of Land Brandenburg whose

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activities are regulated by the Decree on the Flood Information Service.

As the major part of the catchment area of the Oder River is located in the Republic of Poland, an intensive data exchange between Poland and Germany is essential. Especially during flood events updated information needs to be exchanged at short intervals. The principles of data exchange with the Republic of Poland are laid down in the decisions of the German-Polish Boundary Waters Commission. The daily exchange of survey and measurement data and of hydrological forecasts between the two countries is invariably done via the Environmental Protection Agency in Potsdam and the Institute of Meteorology and Hydrology in Warsaw (IMGW), represented by their office in Wrocaw. During the summer flood in 1997 this exchange of information was incomplete because the water gauge network in the upper course partially failed due to the flood, and communication networks were also disturbed. The office of IMGW in Wrocaw as a registration centre was itself affected by the inundation so that information was given by IMGW in Poznan and also by direct contacts via the Waterways Agency in Slubice.

The transmission of information on water levels on a national scale went on almost undisturbed during the whole period. From 09/07/1997 until 12/08/1997 the Flood Information Centre at Frankfurt/Oder published 83 flood reports to inform offices, crisis management groups, district administrations, villages and other affected people. Additional information was given on specific problems. The Flood Information Centre at Frankfurt/Oder did not make a model-based prediction of the water level development of the Oder River. Forecasts were made by evaluating the hydrographs and comparing them with previous events. The existing flood-forecast model, a hydraulic one, furnishes unsatisfactory results for the whole of the flown-through area. One reason among others was the use of the 2-day forecast for the gauge at Polecko (Pollenzig) as an input for the forecast model. The latest development in the upper and central course of the Oder and its confluents was not included. The time for prediction and for reaction in the border area were too short.

Forecasting became much more difficult because of the extreme water masses for which there was no basis of comparison, the deformation of the flood wave by dyke breaches and the influence of reservoir discharges. The present forecast model was unable to deal with these influential factors and could not be employed in situations like this. Neither did the forecast of high water summit levels and entrance times meet expectations when the polish model was used. One reason was the lacking data base which also hindered the Polish colleagues, the other reason was the extraordinary character of the event. There was no experience and accordingly, no test results with respect of those extreme conditions.

The German side expects that a model for flood forecasting for the Oder area gives a precise prediction of the increase in water levels including the summit water levels and entrance times. As the prewarning times for the Oder in the border area are generally sufficient – the time between the summit passage at Miedonia and the arrival of the red-alert water level in Eisenhüttenstadt was 8 days, for example, – the aim is not in the first place a prolongation of this period, possibly including the forecast of precipitations, but a higher grade of precision in forecasting the development of water levels on the basis of measured hydrological data. It is necessary to integrate any kind of influence on the flood flow-off by storage areas and flooding polders as well as the unintentional influence by dyke breaches.

A look at the map of the catchment area of the Oder River shows that all the essential input data for such a forecast model are gathered on Polish territory. As the Oder is also a Polish river up to its mouth, I think it follows with logical consistency that only a joint model will be able to meet future requirements. The activities developed by the International Commission for the Protection of the Oder River and their workgroup "Flood" and by the German-Polish Joint Committee on Boundary Waters follow this direction. With help of the illustration "Running times of the flood summits of important summer flood events on the Oder River" I'd like to emphasise once more the forecast problem (Fig. 11).

In flood events of the Oder River the flood summits used to need a running time of 9 to 12 days from the gauge at Oderfurt (Miedonia) to the area of Stützkow/Schwedt, in bigger events even 13 days, whereas the numerous

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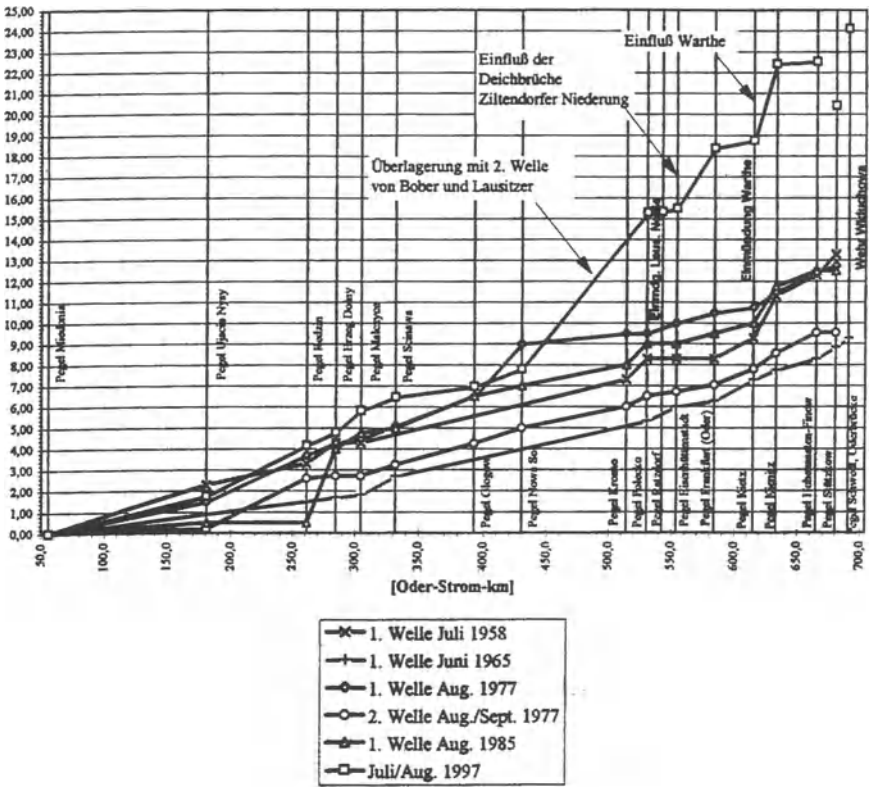


Fig. 11. Running times of the flood summits of important summer flood events on the Oder River. 1) Influence of River Warta, 2) Influence of dyke breaches in the low-lying area near Ziltendorf, 3) Overlapping with second wave from Bober and Lusation Neisse, 4) Mouth of the Lusation Neisse, 5) Mouth of the Warta River, 6) Weir at Widuchowa

dyke breaches and inundations, the flow-off from regional storage areas and new rainfalls produced an absolutely unusual running time during the summer flood of July/August 1997. Starting from Oderfurt the summit arrived at the gauge of Schwedt Oderbrücke only 24 days later. The graphic comparison with previous flood events illustrates this delay.

As the German border is the middle course of the Oder and the flood wave resulting from rainfalls in Czechia and Poland could be detected in good time, we were not riveted by the dramatic events in the neighbouring countries, we acted. On 15th July, the Ministry of the Interior set up headquarters to deal with "Flood and Help for Poland". During this time – after the first flood warnings had been published by the Environmental Protection Agency – first measures were taken to protect the Brandenburg region of the Oder. The crisis management groups in the disaster control authorities at lower levels took up their work. A wheel work of staff and technology which Germany had not seen before was set in train. In the end there were 30 crisis management groups on the spot, and central coordination was effected by the flood headquarters in the Ministry of the Interior.

The army of voluntary helpers, fire brigades, the Technical Emergency Service, the Bundeswehr, the German Society for Lifesaving and others included about 50 000 people. They had to cope with the first bursting of the dyke near Brieskow-Finkenheerd on 23rd July and the subsequent breaches, slippings and seepages on the dykes. This included dyke defence measures as well as evacuations, emergency relief and supply. Measures to fight this flood event were based on the rules stipulated in the Disaster Control Law of Land Brandenburg and in the circular note issued by the Minister of the Interior on February 24th, 1992. Thus, legal aspects were straight. The lower disaster-control authorities subordinated to the district administrators "had the say".

Mainly in the beginning there were information and coordination problems, and the allocation of duties within the different crisis management groups was not always clear. The fact that things ended successfully and that organisational defaults did not cause any real damage, does not exempt from the duty to thoroughly

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analyse the different stages and provide for the necessary future improvement. But this falls within the interior purview. The district administrators with their crisis management groups are important. It would probably be difficult for a central authority to master an evacuation. It turned out that local conditions must be known as well as the psychological situation of those affected. A clear allocation of duties to regional and local authorities facilitates at the same time the cooperation with the Bundeswehr and relief organisations. During the Oder flood it was evident that the well-trained structure of the Bundeswehr helped to stabilise the course of works. In other words, this made things go better. Some uncertainty and delay could be avoided by a clear and situational allocation of duties.

As to the deployment of the Bundeswehr one has to consider that the armed forces are only called to help in a subsidiary way. In any situation of crisis it has to be considered whether the potentialities of police forces, fire brigades, the Technical Emergency Service or business structures have been exhausted. There was no question about that in the flood of the Oder River. As to the future and in particular with regard to disasters of a minor extent it will be necessary to strive for a more precise definition. I do not refer to dissociation or exclusion but to the legal situation.

9 Conclusions and Outlook

The flown-off flood made it clear, once again, that technical securities are always relative. People in the polders will also in future have to live with the danger of floods although the management of the water resources are doing whatever they can to provide for safety in all probability and corresponding to economic considerations (cost and damage potentials).

Immediately after the flood in autumn 1997 efforts were concentrated on repairing the dyke breaches and the sections severely damaged by slope failures. By the end of November the dykes were completely rebuilt for about 10 km. The costs amounted to approximately 36 million DM. Measures were not restricted to mere repair; a new dyke structure was chosen which meets today's technological rules. Slopes were flattened, inside sealings and filters were built in, and also the subsoil was improved. Sectional heightenings of the dykes were deliberately renounced – they will only be possible on the basis of a master plan and international coordination. But other dyke sections also proved their weakness: insufficient freeboard depth, lack of drainage elements, unsuitable substructure and dyke structure. Special attention has to be paid to a detailed geotechnical reconnaissance when future action is planned. Considerable financial means will be necessary for measures of dyke construction in the coming years.

Flood control measures on German territory can only be successful in the long term when coordinated with a programme for the whole catchment area of the Oder River. Not only dyke construction but also the development of new retention and storage areas as well as a flood management across country borders have to be in the centre of activities.

Under the impression of the 1997 summer flood, the Minister for the Environment Mrs Merkel, Environment Minister Zelichowski (Poland), the Vice-Minister for the Environment of the Czech Republic and Brandenburg's Minister for the Environment Platzeck met for consultation on August 4th, 1997 and gave instructions to the International Commission for the Protection of the Oder River to deal with the flood problem. Based on that instruction, the Commission held a special meeting and established a "Flood" work group in September 1997. The "Flood" work group has to set up an action plan for flood events. That action plan shall develop a strategy of flood prevention and flood control in the Oder region defining the aims of activities in the following fields:

1. Securing the existing inundation regions;
2. Recovery of former inundation areas;
3. Possibilities of water retention in larger areas by measures of territorial planning, agriculture, silviculture, settlement planning and nature protection;
4. Technical measures to protect settlement areas;
5. Protection of water resources and inundation areas against flood-generated pollution;
6. Installation of a flood information system based on today's technological level;
7. Development of a flood forecast system which includes the meteorological and hydrological services;
8. Control of barrages and high-water retention works;

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9. Limitation of potential damages in areas with a flood risk.
10. All the aims should have the best possible positive influence on natural wealth in the valleys of the Oder River and its confluents.

First results from the work group can be expected by the end of 1999. Still before the flood had completely flown off the government of Land Brandenburg had started to set up a programme for long-term security and development in the whole Oder region. This Oder River Programme "Safety and Future for the Oder Region" is for the years to come until 2010 and was adopted by the State Government on 25/11/1997. More than 200 concrete measures and projects, some of them already planned, some which are given priority, some of them new, are summarised in a global strategy across department responsibilities. Amongst them there are also the measures to improve flood control in the short, medium and long term.

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Cultural and Political Obstacles to Accepting Early Warnings of the Aral Sea Disaster

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1 Introduction

Strategic export product, Islamic culture, demographic structure, and human diseases are not exactly terms which were familiar to meteorologists and remote sensing specialists a few years ago. Today we have to be involved in a much broader aspect of early warning and disaster reduction.

The excessive shrinkage and potential disappearance of the Aral Sea in Central Asia is a man-made natural disaster with catastrophic influence on a growing number of people. In the late 1970s the crisis area included only the coastal area of the sea but went on to involve the deltas of both the Amu Darya and Syr Darya, the two rivers feeding the sea. Now problems have extended upstream to the lower reaches of the Amu Darya and even the middle reach of the Syr Darya. These deltas are empty and dry almost every year. This disaster did not come about overnight. There was an early warning in the early 1960s, which forecast it.

The warning was based on estimates of the developing water consumption for irrigation due to expanding agriculture and other needs in a region with a rapidly growing population. In the 1970s severe interference with the water balance of the Aral Sea basin ocurred. The prestigious and wasteful Karakum canal in Turkmenistan was lengthened by some hundreds of kilometres, 10 years after the early warnings. But, the interference was not stopped, on the contrary, it is continuing, and the disaster is going on.

From the beginning of the century up to the early 1960s the surface of the sea without islands was 63 thousands km^2. During that time the sea surface evaporated 65 km^3/year. The loss was compensated by annual inflows of 56 km^3 and 9 km^3 precipitation. In 1997 the existing surface was estimated to be about 29 thousands km^2 and the sea surface level was 16.5 m lower than 40 years ago. 34000 km^2 of the former surface are dry and form a new desert with a high salt content at its surface. It has even got a name: Aralkum (Niyazow et al. 1998). Wind erosion removes 8 thousand tonnes of salt per km^2 per annum damaging the adjacent areas.

This paper provides an insight into cultural and political reasons why the society did not accept the early warning of a coming long-term disaster. Here, culture is seen as regionally customary way of life in a country with first Soviet, then Islamic impact on demography as well as impact of political stress on responsibility of the governing elite. The policy both in Soviet times and under the recently declared political independence of five Central Asian republics focused on cotton as a strategic product which constitutes a major export.

The Aral Sea disaster can be seen as an example of the uselessness of a correct forecast from natural scientists when the given political and cultural conditions do not allow for an acceptance of the early warning. A further issue of this paper can be seen in warning that the disaster is continuing and will threaten not only the environment of a disappearing sea, but could trigger widespread collapse of stability of civilisation, at least, of that region.

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The idea of this paper has two origins. The first one is an interview with Academician Prof. Yuri A. Izrael, the former head of the Soviet Union Hydrometeorological Service, given to the Bulletin (No. 1/1996) of the World Meteorological Organisation, WMO, where he said:

> As of about 1960, the amount of water feeding the Aral Sea started to decline drastically. The amount of water that used to flow into the A.S. was on average 53 km^3/yr. Furthermore the Turkmenistan canal was built and part of the water of the Amu Darya was directed southwards. While the water supply was improved in several republics, less water flowed into the Aral Sea and it became clear, some 20-25 years ago, the Sea was facing catastrophe.

Of course, that warning was incomplete. It was rather a recognition than a call to action. But even a call to action had, at that time, no chance of being heard. Even better warnings 30 years later continue to have no chance of being accepted unless cultural and political circumstances are in favour of action.

The second origin is a report issued by the UNEP working group for the project "Diagnostic study for the development of an action plan for the conservation of the Aral Sea basin". This report was compiled between September 1990 and September 1992. That time saw the end of the Soviet Union (December 1991) and the start of the newly independent states. The report contains conclusions: One of them reads as follows (on p. 13):

> Historically, the Independent States in the Aral Sea basin are characterised by numerous similar economic, social and demographic features, and ecological development. The features include a specific way of life, social psychology, and social and cultural relationships. However, all these factors presently are being drastically affected by the environmental crisis in the Aral Sea basin.

Putting crisis and factors, in other words, cause and effect, into their proper relation, you can recognise that the traditional Central Asian way of life, under the influence of 70 years of Soviet Union policy in economic and social issues and under the growing influence of Islam, were the origin of the crisis and the reason why the warning could not have been accepted.

People in Central Asia have been forced to produce cotton. That caused an ecological disaster with a drastic decline in human life expectancy at the beginning 1990s. Now the governments of newly independent states are under heavy stress from political and economic problems and even from civil wars in Tajikistan and Afghanistan. Of course they are inexperienced and compete against each other and are occupied with problems other than ecological ones as they watch helplessly at the catastrophe. Some money from abroad, from the World bank, UNEP, UNICEF and others is hardly more than humanitarian help. People worry about how to survive the next year and cannot be concerned about what is necessary for the next generation.

2 What is the Actual Problem in the Aral Sea Today?

In the 1950s and 1960s the national economy in the Uzbekistan Soviet Republic was expanding. At that time Uzbekistan had in 1950: 6.2 million and in 1970: 11.8 million residents. Large irrigation projects focused on cotton production, but also on food production for the growing population. Additionally other infrastructures had been developed and put into effect. The living conditions improved considerably, but the consequences for the natural equilibrium had been ignored. The population grew and is now 24 million, twice the figure of 1970. All these people need drinking water, food, farmland, water for irrigation and, last, but not least, clean ambient air.

A solution for the Aral Sea problem cannot be to return the sea, but must dwell on the improvement of the living conditions in some hundreds of kilometres around the sea and along the big two rivers, especially where the supply of clean air, drinking water, and food is inadequate. The problem now is: How to reorganise the society of that region with its specific way of life and under the given conditions into a new equilibrium of human life and of natural resources.

2.1 The Culture

The high appreciation of many children together with improved health services in Soviet times caused a population explosion in the whole Aral Sea basin confronting limited natural resources. In addition the waste principles of thesocialist distribution of water, energy,

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food and housing became and continue to be customary. Solidarity between different regions in the mountains, in the plains, and in the river deltas has not been developed. The attention of the native population has been focused more on the well-being of the family and large family groups than on nation-wide feeling, thinking, and acting.

2.2 The Policy

The policy of the Soviet Union always set higher priority on fulfilling macro-economic plans than on avoiding an environmental crisis. The governments of the newly independent states surely want to act more responsibly, but they have insufficient economic power to do it. They want to protect and develop the national culture. There is a revival of the Islamic way of life. Now the demand *Less children!* would sound inconceivable. Even *Less wasteful use of water and energy!* is not enforceable in the present strained social situation.

In 1996 a Tashkent newspaper reported that the Uzbek Cabinet of Ministers had discussed the question of evacuating the whole region of the delta of the Amu Darya. The question has been rejected. A lot of reasons were advanced against that idea. It was unimaginable to evacuate one million people to other parts of the country and to supply them there. Another important reason was, the people of Karakalpakia do not want to be evacuated.

2.3 Demography

The demographic situation in Central Asia is a result of culture under the influence of Islam and Soviet socialism. In the early 1950s, under Soviet policy the health care, education, traffic, and other infrastructures were improved. It was a prerequisite to enlarge the production of cotton and some industries which had been evacuated during World War II from western Russia to Central Asia.

In Uzbekistan the birth rate in Muslim families was as high as ever, about 30 per mille (per 1000 resident per annum). From 1950 to 1960 it increased to 40 per mille (Demogr. Enc. Dict. 1985, p. 488). At the same time the death rate decreased from 9 to 6 per mille. The corresponding figures for 1980 were 33 and 8 per mille. So the population increased during the last 40 years from 7 million to 24 million. A family planning policy taking into account the Islamic relation between men and women and the growing poverty, especially under rural population, since the collapse of Soviet administration is not visible. About 60% of the Uzbek population is rural. Further remarks concerning the rural population's demography can be found in the chapter on agriculture.

The idea of sustainable development, introduced 20 years ago into international environmental policy, came too late to recognise how disastrous the Russian idea of the development of the country actually was. The Soviet demand for more cotton by more irrigation worked only for some years. It then became evident that new ground and enlarged irrigation using old techniques touched the limits of natural resources. Environmental conditions started to backfire against health, welfare, and life expectancy; even against higher crops. The superforced development turned out to be disastrous for human health, first in the Aral Sea coastal area, which is the mouth of the Amu Darya, then in whole of Karakalpakia and the middle reaches of the Syr Darya, and now in Horezm. In future it will move upstream.

A solution to the problem could be a limitation in family size. But the standard is, as ever was, four to eight children, sometimes even 12 and more. Now most of them have a better chance for surviving than 100 years ago. But, the situation of new born children and their mothers is now getting worse than it was 30 years ago. In Karakalpakia drinking water taken from ground water contains up to 3 g salt per litre. Wind takes the salt from the dry bottom of the sea to farmland and human settlements. The annual fall-out is about 52 g salt per square metre (Beknasow & Novikov 1995, p. 286).

The spread of ecological diseases has reached crisis level. The Ecological map of the Aral Sea Region of 1992 shows for 1986–1990 some figures.

- common death rate: 10 per 1000 people per annum,
- children's death rate: 80 per 1000 births,
- virus hepatitis: 900–1400 cases of 100000 people p.a.,
- cancer, malignant neoplasma: 110–189 cases of 100000 people p.a.,

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- bronchial asthma: 10–20 cases of 100000 people p.a.,
- congenital anomalies: 18–30 cases of 100000 people p.a.

The worsening health situation seems to result in a new equilibrium of structure of population. The new Central Asian population structure is being overlapped by a migration phenomenon. The continuing loss of educated and trained specialists and workers from Uzbekistan has been perceptible for some years. About one third of all Russians, almost all Jewish and half of the ethnic Germans have left the country. Officially it is said that the native population of Central Asia is highly stable. But, ecologically caused migrations in the CIS region are estimated (Kalbermatten 1998) to be a significant consequence of regional desertification.

2.4 Policy

Recently, a few years after 1985, when Gorbachov's period of "glasnost" and "perestroika" began, the Aral Sea crisis became an issue of public attention as one of the world greatest ecological disasters. Even today you may find official statements in local newspapers on the great future of the country including the famous Aral Sea. But unfortunately there is no mention of prospect of saving the sea.

In 1991 the five republics of Central Asia began a policy to survive the political crisis in the Soviet Union and declared their political independence and began to construct five new administrations.

As elsewhere, environmental protection or long-range sustainable development cannot, of course, have priority over urgent problems. On the contrary, new burdens came as a result of borders between the Soviet republics, which now became state borders and obstacles to travel within one state. It became necessary to construct new railways and highways avoiding the state borders when going from Tashkent to Karakalpakia, to Termes or to the Fergana valley. These projects are expensive and cause further environmental problems.

Unfortunately the one pre-existing Central Asian administration of water management has been divided into five national administrations with competing aims. An attempt to reunify them has started only now and Turkmenistan refuses to take part in it. So the political independence of five states replacing one former state administration became a manifold obstacle to the rational use of nature resources.

Under "Soviet" leadership, quarrels between Central Asian republics over water management seemed impossible. Now, attempts have been made to use the water resources for short-term economic purposes and at great expense to neighbouring states. An example of abusing independence is the case of the production of electricity with hydraulic power at the Naryn reservoir of the Syr Darya in Kyrgyzstan. The electric power is produced for sale to neighbouring countries, mainly in winter when the price is higher. The increased runoff in winter caused an overflow from the downstream Chardaryn reservoir near the boundary between Uzbekistan and Kasakhstan. Because the Syr Darya is frozen in winter beyond the dam Uzbekistan is forced to direct about 10 km^3/year into the artificial lake Arnasay, overflowing a former swamp. The result is an abundance of water in winter and an absence in summer where it is necessary for living along the Syr Darya up to the Aral Sea.

The presidents of the five republics put into force a common body the "International Foundation for Saving the Aral Sea". This body has already started work and now addresses the difficulties in handling environmental matters.

The foundation, of course, will be useful and cannot be viewed as an obstacle. However, the members recruited from the five member states are only now beginning to recognise that they have to battle against natural problems and other problems resulting from new political structures and financial constructions.

2.5 Agriculture

Agriculture everywhere depends on the specific soil and climatic conditions of the particular areas. In semi-arid areas intense irrigation is needed. Via food production it is connected with demography. The new Central Asian independent states want to be independent of food imports. So the period of transition becomes particularly difficult.

First some remarks, again, on demography in Uzbekistan where more than the half of Cen-

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tral Asia's population lives. About 60% of the population is rural increasing from 1991 to 1995 from 59.9 to 61.6%. About 40% of all working people work in agriculture. Their share of the gross domestic product is smaller than 40%, expressed in market prices. It even decreased from 1991 to 1995 from 37.2 to 28.5%.

Water has been used for irrigation in the cotton and food production and for domestic and industrial water supply. So it was impossible after the warning of the early 1960s to stop the increase of the water consumption. Between 1960 and 1995 the irrigated land enlarged by 150–250 km^2 each year. The farmland grew in that time by a factor 1.7, while the population grew by a factor 2.7.

2.6 Irrigation

Applying old techniques one cubic metre of water is needed per square metre of soil. On the one hand, the water resources are limited and have been entirely consumed, on the other hand, the expansion of agriculture cannot be reduced because the population continues to grow and needs expanding food production. Moreover cotton is the main export earner and must continue to be sold.

From 1940 to 1980 the production of some kinds of food in kg per capita increased and improved. As ever the production of cotton dominates.

Uzbekistan produced in 1988 (Bols. Enc. Dict. 1991) the following crop yields:

- cotton: 5365 thousands of tons,
- cereals: 2200 (of them rice: 450),
- vegetables: 2760,
- fruits and grapes: 1278.

These figures are already somewhat less than those reported for 1979.

The country (447 400 km^2) consists of desert and mountains and only 50 400 km^2 farmland with half of it needing irrigation. About 9 000 km^2 are used for cotton. Large quantities of water are used after harvesting for washing out the abundant chemicals (fertilisers, pesticides, herbicides) before cultivation for the next year. Poisonous agricultural waste water is not purified but drained into the desert. Damage to the irrigation system allows for an exchange between the waste water collectors and the ground water.

The result is a concentration of pollutants in the groundwater what makes it useless as drinking water. The practical result is that in some regions without central drinking water pipelines, people are forced to use water with contents of up to more than 1.5 g salt as drinking water. In Uzbekistan 40% of the rural population and even yet 14% in towns do not have central water-supply.

Another obstacle is the local custom of using rice as the staple diet of many people. Even in the driest areas of the delta of the Amu Darya, where more than half of the agricultural area has been given up because of lack of water, individual fields are flooded to cultivate rice. It is impossible to force the people to give up this tradition and to change to other crops. Moreover, it seems to be impossible under actual market conditions to get rice from somewhere else.

2.7 Money

Can money help to mitigate the crisis? The natural disaster has been investigated for some years. One of the most serious projects is the TACIS WARMAP Project (WARMAP = Water Resources Management and Agriculture Production). Some projects have been prepared for improving the human health care system and sanitary conditions in Karakalpakia. The first portion of their implementation needs of 200 millions USD from World Bank, which now are available (according to a newspaper report of 15 October 1997 of Uzbek Press Agency). A further 600 millions USD were announced in the same report for follow-up projects for improving the use of water resources in Central Asia.

However this money cannot stop the crisis. The amount of 600 millions means that 2.6 million people (= 1.4 in Karakalpakia + 1.2 in Horezm district of Uzbekistan) would get 230 USD per capita for reconstruction of water pipes or sewage system. In Karakalpakia 82% of all rural settlements and 42% in Horezm do not have a central drinking water supply at all. These villages do not have any primary medical service. Actual measures can only do what was already necessary 40 years ago. Real action

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in the next future can be expected only in co-operation with international bodies, regional governments and local administration. The contributions of the five Central Asian states themselves may be remarkable, but, they will never be sufficient.

2.8 Information Policy

Information Policy in Soviet Union was always a strange thing. Environmental disasters were often not published. As the Tchernobyl disaster was kept secret for some days, the Aral Sea disaster did not exist for many years. The main point was not the absence of any official information, but the irresponsible behaviour and delaying action of many people who could have mitigated the disaster. The first maps with actual lines of the shore of the Aral Sea and data on environmental diseases were published only after 1990. As always, the information policy in the governmental administration in the newly independent states is similar to that of the Soviet Union, with a high degree of unreliability. Data from various sources are contradictory. That policy is changing slowly but unfortunately all assistance projects have suffered from it.

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CHAPTER 4.20

Early Warning Systems for the Detection and Response to Severe Floods

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Introduction

Notwithstanding advances in hydrological and engineering technology the world-wide loss of life due to floods has continued to increase. This is because of increased population densities and occupation of flood prone areas previously avoided. The most effective way to save lives is by the development of flood warning systems.

The efficiency of early warning systems in saving lives during severe floods was well illustrated in the floods on the Rhine River in Europe and the Mississippi River in the USA in recent years. These are large rivers in developed countries and where warnings to downstream residents were issued days in advance and evacuation procedures were set in motion.

However, there are many large rivers in developing countries, and small rivers in many other countries where no such warnings can be issued in time to prevent a tragedy occurring. In South Africa for example, the largest loss of life due to floods occurs in communities located on the banks of small rivers that rise within a matter of hours after a severe storm.

Sophisticated flood routing procedures are of little use in these situations. This paper describes a simple but effective method based on antecedent precipitation indices. Most floods in South Africa are caused by large area, long duration rainfall, culminating in a severe rainfall event. By observing the extent and severity of rainfall, communities at risk can develop their own flood watch systems based on the build-up of rainfall as an indicator of the likelihood of floods developing.

Reliability of a Flood Warning System

The success of a flood warning and evacuation system will depend on the following:

- The degree of awareness of the public exposed to flood hazards.
- The length of advance warning of imminent damaging floods.
- The availability of plans demarcating areas susceptible to flooding.
- The availability of information on the maximum safe flow for all bridges and road culverts.
- The availability of trained staff in the right position at the right time to provide information and assistance.
- An efficient communication system between the control centre and staff in the field.
- An efficient means of warning people of pending dangerous situations.

All of the above requirements are feasible in well-planned municipal areas. The risk is also lower in these areas because of engineered drainage systems, and restrictions on development and housing in flood prone areas along watercourses.

The risk is often unacceptably high within unplanned settlement areas, particularly those located on floodplains where the risks of dam-

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age and loss of life are considerably higher. It is also more difficult to establish an efficient flood warning and evacuation system in these areas.

- The occupants are seldom aware of the risks that they face.
- Plans showing the maximum floodlines are seldom available.
- Information on the safe flow at all stream crossings is seldom available.
- It would be difficult to ensure that trained staff were in position at the commencement of the flood to provide information and assistance.

In these areas there is an even more urgent need to achieve the longest possible period of advance warning of severe rainfall and floods, and to issue warnings as early as possible and as efficiently as possible.

Flood-producing Rainfall

Severe floods with the potential of causing large loss of life (more than 100 flood-associated deaths) occur on average about once every seven years somewhere in South Africa. Obviously the probability that associated rainfalls of this magnitude will occur at a specific site in any one year is much less, but the probability that this rainfall may occur within a period of several years is by no means insignificant.

Another alarming property of these rainfall events is that they are often much more severe than previously recorded maxima. For example the rainfall station in Pretoria where 245 mm was recorded has been in operation since 1906 but the previous highest daily rainfall was only 169 mm. The 245 mm has a 0.5% probability of being exceeded in any one year, but a 10% probability of being exceeded at least once in the next 20 years.

On 30 November 1975, 101 mm of rain fell in 16 minutes near Nelspruit. The previous highest 15 minute rainfall recorded anywhere in South Africa was 56 mm.

The estimated flood peak in Laingsburg was 5700 m^3/s compared with the previous highest since 1920 of 740 m^3/s. There are many more examples.

A Simple Flood Warning System

Severe, flood-producing rainfall does not appear out of the blue. Most of the major floods in Southern Africa have been preceded by above average rainfall in the previous days, weeks or months. The weather systems such as tropical cyclones and cut-off low pressure systems that could potentially result in widespread severe floods are usually forecast days in advance.

The role of antecedent rainfall is particularly important in semiarid and arid regions where the soil moisture deficit is high prior to the onset of the flood-producing rainfall. Low intensity rainfall during the period preceding a flood will decrease the soil-moisture deficit and start generating stream flow in ephemeral rivers. A greater percentage of the subsequent rainfall will be directly converted to river flow.

The following simple warning system based solely on antecedent precipitation can be applied successfully in small to moderate size catchments where no sophisticated warning systems exist.

1. Measure daily rainfall from one or more stations in the catchment. If there is more than one station, calculate the average rainfall for the day. In the case of larger catchments dangerous conditions may arise if all stations report heavy rainfall, whereas isolated heavy falls are less likely to produce floods.
2. Apply a decay factor of 0.9 to the antecedent precipitation index (API) of the previous day, and add the rainfall recorded during the past 24 hours. This becomes the API for the day.
3. Continue this process of developing the API for each day.

For most of the time there will be occasional sharp increases in the API on one day followed by an exponential decay during succeeding days. However, where moderate to heavy rainfall persists for two or more days the API will continue to rise. The magnitude and rate of rise of the API are the basis of a simple but effective flood warning system which typically could consist of the following steps:

Calculate the API for the day and note the additional rainfall necessary to trigger the various actions to be taken. When the API for the day plus the subsequent rainfall reaches the following thresholds take the appropriate action.

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- Code Blue: The API has reached 50 mm, and it is still raining. Place emergency teams on alert.
- Code Yellow: The API has reached 75 mm, and it is still raining. Rivers will start flowing strongly in this situation. Send personnel to observe the river flow at key upstream bridges. Most bridges in South Africa are designed to accommodate a 1:50-year flood.
- Code Orange: The API has reached 100 mm, and it is still raining. Severe, life-threatening floods can be expected. Emergency teams should be dispatched to key points in the area to ensure that they are not themselves cut off by the expected floods. From now on a close watch should be kept on the flow in the river at the upstream bridges.
- Code Red: Observers at the upstream bridges report that the water level has nearly reached the road level at the bridges and the water level is still rising. A flood exceeding the 1:50-year flood can be expected and life-threatening flooding is almost certain. The pre-arranged method for warning inhabitants (e.g. sirens) should be activated, and the emergency teams should move into the threatened area. From here onwards take such action as may be required.

Note the most important requirement in each of the above stages is that the rainfall is continuing or the water level is still rising. If the rain has stopped or the river levels are falling the code status should be reduced to the next lower code.

Note also that the residents should only be warned once it is clear that a life-threatening situation has developed (Code Red). This warning should be adequate and will avoid creating false alarms, provided the residents have been informed of the danger and have been told (repeatedly) that when the warnings are issued they can expect floods and that they must closely watch the river.

It must also be appreciated that steep rivers with small catchments will respond very rapidly to intense rainfall, and that the flood could reach the danger area within a few hours of the commencement of the storm.

More Sophisticated Methods for Real-time Flood Prediction

There are several methods that can be used to predict the possibility of damaging floods occurring at a specific site. The most accurate method is a flood warning system based on gauged upstream river flow and conventional hydrological flood routing procedures.

Longer but less accurate warnings are possible if near-real time measured rainfall data are available. This information can be used in rainfall-runoff computer models where flood magnitude forecasts are based on the recorded rainfall. This method can only be used if the models have been calibrated using recorded rainfall and runoff from a number of previous events. Inadequate calibration data could lead to inaccurate and possibly misleading forecasts of river flow. This method will provide a longer warning but will be less reliable than flood routing procedures.

Predictions based on meteorological forecasts of the possibility of heavy flood-producing rainfall within the forecast period (often several days in advance) will provide the longest warning, but the accuracy of estimated flood magnitudes will be poor. However, weather forecasting models are becoming more sophisticated, and the accuracy and lengths of advance warnings are increasing.

In many remote areas there is not an adequate coverage of measured rainfall, and the rainfall has to be inferred from remote sensing systems. Research is currently under way in South Africa and elsewhere on the use of combined satellite images, radar images and recorded rainfall data to develop daily rainfall maps covering the whole of South Africa within a few hours of the rainfall occurrence. These will provide more reliable estimates of the areal distribution of daily rainfall than is now possible. Where radar coverage is available, good estimates of the rainfall that has occurred over a catchment are possible.

A potential flood warning system can therefore be considered as consisting of three phases:

- Phase 1. Flood forecast based on meteorological forecast. Long warning, but poor accuracy.
- Phase 2. Flood forecast based on antecedent precipitation. Moderate warning and increased accuracy.

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- Phase 3. Flood forecast based on gauged upstream river flow. High accuracy but short warning time.

Flood Warning Systems at National Level

It is seldom possible to develop national flood warning systems other than on major rivers, where floods take several days to reach the vulnerable areas. The purpose of a national system for the rest of the country should rather be to collect, process and transfer weather forecasts, warnings of the possibility of heavy rain, and details of rainfall during the previous twenty-four hours. This information could be made available to any user who has access to the Internet.

The next step is the development of methods for the acquisition and processing of this data plus local rainfall information. The authority concerned will then be in a position to take action appropriate to the estimated severity of the pending flood.

We at the University of Pretoria have developed two suites of computer programs under the general titles 'National Flood Advisory Service' for application at national level, and 'River Watch' at local level. The River Watch programs make use of information distributed by the National Flood Advisory Service as well as information collected locally.

The following is an example of the application, of these suites of programs, had they been available at the time of severe flooding in the eastern region of South Africa during September 1987.

On Thursday 24 September, the Weather Bureau forecast the possibility of heavy rain occurring during the coming weekend. The predicted widespread rain commenced around midday on Saturday 26th. Twenty-four hours later rainfall stations within the region reported rainfalls in the range of 100 to 150 mm and that rain was continuing. This information would have been sufficient to place operations staff on the alert. The continued heavy rain during Sunday night changed the situation dramatically for the worse. By Monday morning the antecedent precipitation indices exceeded 200 mm, and floods exceeding the 1:100-year floods could be expected. Floodwater started entering all of the Mgeni River dams. There was sufficient information available by mid-morning to issue general flood warnings and to set evacuation procedures in motion. This was a full 24 hours before the arrival of the flood peak.

In the actual event no action was taken by the authorities prior to the floods despite warnings of heavy rain forecast several days previously. Many lives were lost.

Laingsburg Floods

On Sunday, 25th January, 1981, 104 people lost their lives in the small town of Laingsburg. The high loss of life was due to the combination of two major factors: a lack of awareness of the vulnerability to floods, and the total absence of a flood warning system. The following were some of the contributory causes:

- **Topography**. The town of Laingsburg is located on a floodplain at the confluence of the Buffels River and two of its tributaries. The national road from Cape Town to the north passes through the town.
- **Rainfall**. Unusually heavy rainfall occurred over a wide region on the previous two days. This information should have been sufficient to alert the local authority.
- **Onlookers on the road bridge**. Most of the residential area and the town centre was located on the floodplain of the Buffels River. The national road bridge was directly opposite the centre of the town, and due to the local topography the bridge deck was higher than the low-lying areas of the town itself. When the river overflowed its banks and spread into the town vehicles approaching from the direction of Cape Town could not proceed further and traffic built up on the bridge. Unaware of the danger that they were in, drivers, passengers and other onlookers remained on the bridge. The river continued to rise and crossed the road behind them cutting off their escape route. Sixteen people on the bridge were drowned when the bridge was subsequently inundated by the flood.
- **Bridge openings blocked by debris**. The flood stripped the vegetation from the upstream floodplain. The bridge openings were blocked by this debris with the result that the portion of the flood that would normally have passed through the bridge openings was

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deflected into the town and worsened the situation there.
- **Escape routes cut off.** The highest loss of life was due to residents staying in their houses until it was no longer safe to cross the streets. The streets that they had to cross were parallel to the river and the water velocities were consequently too high to wade through.
- **Rescue system.** There was no co-ordinated rescue plan, or organisation that could carry out the rescues. A number of would-be rescuers lost their lives in rescue attempts.
- **Flood awareness.** The magnitude of the flood was far greater than any previously experienced flood. Residents were unaware that their properties could be inundated by exceptional floods.
- **Flood warning.** There was no flood warning system, and residents had to rely on their judgement of the danger that existed. They did not appreciate that the water would rise to the level that it did, or that they would not be able to escape in time.

The ultimate reason for the loss of life in Laingsburg was the absence of a flood warning system, civil defence organisation and evacuation plan. It should also be noted in passing that the annual exceedence probability of the flood was well in excess of a 1:100-year flood. As a consequence, emergency measures and evacuation plans should be based on an extreme flood and not on the flood used for determining the designated flood line.

The solution

The river overtopped its banks at 10:00 and reached its maximum eight hours later. It took eight hours to move across five street blocks. This would have been more than enough time to warn and evacuate most of the people in this small community IF:
- A civil protection service had been established. (Most towns now have them.)
- There was a map on the wall of the operations room of the civil protection service showing the location of the floodline that would be reached by the regional maximum flood. (Very few towns have this information, and some of those that do have it are reluctant to disclose it because of objections by owners or developers below the floodline that this disclosure would result in the reduction in the resale value of their properties.)
- The map showed all danger points such as bridges that could be isolated by flood water and streets where high velocities could be expected.
- Property owners below the regional maximum floodline had previously been made aware that they were located in a flood-prone area, and provided with information on escape routes, and under what conditions they should evacuate their residences. (This information is seldom available but is essential for a successful evacuation programme.)
- Telephone (or preferably radio) links were established with reliable observers in the catchment. Because of the widespread nature of severe flood-producing rainfall, only three or four observers would be necessary.
- A simple, easy-to-read brochure was available in the operations room which would provide advice on the meteorological and hydrological conditions that could give rise to severe floods. This would include the observation that these floods are usually preceded by two or three days of heavy rain over a wide region.
- A 'browse file' containing details of previous heavy rainfalls and resulting floods was available for quick reference. Reference to this file would provide a good estimate of the magnitude of the pending flood compared with previously experienced floods.
- There was another map in the operations room showing the rainfall in the catchment during the past 24 hours.
- A simple warning system based on an antecedent precipitation as described above was in operation.

This simple system, which is cheap, robust, easy to understand and implement, has a large potential for saving lives. This is confirmed by comparing the situation in Laingsburg, where no flood warning system existed at that time, and the situation in Ladysmith where frequent flooding occurs (inhabitants are aware of the danger) and a flood warning system is in operation. The number of families at risk in Ladysmith is about 700 compared with about half of this number at

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Laingsburg. One hundred and four people lost their lives at Laingsburg while only one life was lost in the September 1987 flood in Ladysmith which was the third highest since 1884.

Another example is the September 1987 floods elsewhere in Natal where there was a high loss of life. The Weather Bureau issued a warning of the possibility of severe rain five days before the floods occurred. There was also a build-up of preceding rainfall. None of the authorities reacted to this information because they could not relate it to the possible severity of floods that could result from it. Consequently, no action was taken prior to the arrival of the floods, and lives were lost.

Conclusion

Occupation of flood prone areas, including areas above the proclaimed floodlines but below the maximum floodlines, and unplanned residential occupation of floodplains have escalated during the past few years. The risk of drowning during floods has increased significantly as a consequence. Most of these people have not experienced floods and are generally unaware of the risks that they face. Due to their social conditions their safe evacuation will be a difficult operation. Every additional hour of prior warning can potentially save tens to hundreds of lives.

The position has become acute in South Africa due to the influx of rural poor into urban areas. The rate of influx has been accelerated by the recent drought and refugees from neighbouring countries. It has been estimated that there are between 50 000 and 100 000 people in South Africa living below levels reached by previous floods. Resettling these people elsewhere is the obvious solution but for a number of reasons it will not be possible to achieve this in the foreseeable future.

Engineering solutions, such as the construction of flood control dams, flood levees and river canalisation, are costly and do not reduce the long term risks. The only viable option to reduce the risk of loss of life is to operate efficient flood warning systems.

The development of flood warning systems can vary from simple systems based on antecedent precipitation indices to near real time information acquisition including radar images, rapid computer-based data processing and flood forecasts of sufficient accuracy to place observers in the field and rescue teams on standby. Direct warnings should only be issued once life-threatening floods are observed in the river. Ultimately, the success of the system will depend not only on hydrological technology, but also on effective communication with the people at risk, and the trust that they have in those who are responsible for operating the flood warning system.

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IVc Early Warning Systems Related to Drought and Mitigation of Famine

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Prediction of African Rainfall and Household Food Security

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1 Introduction

More than a century has passed since some of the earliest scientific efforts at understanding the variability of tropical and subtropical rainfall (Blanford 1884), while Walker made extraordinary progress in uncovering the three largest known modes of interannual atmospheric variability (Walker 1930; Walker & Bliss 1930; 1932). Despite this promising grounding, seasonal forecasts of rainfall have only become operational in the last ten years or so (see Hulme et al. 1992).

With its marked record of droughts, high interannual variability of rainfall and its largely agricultural economy, Africa is a prime potential benefactor of seasonal forecasting.

This paper reviews recent developments in both climate prediction and the use of climate forecasts in promoting household food security. We outline the process of compiling and distributing seasonal forecasts. Components of operational seasonal forecasts for Africa are examined. The utility of climate forecasts is described against the background of household vulnerability and strategies to cope with food insecurity.

Climate forecasts may indeed revolutionise resource management in Africa. Yet, their utility ultimately depends on the linkages between geophysical, economic and social science insights as well as global linkages between institutes that provide and distribute forecasts and those responsible for responses, ultimately the vulnerable households throughout the world.

2 Seasonal Forecasting

Daily weather forecasts of specific rainfall events, associated with explicit synoptic rainfall producing systems, are only accurate to about five days. In contrast, probabilistic forecasts of monthly or seasonal rainfall totals, usually expressed in categories ranging from very wet to very dry, are being issued for several parts of the world.

The process of deriving a seasonal forecast is shown in Figure 1. As for any climatological analysis, data preparation and evaluation of key relationships require significant resources and expertise. For a thorough regional analysis, global data sets are required, even for relatively simple multivariate statistical analysis. These data should be continuously updated in order to monitor performance of the prediction model. Technical problems can arise if the time series are not homogeneous, if underlying trends are present or due to missing data.

Methods for climate prediction began with statistical analysis of rainfall periodicities. Most

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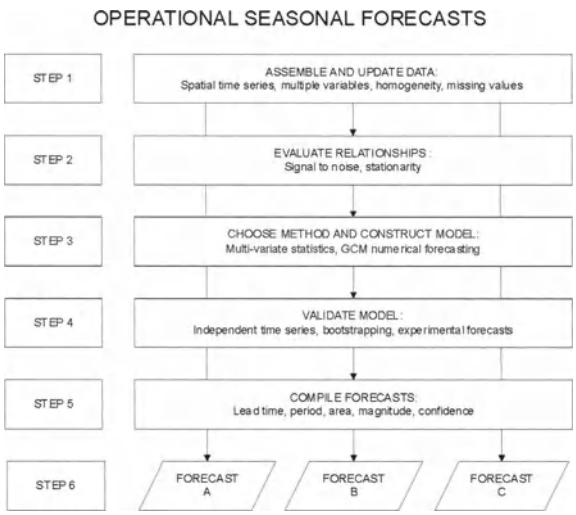


Fig. 1. Steps in preparing operational seasonal forecasts

predictions are now based on multivariate empirical approaches and numerical methods using global climate models.

Once a predictive model has been constructed, it needs to be validated. Only then can reliable operational forecasts be issued. These steps are duplicated in every forecast centre. The result is a range of forecasts based on different assumptions and methods.

Next we review seasonal forecast methods used to predict African rainfall.

2.1 Statistical Analyses of Rainfall

Seasonal rainfall forecasts have been based simply on the analysis of the rainfall time series of a region alone, without linking rainfall variability to the atmospheric circulation or underlying physical mechanisms. In these instances the time series of rainfall typically displays marked multi-annual variability so that wet or dry conditions persisting for several years are recognisable in the form of pronounced autocorrelation or significant low frequency spectral peaks in the time series.

Southern Africa, for example, experiences a large component of quasi bi-decadal variability (Tyson 1986) which accounts for a little under 30% of the total rainfall variability. Future projections of this signal were used to warn of the drought of the early 1980s (Tyson & Dyer 1978, 1980). While the largest ENSO event of the century in 1982/83 no doubt helped to secure the veracity for this particular forecast, such endeavours remain bold when the physical mechanisms for the underlying variability have not been properly understood. This is particularly so when other variables in the climate system, such as temperature, are non-stationary. In this sense, purely statistical methods are the most basic of the seasonal prediction approaches.

2.2 Numerical Approaches

Numerically based forecasts entail the integration of General Circulation Models (GCMs), usually with sea surface temperature (SST) forcing, typically over a period of 50 or more days. Such approaches usually feature multiple runs of the GCM, each initialised with different starting conditions (corresponding to different states of the atmosphere). A set of these integrations is known as an ensemble. If all ensemble members (i.e., each of the time series of rainfall for a particular region for each of the integrations) are similar, then the forecast confidence for the forthcoming season would be regarded as very high, since the model indicates that the atmosphere is insensitive to the nature of its starting conditions given the nature of SST forcing. The SSTs would then be acting to impose a signal on the atmosphere regardless of the nature of that overlying atmosphere. In reality this is seldom the case. Some of the ensemble members may show similarity, but this does not mean that the emergent evolution of the real atmosphere will necessarily assume any one of the clustered trajectories.

Forecasts based on this broad method are undertaken by several research groups such as the United Kingdom Meteorological Office (UKMO) (Harrison pers. comm.). This method is dependent on the ability of GCMs to simulate accurately the regional climatology of the target area, which, in turn, depends on factors such as the model resolution, the degree of topographical diversity of the target area and the sophistication of the model parameterisation, particularly that of the convective scheme. For some models and some areas, this level of accuracy is excellent (e.g. North East Brazil in the UKMO HADAM2B model), whereas for other regions the model rainfall climatology is poor (e.g. the Asian Monsoon region in UKMO HADAM2B). On the whole GCMs appear to be

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oversensitive to initial conditions and under represent the amplitude response of SST forcing, but it is generally accepted that this route to seasonal forecasting offers the largest potential for future improvement.

2.3 Multivariate Empirical Approaches

The ability to predict seasonal rainfall totals several months in advance is due to the exchanges of energy between the oceans and the atmosphere, which includes the weather systems that produce rainfall. Mass, momentum and heat are readily exchanged between these two fluids. Rain falling into the ocean and evaporation of water from the ocean constitute the mass flux, wind stress on the ocean surface from near surface wind forms the momentum exchange; heat transfers occur as either latent or sensible heat flux both into and out of the ocean.

In practice, quantification of the interaction between the ocean and atmosphere in empirical studies typical of those which lead to forecasting schemes, is assumed to be represented by sea surface temperature anomalies (SSTAs) alone. This assumes, for example, that large positive anomalies will be associated with enhanced flux of sensible heat, even though the temperature gradient between the atmosphere and ocean is not explicitly calculated.

Sea surface temperatures evolve very slowly compared with the atmosphere, owing to the much larger mass and heat capacity in the oceans. Seasonal forecasts based on the impact of the current condition of the ocean surface on the atmosphere retain accuracy through the persistence in the sea surface temperatures.

This approach to seasonal prediction therefore rests on several important factors:

1. Existence of tolerably accurate SST data sets with good spatial and temporal coverage of the globe.
2. SSTAs that are spatially coherent and temporally persistent so that broadscale modification of the overlying atmosphere occurs.
3. SSTAs are of sufficiently large amplitude to impact on the overlying atmosphere.
4. Mechanisms in the atmosphere deliver the signal imposed by the anomalous heat flux over distances that may be much larger than the individual synoptic or mesoscale systems which generate rain.

For much of the last 50 years, factors (2–4) were not thought to occur in reality. SSTAs were thought to be too small and too spatially incoherent to impact the atmosphere in an organised way. While the nature of ocean-atmosphere interaction in the Pacific Ocean (Bjerknes 1966, 1969), as well as the mechanisms which were likely to drive the interaction (Wyrtki 1973), had been identified by the early 1970s, adding to the work of Walker some 40 years previously, it took a few more decades to appreciate that events on one side of the planet, in the Pacific, could have an impact on rainfall half way round the world in Africa (Lindesay 1988, van Heerden et al. 1988).

An important part of the empirical route to seasonal forecasting therefore lies in determining the location of SSTAs that show the best statistical relationship with rainfall for an area of interest. The starting point for this is a data set of both rainfall and SST. Several global SST data sets are available (e.g. COADS, GISST) which provide monthly historical anomalies at resolutions between $2\times2^\circ$ and $5\times5^\circ$ latitude-longitude. Similarly, global rainfall data sets are available, such as Hulme (1994) which provides monthly totals at $2.5^\circ\times3.75^\circ$ latitude-longitude resolution.

Empirical seasonal forecasting requires the identification of lagged statistical associations between SST indices and rainfall indices. This may be achieved through any one of the following methods: a) correlation; b) multiple regression (e.g. Ward & Folland 1991); c) canonical correlation (e.g. Landman 1995); d) discriminant analysis (e.g. Folland et al. 1991); and e) neural networks (e.g. Hastenrath et al. 1995).

Correlation is the simplest of these techniques. It measures the matched variance (specifically, the standardised covariance) between say rainfall and SSTs. Problems result from the number of time series involved. In the case of evaluating the correlation between a single index of rainfall and global SSTs, several hundred correlation coefficients need to be calculated.

Figure 2 shows a typical way of displaying these statistics. Here rainfall from a single grid box (overlying southeastern Namibia) for the season January to March (JFM) has been correlated with global January to March SSTs at a 10×10 degree resolution for the years 1950–1993. The locally significant (95% level) correlation coefficients have been mapped to the loca-

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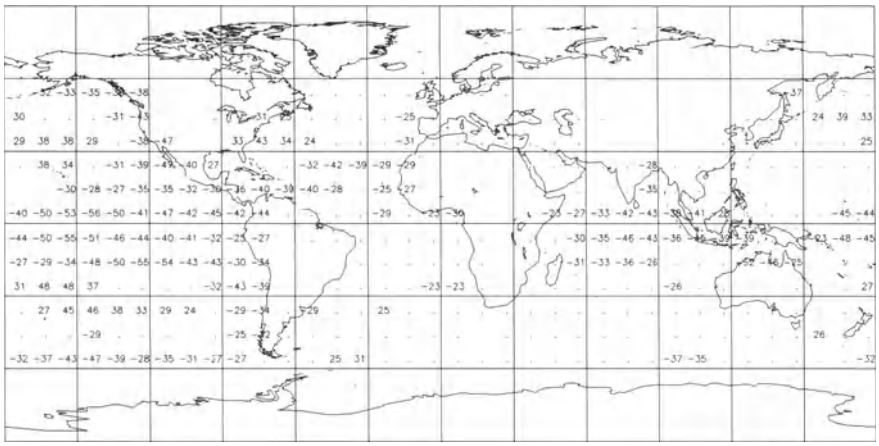


Fig. 2. Correlations×100 between JFM rainfall in southeastern Namibia and JFM sea surface temperatures, 1950–1993. Only correlations locally significant at the 95% level are shown

tion of the SST used to calculate the coefficient. Significant negative correlations between rainfall at this location and SSTs are found across the tropical eastern and central Pacific. Warmer (cooler) than normal SSTs in this region are therefore associated with drier (wetter) conditions in the southern Kalahari. The strongest correlations reach r=–0.55 near 120° W in the southern tropical Pacific. Weak negative correlations are also found in the northern tropical Atlantic and tropical Indian Ocean. A clear ENSO signal is apparent in the Pacific SSTs, although positive correlations are absent over the western Pacific. Reasons for this might lie in the small variance of the SSTs in the Indonesian warm pool but point to the utility of the SSTs in the central and eastern Pacific in the seasonal forecasting process, particularly if the rainfall-SST correlations maintain significance at several months lead time. It is interesting to note that the largest correlations between Namibian rainfall and SST occur half way round the planet.

When a single rainfall grid box is used in the calculations described above, the signal to noise ratio in the rainfall time series is often low. This may be improved by generated area averages or weighted area averages using techniques such as Empirical Orthogonal Functions (EOFs). Figure 3a shows the weights of a rotated rainfall EOF for JFM. In essence this EOF may be used to calculate an objectively derived area index of rainfall representing much of southern Africa. This particular EOF, which is derived from a set of Africa-wide rotated EOFs,

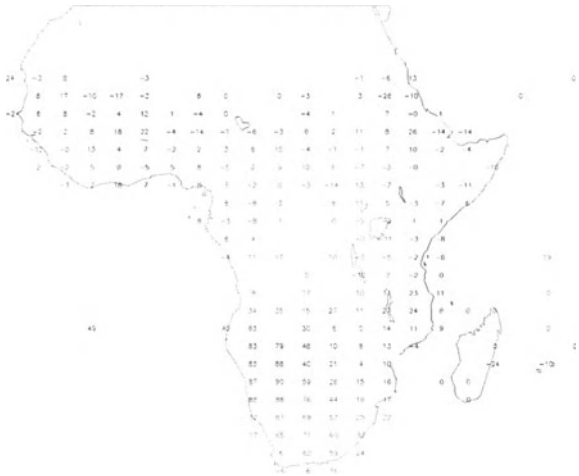


Fig. 3a. January to March (JFM) Varimax rotated rainfall EOF3 for 1900–1996. The values indicated are the correlation form of the EOF×100. Data is from the Hulme (1994) precipitation data set at a resolution of 2.5×3.75

represents the variability of JFM rainfall over Namibia and northwest southern Africa. Correlations between the EOF time coefficients and JFM SST (Fig. 3b) confirm that southern African rainfall in JFM tends to be enhanced (deficient) when JFM SSTs in the eastern and central Pacific are anomalously cool (warm). The correlations in the Atlantic Ocean shown in Fig. 3b are absent when a large area of southern Africa rather than a small region of Namibia is used as the rainfall index. In addition, the strength of the correlation coefficients increases when an area average (EOF) is used.

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Figure 3c shows the correlations between the EOF time coefficients and JFM sea level pressure. Moderate to strong positive correlations are evident in the central and eastern tropical Pacific. Correlations are negative over much of the south Atlantic and Africa as well as the western Pacific. Figure 3d shows the correlations between the EOF time coefficients and October to December (OND) SST, with the SSTs leading the rainfall by one season. At a season lead, the SST correlations compare well with the simultaneous values shown in Fig. 3b, in some cases even strengthening.

Correlation is a useful 'first look' at the location of SST and SLP anomalies which relate to rainfall of a particular region. The results considered here suggest that rainfall over the Kalahari and Namib arid regions contain some useful predictability. Predictive models, however, cannot be built from correlation alone.

A multiple regression model offers direct statistical predictive ability. Where SSTs are being used as the predictors, there is a clear need to reduce the dimensionality of the data set. If interpolated to $10\times10^{\circ}$ latitude-longitude resolution, some 400 boxes cover the domain 55° N to 55° S. Submission of so many predictors to a multiple regression would lead to a false perfect fit. The number of predictors may be reduced by creating simple area averages of the predictors (such as the Nino3 SST region). EOFs offer a useful means of reducing the number of variables to a few indices without losing important signals in the SST data set (e.g. Folland et al. 1991). At the same time the EOFs would indicate those regions which might contribute a minimal signal to the area average. A problem with multiple regression is that the predictors are modelled against one predictand, in this case a single time series of rainfall.

Canonical correlation is conceptually similar to multiple regression, except that the method involves more than one predictand. A combination of rainfall indices is related to a combination of SST in such a way that the two combinations have maximum correlation. This feature makes canonical correlation an ideal method for empirical prediction of seasonal rainfall.

Discriminant analysis involves the training of predictor variables such that their combination, linear or multiplicative, optimises the distinction between target classes of predictor variables, in this case rainfall. In practice, the skill of multiple regression and discriminant analysis in linking predictors to a target rainfall index is comparable.

Neural networks likewise train sets of predictor variables in order to optimise relationships between groups of variables. Use of this technique has been confined to only a few studies (Hastenrath et al. 1995), but is theoretically promising.

Regardless which of the statistical methods are employed, it is generally accepted that the relationship between predictor and predictand should be developed over an independent period of time. This is referred to as the training period. The statistical models developed from this training period are then used to 'forecast' (in reality to hindcast!) values for another independent time period, but for which the observed rainfall values are known. These time slices may be made up of either (a) two blocks of years, for example a training period from 1900–1949 and a later period from 1950–1991 or (b) randomly selected years from a single time slice (jack knife technique). Of these the former is more desirable since it provides truly independent periods, whereas the latter may not be truly independent owing to the high degree of interannual persistence in some rainfall and SST time series.

Forming relationships on the basis of truly independent periods may be problematic owing to the non-stationarity of the climate system throughout the twentieth century. This problem besets the calculation of SST EOFs in particular, which are sensitive to the length of the time period and the region for which they re calculated. If calculated over the entire globe, the leading EOF is a climate change signal, indicating the general warming of SSTs in most locations across the global oceans. The sub division of the SST record into two separate periods is thus problematic since the first EOF is often a mixture climate change and some other mode of variability in the SST data such as ENSO (Folland et al. 1997).

Thus far SSTs have been stressed as examples of predictor variables. The paradigm within which much of the seasonal forecasting is currently practised rests on the notion that heat fluxes between the ocean and the atmosphere pre-condition the atmosphere and determine the nature of the broadscale flow within which rainfall systems may (or may not) develop. An important addition to this idea is that the condition of the atmosphere into which that forc-

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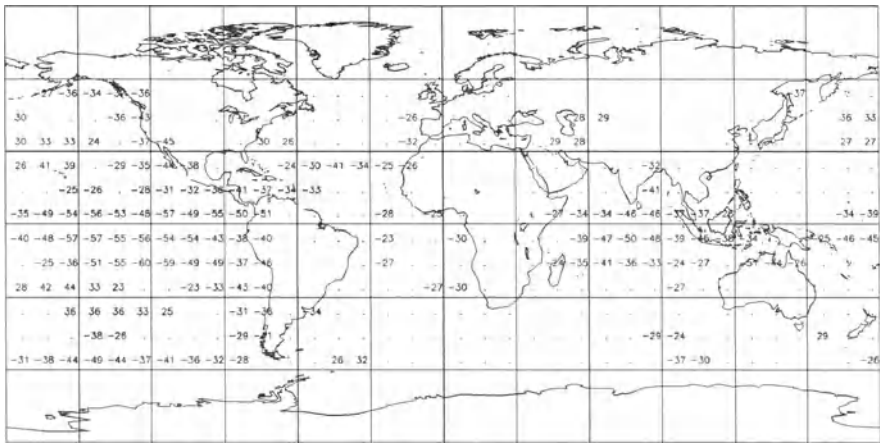


Fig. 3 b. Correlation coefficients (×100) between Varimax rotated rainfall EOF3 and JFM SST for the period 1950–1993. Rainfall data are from Hulme (1994) and SST data from the UKMO GISST data set. Only correlation coefficients locally significant at the 95% level are shown

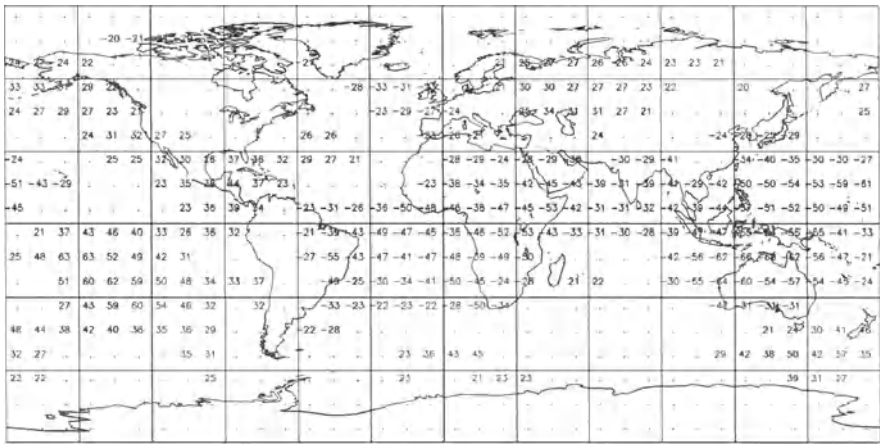


Fig. 3 c. Correlation coefficients (×100) between Varimax rotated rainfall EOF3 and JFM sea level pressure for the period 1950–1993. Rainfall data are from Hulme (1994) and SLP data from the UKMO GMSLP21F data set. Only correlation coefficients locally significant at the 95% level are shown

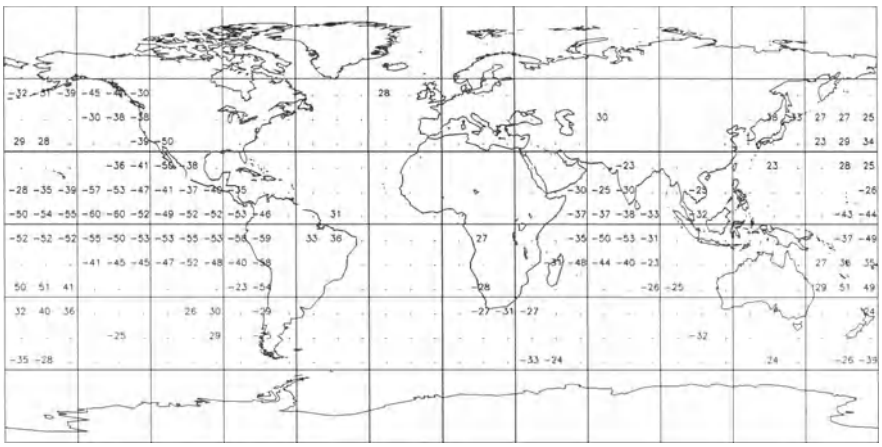


Fig. 3 d. Correlation coefficients (×100) between Varimax rotated rainfall EOF3 and the previous October to December (OND) SST for the period 1950–1993. Rainfall data are from Hulme (1994) and SST data from the UKMO GISST data set. Only correlation coefficients locally significant at the 95% level are shown

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ing is delivered may have a crucial impact on the outcome of such forcing. In other words, the atmosphere may or may not be susceptible to the SST forcing, depending on the atmosphere's state at the time of the forcing. Atmospheric variables are thus often built into the statistical associations which have been described above. These typically include the strength and direction of near surface, upper tropospheric and stratospheric winds and the location and strength of important standing eddies such as the sub-tropical anticyclones. Such circulation variables are generally available only from 1950 onwards, being particularly scarce for non surface parameters. Difficulties result from the few degrees of freedom available to develop statistical models when using such data and the added problem of truly independent testing and training periods.

2.4 Numerical and Statistical Approaches

Success in predicting future states of the tropical Pacific Ocean through numerical modelling (Cane & Zebiak 1985), have opened new opportunities for seasonal forecasting schemes whereby the empirical models of the sort discussed above may benefit from the predictions of SST from numerical modelling. The assumptions of persistence of SSTs ahead of the forecast delivery date are therefore no longer needed in the case of forecasts which use Pacific Ocean SST. Much then rests on the skill of the models used to predict the SSTs.

3 Operational Forecasts in Africa

Table 1 shows a selection of operational forecasts for several regions in Africa. Most of these appear in the NOAA Experimental Long-Lead Forecast Bulletin. All employ empirical methods. The regions for which seasonal forecasts are available depend on the following factors:

- Marked component of interannual rainfall variability which is coherent over a large region
- History of research into the mechanisms associated with the rainfall variability
- Success in statistically linking predictors such as sea surface temperature with rainfall
- Economic incentive to generate the forecast.

Seasonal forecasting in Africa has focused on the Sahel and the region directly to the south (Soudan), the Guinea Coast, East Africa and southern Africa. Empirical relationships between sea surface temperatures and rainfall exist for all these regions in the rainfall seasons and is indicated in Table 1. In addition, each region has experienced crippling droughts during recent years. We consider the general nature of these forecasts, concentrating on southern Africa.

3.1 Sahel

Seasonal forecasts of Sahel rainfall have been issued for over a decade. The UKMO forecast

Table 1. Selected operational seasonal forecasts for Africa

Area	Institute	Months	Method	Inputs
East Africa	UKMO	Oct–Dec	Regression	SST
East Africa	Univ. of Wisconsin	Sept–Dec	Neutral Nets	SST+A
East Africa	NOAA	Oct–Dec	CCA	SST
Sahel	NOAA	Jul–Sep	CCA	SST
Sahel	CSU	Jul–Sep	Regression	SST+A
Sahel	UKMO	Jul–Sep	Regression+LDA	SST
Sthn Africa	Univ. of Witwatersrand	Jan–Mar	Regression	SST
Sthn Africa	Univ. of Zululand	Oct–Mar	Regression	SST+A
Sthn Africa	Univ. of Wisconsin	Jan–Mar	Neutral Nets	SST
Sthn Africa	South Africa Weather Bureau	Jan–Mar	CCA	SST

Notes: U.K. Met. Office (UKMO), National Oceanic and Atmospheric Administration (NOAA), Colorado State University (CSU), Cononical Correlation Analysis (CCA), Linear Discriminant Analysis (LDA), sea surface temperature (SST), other atmospheric variables (A)

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Table 2. Skill (given by correlation coefficients between forecast and observed rainfall) of the UKMO forecasts for the Sahel and the Guinea coast

	Sahel	Guinea
Forecasting 1901–1945 Using 1946–1992	0.51 (0.10)	0.44 (0.02)
Forecasting 1946–1992 Using 1901–1945	0.68 (0.66)	0.53 (–0.33)

Note: The skill of persistence forecasts is shown in parentheses (after Coleman et al. 1997)

(Folland et al. 1991) and the CSU forecasts (Landsea et al. 1993) are examined here. UKMO forecasts use the Hulme (1994) rainfall data set and the GISST SST data set (Parker & Folland 1995). Area averages of rainfall are used to develop an historical time series against which the predictors are trained. Reduction of the SST dimensionality is achieved through the calculation of global SST eigenvectors of which EOF3, showing an interhemispheric contrast in temperature, is a key predictor. In addition, local SSTs in the Guinea coast region and ENSO serve as further inputs. Regression and discriminant analysis are both used as the statistical link between the rainfall and SST predictors. The training period used is from 1946–1992 and the hindcast period 1901–1945.

Table 2 shows the independent hindcast skill (temporal correlation between forecasts and observations) in forecasting two of the four North African rainfall regions. In practice this translates to seasonal forecasts falling within one rainfall quint.

Sahel rainfall forecasts issued by Colorado State University (Landsea et al. 1993) divide the region into central and western zones. Predictors include the Quasi-Biennial Oscillation (QBO), previous North African rainfall and surface temperature data, Atlantic ridge and sea surface temperatures, the state of ENSO and Caribbean SST, wind and SLP. The predictors are linked through Least Absolute Deviations (LAD) regression with the model developed over a 1950 to 1995 training period. This forecast model is thus an example of an empirical forecast that includes both SST and atmospheric predictors.

The skill indicated by hindcast testing of the early June regression models for the years 1950 to 1995 is for 58% of the variability in the West Sahel (for four predictors), 59% for the Central Sahel (for five predictors), and 58% for the Guinea Coast (for seven predictors). Recent tests suggest that the true skill (against independent data) would be to the order of 43, 44 and 41%, respectively (Mielke et al. 1996). In contrast, persistence yields skills of 20, 28 and 0% for the three regions, respectively.

3.2 East Africa

East Africa has two main rainfall seasons. The Long Rains fall from March to May and the Short Rains from October to December (Washington et al. 1997). Although the Long Rains produce more rainfall, the post-Monsoon season from October to December is characterised by more spatially coherent rainfall and more widespread correlations with SST. It is likely that the boreal Monsoon reversal, particularly in the Indian Ocean during the Long Rains, disrupts the Walker Circulation in the Indian Ocean, breaking the links with ENSO (Washington et al. 1997).

Two important points are apparent in the correlations between an area index of East African rainfall and global satellite derived rainfall (using the Xie & Arkin 1996 data) over the period 1979–1995 for the two rainfall seasons March–May and October–December:

The region of coherent rainfall in March–May over East Africa (measured as high correlations of rainfall area index with gridded rainfall) is small and confined to East Africa. During the October–December season the region of coherent rainfall is large and extends across the tropical Indian Ocean.

Relationships between East African rainfall and rainfall over Indonesia and the eastern tropical Pacific is weak and incoherent in March–May compared with October–December. The structure of the Walker Circulation is clearly evident in October–December. Enhanced rainfall over East Africa is associated with enhanced rainfall in the central and eastern tropi-

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cal Pacific but suppressed rainfall over Indonesia. An ENSO-like structure is only very weakly evident in March–May and the sign of the correlation is reversed.

Efforts at empirical forecasting of East African rainfall have relied on fundamental research relating to ocean-atmosphere dynamics in the Indian Ocean (Hastenrath & Greischar 1993; Hastenrath et al. 1993) which have shown that equatorial Indian Ocean wind direction is a key parameter relating to rainfall. Greischar and Hastenrath (1997) use neural networks as the statistical tool linking the near surface equatorial wind with rainfall. Persistence in the wind field from the pattern set in the previous seven years is the basis of the link.

3.3 Southern Africa

The rainfall season in southern Africa runs from October to March, but the late summer (January–March) includes rainfall of tropical origin which is generally thought to be more predictable than rainfall of midlatitude origin (Harrison 1984; Tyson 1986; Barnston et al. 1996). Work on southern African rainfall and circulation variability in late summer is extensive (see reviews in Tyson 1986 and Mason & Jury 1997). Southern African rainfall has been shown to respond directly to SST (Walker 1990; Jury & Pathack 1993; Jury et al. 1994; Mason 1995; Mason 1997). Seasonal forecasts in southern Africa have been developed and coordinated by the recently founded South African Long-Lead Forecast Forum (SALLF).

The seasonal forecasts issued by Jury (1996) are considered here. This seasonal forecasting scheme is an example of a multiple regression scheme with numerous predictors from both the atmosphere and ocean. These include Niño3 SST, Southern Oscillation Index, tropical Atlantic 200 hPa winds, Indian Ocean SSTs, near surface tropical Indian Ocean winds, convection near the equatorial African coast, SW Atlantic Ocean SST and SSTs of the coast of NE Brazil. Data used in this scheme originates from COADS and GISST, CPC, ECMWF. Data reduction has been achieved through rotated EOFs (SST) and area averages. Owing to the satellite outgoing longwave radiation (OLR) indices, all model training periods were limited to 1971–1993.

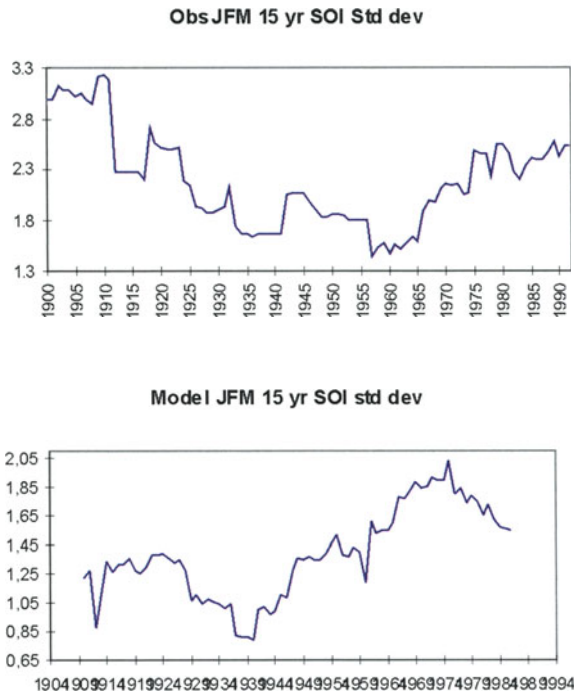


Fig. 4. Variability of the Southern Oscillation Index as determined by a 15 year running standard deviation of the Southern Oscillation Index for observed (top) and modelled (bottom)

A mean hindcast r-squared of 65% (assuming 17 degrees of freedom) shows a high model skill. Several multiple regression equations, each relating to rainfall of a number of sub regions had a mean hindcast r-squared fit of 69%. Jury (1996) notes that a partial validation of the model skill was undertaken using a jackknife technique, where each year was held out in turn and the predictor term coefficients (but not the choice of predictors) were determined from the remaining years and used to forecast the withheld year. Mean correlations between observed and model predicted values were 0.73 for early summer and a somewhat higher 0.79 for late summer models.

3.4 Problems in Seasonal Forecasting

The role of ENSO in modulating African rainfall variability has been stressed throughout this paper. ENSO imparts a significant signal to most of the core areas of operational forecasts in Africa. Clearly, changes to the ENSO system would have important implications for the veracity of the operational forecasts. Such changes

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are not unprecedented in the twentieth century record.

Figure 4 shows the secular variability of the Southern Oscillation Index for the austral summer (January–March). This has been calculated by means of a 15-year running standard deviation of the SOI of both observed standardised Tahiti-Darwin sea level pressure and the standardised Tahiti-Darwin equivalent from a century long integration of the UKMO GCM (HADAM2A). The collapse in variability of the SOI, corresponding to a reduced number of intense ENSO events, is apparent in both the model and the observed data. Until this feature of global climate variability is better understood, seasonal forecasts which rely on ENSO as their main predictor may be subject to unacceptably low levels of predictability were the current phase of ENSO activity to wane. Indeed, much of the early work of Walker and Bliss (1932) lost favour owing to the demise of ENSO events following the publication of his pioneering work.

3.5 Decadal Variability

The importance of the low frequency component of southern African rainfall has long been known (Tyson et al. 1975). Although bi-decadal variability explains less than 30% of the total rainfall variability, the underlying oscillation has been used to predict the prolonged southern African drought of the 1980s (Tyson & Dyer 1980), to infer climates of the Last Glacial Maximum (Cockroft et al. 1987), the late Holocene (Tyson & Lindesay 1992; Cohen & Tyson 1995) and those of the next century (Tyson 1993). Physical mechanisms to explain this bi-decadal rainfall variability have, however, remained elusive.

The relationship between low frequency southern African January to March rainfall and the January to March component of global low frequency SST EOFs, suggests that much of the rainfall variability is associated with SSTAs in the southern central Pacific (5°–15° S) and the southern Indian Ocean, (25°–45° S) ($r = 0.59$ $p = 0.05$). The southern African droughts of the 1980s, 1960s and 1920s, together with the wet spell of the 1970s and 1950s, are in phase with modulation of these SST EOFs. The relationship degrades between the years 1925 and 1945, corresponding with the broad period of low variability in the SOI shown above. An important question thus surrounds the utility of rainfall forecasts which are issued on multi-annual timescales. That such skill exists is beyond doubt.

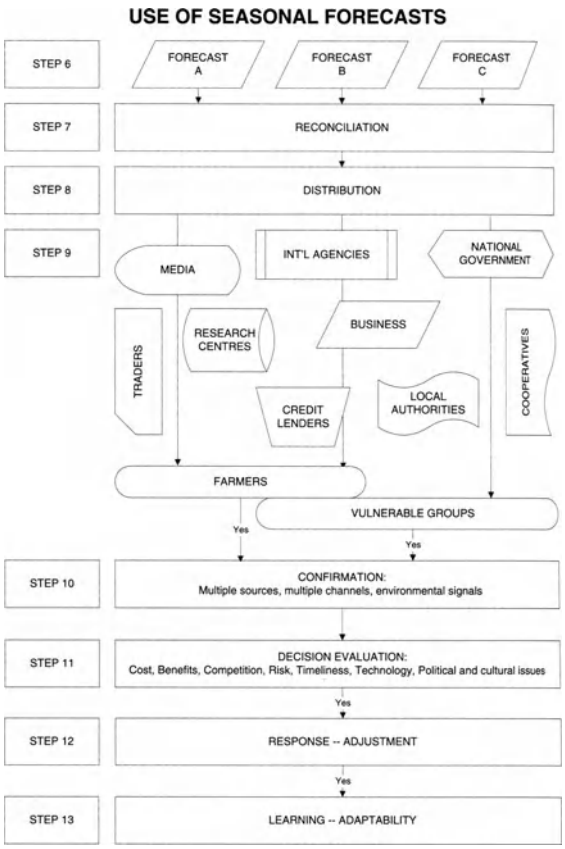


Fig. 5. Use of seasonal forecasts

4 Responses to Seasonal Climate Forecasts

The preparation of operational seasonal forecasts results in multiple forecasts from different model centres (Fig. 1). Successfully using and responding to the seasonal climate forecasts depends on how the forecasts are disseminated, reviewed and acted upon (Fig. 5). In some cases, there may be efforts to reconcile the various predictions and provide a composite forecast. For instance, the International Research Institute for climate prediction have initiated forecast panels to review the predictions and discuss issues of how the forecasts should be used (IRI 1998).

With or without reconciliation, the forecasts are disseminated through a wide variety of

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channels. The traditional mode is through the World Meteorological Organisation's network of national meteorological centres (NMCs). In contrast to hierarchical and official channels, widespread access to the Internet has accelerated the speed of communication. Many organisations are intermediaries, as well as responding in their own way. For example, NMCs might act on a warning to inform a governmental drought preparedness working party at the same time as passing on the warning to the public.

Local users, in terms of farmers and resource managers are the ultimate beneficiaries of forecasts. Figure 5 explicitly highlights vulnerable socio-economic populations as a separate beneficiary. To prevent famine, forecasts much reach and benefit such populations. But, this is far from a necessary response to issuing climate forecasts.

Each decision maker must decide how to respond. Confirmation of the forecast is often achieved by checking with other official and informal sources. Clear environmental signals may be required to confirm the formal prediction based on remote statistical techniques. Specific responses are subject to diverse forms of analysis, ranging from formal cost-benefit analysis to collective, precautionary behaviour. Initial responses are specific adjustments to the expected conditions. Over the longer term, as forecasts prove reliable this information may be included in strategic management decisions.

The next section focuses on aspects of household food security that influence the utility of climate forecasts. Our particular concern is with vulnerable populations and responses that promote food security in Africa.

5 Household Vulnerability and Coping Strategies

Since the World Food Conference in 1974 there have been three major shifts in food security thinking: changing scale from global to household and individual; broadening the focus from food alone to long-term resilience of livelihoods; and diversifying from objective indicators such as target levels of consumption to more subjective perceptions of security (Maxwell 1994).

A rich literature now exists on coping strategies, capacity to withstand shocks and stress,

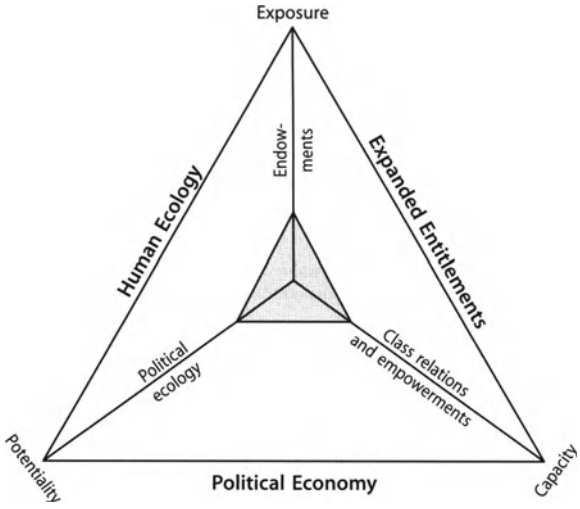


Fig. 6. Three dimensions of vulnerability, implied in the conjuncture of the human ecology of production, exchange entitlement and political economy. Vulnerable groups can be located in different sectors of the triangle. For instance, subsistence farmers would be more dependent on their land and labour resources than on market exchanges. The destitute and refugees are closely tied to the political economy of aid. The urban poor are dependent on what they can earn in informal markets. Source: after Bohle et al. (1994)

and more generally vulnerability (see IDS 1991; Downing 1991 for famine early warning systems; Downing 1996 in relation to climate change; and the special issue of the Internet Journal for African Studies (e.g. Glantz 1997) for papers on climate prediction).

Vulnerability can be defined as the "degree of loss resulting from a potentially damaging phenomenon" (UNDHA 1993, p. 63) or "the insecurity of the well-being of individuals, households, or communities in the face of a changing environment" (Moser 1996, p. 2).

Critical questions are: What determines the relationship between a hazard and its effects? Who are vulnerable? Why? These require a broader analysis of vulnerability. This amplification of vulnerability stems from the literature on development and livelihood security (e.g. see Chambers 1989; Dow & Downing 1995) rather than the more circumscribed work on disaster relief. As such, it begins to place vulnerability in the wider structures of political ecology.

Particular vulnerabilities are the conjuncture of social, economic and political structures. Anderson and Woodrow (1989) chart vulnerability and capability related to physical/material

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Level of Vulnerability	Conditions of Vulnerability	Typical Coping Strategies and/or Behaviours
SLIGHTLY VULNERABLE	Maintaining or Accumulating Assets	**Assets/resources/ wealth**: either accumulating additional assets/resources/ wealth or only minimal net change (normal "belt-tightening" or seasonal variations) in assets, resources or wealth over a season/year; i.e., coping to minimise risk
	Maintaining Preferred Production Strategy	**Production Strategy**: any changes in production strategy are largely volitional for perceived gain, and not stress related
MODERATELY VULNERABLE	Drawing-down Assets	**Assets/resources/ wealth**: coping measures include drawing down or liquidating less important assets, husbanding resources, minimising rate of expenditure of wealth, unseasonable "belt-tightening" (e.g., drawing down food stores, reducing amount of food consumed, sale of goats or sheep)
	Maintaining Preferred Production Strategy	**Production strategy**: only minor stress-related change in overall production/income strategy (e.g., minor changes in cropping/planting practices, modest gathering of wild food, inter-household transfers and loans etc.)
HIGHLY VULNERABLE	Depleting Assets	**Assets/resources/ wealth**: liquidating the more important investment, but not yet "production", assets (e.g., sale of cattle, sale of bicycle, sale of possessions such as jewellery)
	Disrupting Preferred Production Strategy	**Production Strategy**: coping measures being used have a significantly costly or disruptive character to the usual/preferred household and individual life-styles, to the environment, etc. (e.g., time-consuming wage labour, selling firewood, farming marginal land, labour migration of young adults, borrowing from merchants at high interest rates)
EXTREMELY VULNERABLE	Liquidating Means of Production	**Assets/resources/ wealth**: liquidating "production" resources (e.g., sale of planting seed, hoes, oxen, land, prime breeding animals, whole herds)
or AT-RISK	Abandoning Preferred Production Strategy	**Production strategy:** Seeking non-traditional sources of income, employment, or production that preclude continuing with preferred/usual ones (e.g., migration of whole families)
FAMINE	Destitute	**Coping Strategies Exhausted**: no significant assets, resources, or wealth; no income/production

Fig. 7. Vulnerability Matrix for the U.S. Famine Early Warning System. Vulnerability is portrayed as a progression from slightly vulnerable to famine. At each level of vulnerability, households pursue different strategies – from production to survival. Consequently, different forms of intervention are warranted for different levels of vulnerability, from targeted development assistance to supporting coping strategies and ultimately emergency food relief. Source: U.S. Famine Early Warning System (FEWS) (1992)

resources, social/organisational relations, and motivational/attitudinal aspects. Bohle et al. (1994) suggest a tri-partite causal structure of vulnerability (Fig. 6) based on the human ecology of production, expanded entitlements in market exchanges, and the political economy of accumulation and class processes. Vulnerability *per se* is best viewed as "an aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of harmful perturbations" (Bohle et al. 1994, p. 37–38). In one of the fullest treatments of vulnerability and disasters, Blaikie et al. (1994) regard vulnerability as a product of such characteristics as ethnicity, religion, caste membership, gender and age that influence access to power and resources. One application of the concept of vulnerability is in the US Famine Early Warning System, which monitors food crises in Africa (Fig. 7).

Regardless of the nuance of vulnerability frameworks, key concepts are:

- Vulnerability is a relative measure. The analyst, whether the vulnerable themselves, external aid workers, or society in broad terms, must define what is a critical level of vulnerability.

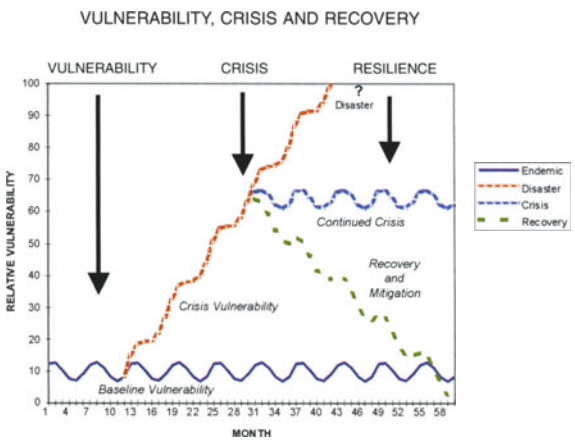


Fig. 8. Dynamic vulnerability during a food crisis. Source: after Bohle (1993)

- Everyone is vulnerable, although their vulnerability differs in its causal structure, its evolution, and the severity of the likely consequences.
- Vulnerability relates to the consequences of a perturbation, rather than its agent. Thus, people are vulnerable to loss of life, livelihood, assets and income, rather than to specific agents of disaster, such as floods, wind-

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storms or technological hazards. This focuses vulnerability on the social systems rather than the nature of the hazard itself.
- The locus of vulnerability is the individual related to social structures of household, community, society and world-system. Places can only be ascribed a vulnerability ranking in the context of the people who occupy them.

These concepts of vulnerability shift the focus of vulnerability away from a single hazard to the characteristics of the social system. Vulnerability is explicitly a *social* phenomenon related to a human value system.

Vulnerability changes over time incorporating social responses as well as new rounds of hazardous events. Bohle (1993) captures the dynamic nature of vulnerability (Fig. 8). In this illustration, vulnerability begins to increase at the end of the first year, reaching a crisis at 30 months. Here the outcome of the crisis is uncertain. In a resilient society with appropriate interventions, recovery and mitigation can bring vulnerability back down to baseline (or lower) levels. Unmitigated, or in conjunction with another event such as civil strife following drought, the crisis may become a disaster. Or, some groups and communities may continue in crisis, on the edge of disaster. Social groups vary in the structure of their vulnerability. For example, the rural landless (without non-agricultural incomes) are typically more sensitive to food shortages, with less on-farm storage and buffering capacity than smallholders. So, the trajectories shown here may be sharper and the outcome different for different groups, even in the same region.

Specific groups of vulnerable peoples can be defined. While the precise boundaries of vulnerability vary between cultures and environments, the common catalogue often starts with the characteristics of individuals:
- Women, especially those with special nutritional needs during and after pregnancy
- Children, who are less resilient in terms of nutrition or who may already be malnourished
- Elderly, who may suffer from a lack of mobility and less mental awareness
- Disabled and disease-stricken, who have special needs and require routine assistance for survival.

At the household level, vulnerability may be delineated by socio-economic class and means of securing a livelihood: In rural areas:
- Smallholder agriculturists may be resource-poor with limited access to land and labour, in marginal lands, with varying degrees of empowerment and access to emergency and development assistance.
- Pastoralists often have little empowerment to recurrent development resources, yet operate in regions with pronounced climatic hazards. However, they often attract international assistance during a disaster.
- Landless labourers relying on casual employment are often at the margin of poverty with little ability to accumulate savings or to invest in more productive activities.
- Destitute peoples have been forced out of productive activities, often due to ill health and old age in addition to being impoverished through natural disasters and other causes. Where the destitute migrate to urban centres, they may have more opportunities for assistance and work, although this depends on the nature of the receiving society.

In urban areas:
- Unemployed destitute in urban areas may be incorporated into social welfare systems (often informal), but suffer significantly in times of disaster if the numbers become too large and if relief fails to target their pressing needs.
- Underemployed poor people, comparable to landless labourers, are on the margins of survival. A slow deterioration in the economy can affect this group, often leading to a major but largely hidden crisis.
- Refugees are the most visible vulnerable population, usually swelling in numbers after a disaster. They may also be vulnerable to further hazards, for instance while attempting to return to their homes and occupations or in camps with inadequate protection against floods, heat and frost, among other hazards. Yet, this group tends to benefit from its visibility and various formal channels of assistance.

Finally, community characteristics may be enumerated that place vulnerable social groups at risk from specific types of hazards. Such vulnerability includes, for example:

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- Building location, design and standards that determine the resilience of homes, work places and community meeting places.
- Occupancy patterns and who is in substandard buildings, when, for how long, etc.
- Transport and mobility, for example the pathways between home and work may cross hazardous regions and access to safe areas such as cyclone shelters in Bangladesh.
- Health, water, power and communication infrastructure that sustain life as well as provide channels for relief assistance.

6 Coping and Climate Prediction

How does the broad range of vulnerability and capacity in Africa relate to emerging skills in climate prediction? On the one hand there are tremendous opportunities.

Climate, and particularly drought, affects a wide range of activities beyond just crop yields: land quality; on-farm storage; water supplies; labour migration; rates of urbanisation and rural population growth; use of inputs such as fertiliser; farm income; farmers' skill and experience and so forth (Glantz 1996, p. 145–148).

Seasonal forecasts already have been used in Africa, for example in predicting maize yields in Zimbabwe (Cane et al. 1994). Several studies have analysed costs of El Niño events, for example, and predict considerable savings could be made if accurate warnings of the onset of the phenomenon could be used (see Glantz et al. 1997). The 1991–1992 El Niño-related drought in southern Africa was estimated to cost the US government $800 million in responses to the phenomena (Farmer 1997).

For agriculture and water resource management the benefits could be quite extensive, altering the entire basis of economic planning in Africa. The utility of reliable long range forecasts, therefore, could be enormous, not just for earlier warning of need for emergency aid. Policy makers and farmers alike should benefit.

Beyond the immediate concerns of an individual season, the process of developing climate prediction and response capabilities could have substantial benefits. Long-term learning and partnership between climatologists, agriculturists and decision makers should heighten awareness of information needs and focus development. An open process of information access, as in the case of forecasts distributed over the Inter-

Table 3. Users and potential applications of climate forecasts

Type of User	Potential Application of Forecast			Benefits
	Multi-year Forecasts	Seasonal Forecasts	Within-Season	
Commercial Producers	Capital and land investment	Acreage planted; Planting dates; Crop/variety selection; Water management	Water management; Application of inputs; Harvest dates	Increased certainty and reduced risk; Improved financial viability; Long-term survival; Enhancement of comparative advantage
Subsistence Producers	Limited, possibly diversification and off-farm savings	Planting dates; crop/variety selection	Limited	Improved food security in poor years; Improved marketable surpluses in good years
Agricultural Support Services	Plant and capital investment; Research and development priorities; Location decisions; Production strategies	Product selection; Sales forecasts; Pricing policy	Adjustments to marketing strategy	Improved financial viability; Ability to respond better to farmers' requirements; Recovery from drought
Agricultural Extension Services	Promotion of drought mitigation strategies; Development of improved extension advice	Preparation of dynamic, climate specific extension advice to subsistence and smallholder producers	Specific adjustments to earlier extension messages and advice	Better extension service to subsistence and smallholder producers

Source: after Gibberd et al. (1996)

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net, could assist development of efficient and equitable agricultural and food marketing systems. An ultimate goal is to reduce uncertainty and risk in investment in drought-prone areas.

Making the best use of climate predictions is not without problems. As for both climate prediction and vulnerability, a considerable literature addresses the use of weather prediction, but mostly from a developed country perspective (see Easterling 1986; Sonka et al. 1987; Changnon 1992; Nichols 1996). Issues of particular interest in Africa include:

- Targeting users. The potential users of climate forecasts vary, from the local to global, from producers to consumers, from the at-risk to those with a general interest in the state of the world (Table 3). Each has different needs for information, and different potential benefits. Common concerns are type of weather event, forecast lead time and precision.
- Reaching vulnerable livelihoods. Beyond "decision makers" or "users", the context of vulnerability conditions the utility of climate predictions in preventing famine and ameliorating poverty. The vulnerable may not receive predictions through timely and reliable channels, and may distrust official warnings. They are likely to have fewer resources to respond to predictions – already land and land tenure, labour for planting, credit for inputs, storage of surplus and access to markets hinder agricultural development among the rural poor. Additional information may not be the major constraint to ameliorating vulnerability.
- Generalising spatial and temporal information. Climate predictions may enter the process with clear spatial and temporal resolution, bands of uncertainty, and even colour maps and visualisation techniques. As the predictions work their way through various dissemination channels, predictions are likely to be generalised. Warnings at a regional scale will be taken as true for each locale within the region. Projections for local conditions (such as the semi-arid maize growing region of southern Zimbabwe) are likely to be extended to similar zones elsewhere and adjacent geographic regions, even though they may experience wetter conditions on average. Forecasts for specific time periods, such as the start of the rains, may be interpreted as true to the entire season. The generalised message may well be more extreme than intended, as appears to have been the case in southern Africa in 1997/98.
- Lag between forecasts and dissemination. Working through the forecast process and dissemination channels takes time. The original message and subsequent revisions will not be current for any user. For some users, perhaps most critically for the vulnerable populations, this delay may be significant. Where organisational rules resist change, an early planned response may be inappropriate in light of new information. For example, a prediction of good rains following drought may not be sufficient to reduce food aid operations, which have long lead times in planning, ordering, shipping and distribution. The long lead times also allows messages to be distorted (Table 3), in contrast to short-term forecasts which quickly expire.
- Maladaptive responses. Not all responses to predictions will be beneficial to every user. Information is not a public good; and climate predictions should be seen as part of competitive and institutional processes that may be maladaptive. Smallholder agriculturists, for instance, compete in a mixed commodity/subsistence farming system. During a drought, without irrigation, they may be relatively worse off if commercial producers can maximise production and control markets. In South Africa, credit organisations apparently reduced credit to smallholders during 1997, in response to the early warning of delayed rains and a poor season (Schulze pers. comm. 1998). Lower yields in this sector may reflect this institutional risk management rather than poor rains (which turned out to be wetter than the initial forecast suggested). The urban poor may be particularly susceptible to rising prices, perhaps in anticipation of shortages as a consequence of climate forecasts.
- False alarms. Reliability is often seen as a major constraint in climate prediction. The effect of a false alarm, or misleading forecast, can taint an emerging system. This is a major concern for weather offices, which regularly measure their skill. It is more difficult to demonstrate skill in climate prediction since there are far fewer independent events for validation (perhaps only two per year).

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The effect of false alarms will vary for each user. Few will use climate predictions as the sole criteria for decisions; all are accustomed to risk in decision making.

7 Conclusions

Droughts in 1983–1984 and 1991–1992 were both described as unusual or the worst to affect the subcontinent in the 20th Century (Downing et al. 1989; Rook 1997). It is remarkable that, despite serious reductions in harvests, widespread hunger was averted in 1991–1992, largely attributed to the rapid responses instigated by regional early warning systems. In early to mid 1997, prediction of drought (in southern Africa) and flood (in eastern Africa) raised the question of whether improvements in climate predictions would be able to improve household food security (see the IJAS 1997, especially papers by Buckland, Callear, Cane, Dilley, Farmer, Nicholls, Ogallo and Wolde-Georgis).

The effects of climate, and in particular climatic hazards, depend very much on the vulnerability of the population. The use of climate predictions is also related to vulnerability, both in terms of direct effects and in terms of how easy it is for a given group to access climate predictions and respond to them. Building institutional capacity to provide medium-term climate forecasts to enhance adaptive resource management in Africa would be a major step forward both in achieving present development aims and in preparing for climate change. Research on how to disseminate information, and ensure it is applicable at a household level is crucial.

Would better forecasts have altered the outcomes of diverse African food crises over the past decade or longer? The answer depends on how the political economy would have adapted to widespread dissemination of forecasts (and other data on climate and production). Good forecasts, in each case, would not have been sufficient to ensure early responses, to bolster sustainable livelihoods and to prevent vulnerable populations from being displaced. "There is frequently a danger that forecasting can become an end in itself, detached from many of the social processes that give rise to hunger and starvation" (Tapscott 1997).

Acknowledgements

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Global Information and Early Warning System on Food and Agriculture: Appropriate Technology and Institutional Development Challenges

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Abstract

FAO's Global Information and Early Warning System (GIEWS) was established in 1975 in the wake of the world food crisis of the early 1970s. The System has the mandate to continuously monitor the global food supply and demand situation and alert the international community of countries or regions threatened by serious food shortages or which have exceptional localised or exportable surpluses of food available for donor purchases and distribution to deficit areas. One of the System's exceptional assets lies in the vast database at its disposal on global, regional, national and sub-national food security which is continuously updated and refined.

Recently, GIEWS has invested in innovative methods for collecting, analysing and disseminating information, making full use of the revolution in information technology and exploiting the possibilities offered by recent hardware developments and ever more specialised software including GIEWS' own Workstation. The System provides policy-makers and relief agencies throughout the world with timely and objective information and has repeatedly demonstrated its capacity to alert the international community to impending food emergencies. The System, constantly endeavours to improve the quality and flow of information from the field, enhance the objectivity and credibility of its assessments, speed up the dissemination of its outputs to the users and strengthen linkages between its early warnings and the response mechanisms.

The paper deals with the objectives of GIEWS, the institutional links forged by the System and its extensive information sharing arrangements with national governments, intergovernmental agencies, NGOs and other early warning systems. It highlights the recent innovations and the improvements introduced in the assessment methods by the System.

1 Background

GIEWS was established on the recommendation of the World Food Conference (1974). It serves policy-makers and researchers in a world-wide network that includes UN and donor agencies, 117 national Governments, 60 NGOs and numerous universities and trade organisations. The members of the System have one thing in common: a commitment to the fight against hunger. Information is a vital weapon in this fight. It is the basis for sound policy.

The ultimate aim of GIEWS is to avert hunger and suffering, by providing accurate, timely and apposite information on food supply and demand at the global, regional, national and sub-national levels. Strict early warning, in this context, is the prediction of food crises before they happen.

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The System provided timely warnings of famine in the Horn of Africa in the early 1980s, of drought-induced crop failures in southern Africa both in 1991/92 and 1994/95, of grave food crisis emerging in Korea, D.P.R. since 1995, the food emergency in Indonesia and famine conditions in southern Sudan early this year. Since its inception, the System has issued 285 Special Alerts and 122 Special Reports to the international community of impending food emergencies due to man-made and/or natural disasters in various parts of the world. The latest such alerts was issued on 3 September to warn of the looming food and humanitarian crisis in the Democratic Republic of Congo.

This paper examines the two dimensions to effective early warning: the institutional and the technical.

2 Institutional Structure

It is fair to say that technological development is only useful and effective if the technology is nested in the right institutional setting. GIEWS has found that the following institutional ingredients are necessary for an effective early warning system:

1. Sensitivity to user needs
2. Effective inter-institutional information flows
3. Capacity building: enhancing the local institutions involved in data collection and analysis
4. Rapid field assessment: intervening quickly when the regular monitoring system malfunctions
5. Bridging the information-response gap: making sure that there is the appropriate follow-up.

2.1 Sensitivity to Users' Needs

An information system must justify its costs, meaning that it provides a valuable and well-defined service to its users. GIEWS' users are heterogeneous, suggesting the need for a wide range of outputs. Indeed, the outputs of the GIEWS cover a range of topics with wide geographic coverage combined with more detailed reports on food crisis hot spots. Publication facilities have been upgraded. All GIEWS outputs are available through the Internet and the content, presentation and dissemination of hard copy publications have been enhanced.

User-feed back has always been the benchmark against which the system is measured. Regular readership surveys and informal comments, as well as internal reviews, help to keep the System sensitive to user needs.

The value of the service also depends on the extent to which information is disseminated. All GIEWS information is public domain. The Internet has greatly expanded the potential user group, in all but the least developed countries (where a recent GIEWS survey suggests that Internet access is still rather infrequent).

2.2 Effective Information Flows

GIEWS (Fig. 1) collects and compiles information from numerous sources. The effectiveness of the system depends on comprehensive, consistent and timely access to information. Data access in turn is much more than the technical question of transferring data from A to Z. There is nothing automatic about information flows: The development of a network of "friendly institutions" is a long but essential process. For this reason, the System has cultivated strong institutional links with its users and information providers. The network is vast and complex, characterised by two-way communications. This section briefly describes the

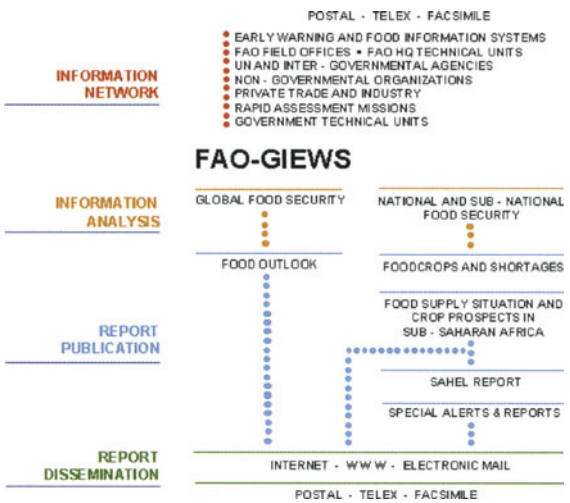


Fig. 1. Global Information and Early Warning System – a simplified diagram

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information flow mechanisms, which are presented in a simplified diagram below.

GIEWS has the advantage of the network of FAO offices covering 112 countries globally. These offices usually have privileged access to official information on food and agriculture. The System has also developed a large NGO network and has established formal links with all the main donor and UN agencies working in the field of food security.

2.3 Capacity Building

For the system to maintain global coverage, it needs to cope with the varying levels and quality of data generated at the national or sub-national level. Regional, national and sub-national early warning and food information systems (EWFIS) have been established, often with FAO support, in many countries.

These are the critical source of information for the most food insecure countries in the world. Given the complex and multi-disciplinary nature of data collection and analysis, these systems require high levels of investment in computer systems and staff training. Strengthening the capacity of local, national and regional EWFISs has long been an objective of FAO. GIEWS contributes to this process through the provision of data, expertise and software. Regular contacts have been established with focal points in the key institutions.

GIEWS has also sought to ensure that its activities maintain a strong element of local participation and knowledge transfer. To this end, national consultants are hired to assist in detailed in-country assessment and consultants from developing countries are utilised through FAO's Technical Cooperation between Developing Countries (TCDC/TCCT) programme.

2.4 Rapid Field Assessments

Local EWFISs do not necessarily provide continuous and reliable information. Food information is often politically sensitive. National governments can suppress details of food crises, especially when they reflect poorly on national policies. Sometimes Governments may exaggerate requests for food assistance. Equally, donor countries may seek to underplay resource requirements in countries that are politically out of favour. An independent and objective body is able to assess the plausibility of information. In conflict situations, Government institutions may collapse. Data can be lost with no structures for collection and reporting. Such was the situation in Rwanda in 1994 and Somalia from 1992. GIEWS acts as a "backup" in these cases.

GIEWS dispatches Crop and Food Supply Assessment Missions (CFSAMs) to data scarce countries facing food crises. These missions use rapid field assessment methods, with a strong emphasis on sound and independent judgement rather than formal methods. The missions are often a critical element of the donor resource-mobilisation process, providing and independent perspective on the food security situation. On average, some 25 such missions are dispatched each year although the number is increasing and 37 were launched in 1997. Most of the missions are dispatched to Sub-Saharan Africa. Since 1994 there have been frequent assessments, for example, in the Great Lakes Region and to the Democratic Republic of Korea. The missions use rapid field methods, described in a detailed set of "Guidelines for Crop and Food Supply Assessment Missions" (GIEWS 1997), to compile and check the reliability of local available information.

The scope and objectives of the mission vary. Although most teams are dispatched in the wake of natural disaster or civil war, assessments cover situations as diverse as sanctions in Iraq or macroeconomic shocks in Indonesia. Recently teams have been dispatched to evaluate the food security implications of strong El Niño events in Asia and Africa. Whatever the context, the teams will usually make an independent evaluation of the national food supply and demand situation, identifying the areas and population groups that are most at risk, and quantifying the requirements for relief assistance. In disaster situations, the teams assess the probable needs for rehabilitation or emergency support to the agricultural sector. The teams are often launched jointly with WFP. Representatives of donor agencies and NGOs have also participated on the teams. The reports are quickly compiled and dispatched to the GIEWS users, within ten days of the teams' return to Rome.

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2.5 Bridging the Response Gap

Early warning does not stop when the alarm bell is rung. The suggestion has even been made that there is a missing link between early warning and response. An information system can never be judged in isolation from the decisions that it supports. Although effective early warning is a prerequisite for timely/effective response, the two are not fundamentally linked. Early warning and response facilities are often housed in different offices or agencies. This is advantageous, as EW thereby maintains its independence and claims to objectivity. The downside is that EW systems, like GIEWS, have little direct control over the outcome.

While there is no way to guarantee that responses will be adequate and appropriate, GIEWS strives to ensure that the link is continuously maintained. Since its inception, it has monitored and reported on responses to food crises, highlighting areas where responses fall short of requirements and pressuring the concerned authorities to act. Strong working relations have been cultivated and maintained with WFP, the food aid arm of the UN, FAO's specialists on emergency agricultural sector support and rehabilitation and the donor countries. Tight GIEWS/WFP coordination help to ensure that reports and appeals for food assistance are consistent and well supported by up-to-date analysis.

There are several dimensions to GIEWS advocacy in the donor community. Part of the process is about cultivating and maintaining regular informal communications, aimed at increasing trust. Another important dimension is transparency – meaning that donors have a clear idea of why assistance is needed and how the requirements have been quantified. To this end, the GIEWS and GIEWS/WFP assessments are open for donor observers.

Regrettably, humanitarian concerns are often over-shadowed by political and resource concerns. GIEWS performs an important role in advocacy, through its regular reporting and through the news media, for all countries in need of humanitarian assistance, regardless of their political status. GIEWS has cultivated links with national and international news media groups. In recent years the media profile of the system has risen, expanding both the reach and the impact of early warning signals.

3 Giews' Technology and Methodology

This section describes some of the main technical and methodological features of GIEWS.

3.1 Technology

With the need to manage and analyse information from many different sources ranging from in-country reports to near real-time satellite images covering several continents, GIEWS, with funding and support from the EC, has developed an integrated information system known as the "GIEWS Workstation". Through the Workstation, GIEWS has developed, and now maintains, a unique reference database for early warning and crop monitoring with information pertaining to food security at global, regional, national and sub-national levels.

The Workstation provides access to these data through of a series of data display and integration tools, which are launched via an easy to use geographic interface. These tools include a map and image display module for the analysis and integration of map, satellite, and tabular data; a spreadsheet based application which provides up-to-date national level cereal balance figures for primary cereal crops; and a custom application used to display, archive, and redistribute news items within the service, obtained through the Reuters, Reuters Business Briefing, and AFP news services. In addition, GIEWS has recently developed an Internet based system called GeoWEB which allows users to view maps and satellite images from the GIEWS Workstation data base using only a standard Internet WWW browser. Though originally developed for use at FAO Headquarters, the capabilities of the GIEWS Workstation and its ease of use has prompted its adoption by other early warning units. (For details see Annex 1.)

3.2 From Drought Monitoring to Multiple Causality

In the past, early warning of food crises has focused, excessively perhaps, on hydro-meteorological determination. The historic bias reflects, in part, the availability of data. Remotely sensed data are perhaps unique in that they are

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available over a very wide area, at a high resolution, on a continuous and near real-time basis. It can also be attributed to a common, and outdated perception that drought, and consequent declines in production and availability, is the main cause of incidents of acute food insecurity.

Drought monitoring remains an important element of the day-to-day activities of the System, However, in the last 22 years, GIEWS has undergone a number of profound transformations in its thinking, towards an eclectic, multiple variable approach. To provide a truly global coverage, the System must be capable of assessing the food security implications of a variety of risk processes, hazards and shocks: economic, environmental and political. Annex 2 outlines some of the recent activities of GIEWS, to illustrate the variety.

3.3 From Availability to Availability-plus-Access

Expanding the types of process that we monitor is important, but not enough. There has also been a fundamental shift in views on the impact of risks, hazards and shocks on food security. For many years, the focus was on crop production and stocks and their influence on market supplies or subsistence availability. In the early to mid 1980s a consensus developed among academics on the need for a sharper focus on the issues of effective demand for and access to food, or "entitlements". It is now recognised that food crises are not necessary or directly linked to production shortfalls.

The movement in the thinking coincided with a shift in market structures. During the 1980s, in most countries of the developing world there have been radical changes to the ground rules, associated with sector reform in the context of Structural Adjustment Programmes (SAPs). The world has moved away from controlled economies and parastatal food market management, toward private markets. The parastatal mechanisms served (with varying degrees of inefficiency) to protect farmers and consumers from the vagaries of the world and domestic markets. With the demise of regulated food markets, we must consider a large number of market-related variables, and their impact on food security.

3.4 From Blanket to Target: the Need for Detail

From the late eighties onwards, there has been a decline in world food aid resources, reflecting underlying changes in price and stock policies in the donor countries. Food aid has become a scarce resource and donors are ever keen to see that it is used only when it is most needed. This has resulted in a move away from blanket programmes (more commonly known as dumping) towards programmes that target only the needy. There has also been a change in the thinking on food policies and welfare. A growing body of academics and practitioners is convinced that the experiments in national subsidies and supply side stabilisation of the 1970s were costly and misguided. Target programmes achieve more, at a lower cost. For early warning this implies that we need a much better understanding of whom is affected by food crisis, and why. Our concerns shift from the national to the sub national, and from the total population to specific groups. To this end, GIEWS has collaborated with Save the Children (UK), WFP's Vulnerability Assessment and Mapping Unit (VAM), and numerous national and international organisations, in an effort to reach a common understanding on the appropriate tools for localised food security monitoring. The process of developing and harmonising such tools is in its infancy and remains a priority for the coming years.

4 Concluding Remarks

A large number of variables contribute to food crises. Our understanding of the nature of food crises has broadened and deepened. Yet, the data resources for early warning remain patchy and inconsistent. There is a need for appropriate technology. This means that the developers of tools must be fully cognisant of the serious data limitations. The development of local capacity for collecting and processing early warning information is also a sine qua non of an effective global system.

Many of the papers presented at this conference focus on early warning techniques. Yet, effective early warning systems require much more than a group of experts, equipped with state-of-the-art technology. In GIEWS' experience, forging proactive institutional relations

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with users and information providers (many participants in the GIEWS network are both) is as important as technological development.

Appendix 1

The GIEWS Workstation: Information Technology Developed by GIEWS to Support Early Warning Analysis and Monitoring.

Appx. 1.1: Introduction

As part of its monitoring activities, GIEWS collects and archives information from many different sources ranging from in-country reports to near real-time satellite images covering several continents. GIEWS has developed a unique reference database with information pertaining to food security at global, regional, national and sub-national levels. In order to maintain this diverse information base, GIEWS, with funding and support from the EC, developed an integrated information system known as the "GIEWS Workstation". The Workstation is now recognised as a major contribution to the enhanced effectiveness of the GIEWS analysis and in the presentation of reports and alerts.

The Workstation is composed of a series of data display and integration tools which are launched through an easy to use, geographically based interface which runs applications linked to the appropriate databases. The Workstation includes (1) a map and image display module for the analysis and integration of map, satellite, and tabular data; (2) a spreadsheet-based application providing up-to-date national level cereal balance figures for primary cereal crops; and (3) a custom application to display, archive, and redistribute news items obtained from a variety of news services. In addition, the recently developed Internet based GeoWEB allows users to view maps and satellite images from the GIEWS Workstation data base using only a standard Internet WWW browser. These modules are described in detail below.

Appx. 1.2: The GIEWS Workstation Software

Appx. 1.2.1: GeoFile

GeoFile is the GIEWS Workstation interface, providing rapid access to information based on spatial queries of map layers linked in a hierarchical structure. It permits rapid overlays of baseline information in the primary information window and launches other Workstation modules for analysis of information at the level at which the spatial query is being conducted (i.e. world, continent or country). GeoFile can easily be modified to incorporate new modules and databases.

Appx. 1.2.2: WinDisp

WinDisp is the map and image display module of the GIEWS Workstation, and permits the analysis, integration, and overlay of digital map and satellite data in common windows. It simplifies the display of satellite images, maps and associated databases. WinDisp has several types of interfaces in order to provide varying degrees of automation.

Appx. 1.2.3: CCBS

The Country Cereal Balance System was designed to assist in monitoring national food production, stocks, trade and demand in all countries of the world, on a continuous basis. The system is used to store country level data on all aspects of supply and demand for nine cereal commodities. A cereal country balance spreadsheet, with the food supply and demand situation is available for each country of the world, is regularly updated by the country analysts.

Appx. 1.2.4: GIEWS News Utility

The GIEWS News Utility was developed to receive the digital news feeds from the Reuters' News Agency, Reuters' Business Briefing and Agence France Presse (AFP) news services. News items are transmitted to users on requested subjects and key words. Items can be viewed on-line, printed, copied to other data applications, saved in text files, transferred to other news files or deleted.

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Appx. 1.3: External users of the GIEWS Workstation

GIEWS has encouraged the use of the Workstation by other organisations. The Workstation software is freely available to all Early Warning and Food Information Systems in order to encourage data standardisation and exchange. The Workstation is easy to use, and can easily be installed on small LANs, desktops, or laptop computers. Several Workstation modules are available with English and French language interfaces.

The Workstation is being used at FAO Headquarters by the Africa Real Time Environmental Monitoring Information System (ARTEMIS) and the Dessert Locust Information Service. Several U.S. Government Agencies have been provided with the Workstation and have contributed financially to the enhancement of some of the software modules of the Workstation. These include the USAID Famine Early Warning System (FEWS), the US National Forest Service, and the US Geological Survey's EROS Data Center.

The SADC Food Security and Technical Assistance Unit has implemented the GIEWS Workstation on its computer network, and has provided WinDisp and SADC specific databases on CD-ROM throughout the region. The FAO "Regional Remote Sensing Project" support this effort and contributed funds to the enhancement of WinDisp.

WinDisp has been adopted as part of the Eritrea National Food Information System for the analysis of satellite images provided by the Eritrea Civil Aviation Department. It is also being used as part of a CD-ROM based course and self-study tutorial entitled "Monitoring of Crops, Rangelands and Food Security at National Level" (produced for developing countries by the Agriculture, Conservation and Environment Division of the International Institute for Aerospace Survey and Earth Sciences in the Netherlands). The French version of the Workstation in being implemented in the National AGRHYMET Centers in the nine CILSS member countries, with the implementation being coordinated through the CILSS AGRHYMET Centre in Niamey, Niger. The Ethiopia Disaster Prevention and Preparedness Commission (DPPC) Early Warning Department (EWD) in Addis Ababa plans to use the Workstation module for the analysis of satellite and digital map data as part of its information system being set-up with support from UNDP.

Appx. 1.4: Data and Software Exchange Agreements

Perhaps one of the greatest benefits offered by the Workstation project is the data exchange agreements which have been developed between GIEWS and other early warning systems and agencies with similar data needs. As georeferenced software and data are both very expensive and time consuming to develop, any collaboration and data exchange proves beneficial to those involved. GIEWS has established data and software exchange agreements with the WFP Vulnerability Analysis and Mapping unit, the CILSS AGRHYMET Centre, the SADC Food Security and Technical Assistance Unit, the USAID Famine Early Warning System, the USDA World Agricultural Outlook Board, and the US NOAA Climate Prediction Center. In addition, through Trust Fund project GCP/INT/535/EEC "The Riskmapping Project" digital mapping software routines and data for the Workstation were provided to support the SCF-UK Risk Mapping Program. GIEWS, with support from FAO ARTEMIS, has also brokered low-cost data purchase agreements for real-time satellite images over Latin America with US NASA, and are now working on an exchange agreement with the University of Tokyo for similar data over Asia.

Appx. 1.5: GIEWS Workstation Information on the WWW

The Workstation Project, in conjunction with a French Trust Fund Project, and the SADC Food Security Unit, have developed a comprehensive information base for all countries in Africa. These were derived from the GIEWS Workstation database, and are now available on the FAO GIEWS web pages. GIEWS is now working on expanding this information to cover Asia and Latin America. Several agencies have expressed an interest in having Internet based access to the database and analytical tools of the Workstation. This led to the development of a new prototype WWW interface known as GeoWEB, which provides access to Workstation da-

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tabases, and many of the analytical and display features of the GIEWS Workstation, using only a standard web browser. In addition to the GIEWS Workstation database, the system also maintains a database of "WWW links" which is organised by country and topic. This prototype has received favourable reviews when it was demonstrated at the World Bank, at two Inter-Agency Meetings on Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS), at a DHA-sponsored International Symposium on Emergencies Information Systems, and most recently at the 1998 Committee on Food Security held at FAO. As a result, some external agencies have discussed the possibility in allowing GIEWS analysts access to their internal web databases, in exchange for full Internet access to the GIEWS database.

Appendix 2

Illustration of some Recent GIEWS Activities

This is a small sample of the activities of GIEWS in recent years (Table 1). It serves to illustrate the diversity of situations in which the System operates. Although drought frequently raises its head, political and economic shocks are also of major concern.

Table 1. Examples of GIEWS activities 1991–1998

Date	Location	Activity
Dec. 1991–June 1992	SADC Region	GIEWS, together with FAO supported SADC systems, warned that an intense drought would lead to extensive crop failures. In April teams were dispatched to assess the crops at harvest time. They found that production had drastically declined and large imports would be required. The teams also warned of the consequences of insecurity along the crucial logistics corridor. The donor response was swift, and subsequent studies found that a major crisis had been averted.
1993	Burundi	Reports were issued that civil war and drought had resulted in a precarious food situation.
mid 1993	Kenya	GIEWS alerted the international community that drought reduced production and severe constraints to commercial import capacity would require large-scale international assistance.
1993	Brazil	A GIEW report explained how chronic poverty in remote northern areas had been exacerbated by a drought, which hit crop production and water supplies.
early 1994–1998	Rwanda	Shortly before the tragic events of May 1994, GIEWS warned that mounting civil war and localised drought could have serious consequences for food security. After the massacres teams were dispatched to report on the impact of massive death and depopulation on food production and food security. Follow-up missions have been launched every six months since then.
1994–1995	SADC	One again, many countries in the sub region faced drought and intense, if localised pest damage. The problem was identified well in advance of the harvest and relief resources were mobilised.
1995	Iraq	GIEWS drew the international community's attention to the disastrous consequences of sanctions for food security. FAO and WFP put pressure on the international community to increase the flow of desperately needed food imports.
1996–1998	DPR Korea	In late 1995 a GIEWS and WFP team conducted an evaluation of the impact of progressive agricultural and economic decline on food security. It was the first international assessment of its kind for many years, opening up the way for large-scale food assistance. Since then, reports and updates have been released at regular intervals, and teams have been sent every six months.
1998	Indonesia	GIEWS reported on the consequences of the "triple blow": high rice prices, macroeconomic/political chaos and drought, sending two missions to collect and review the relevant data.

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Early Warning and Geography: Space, Time and User Needs (Examples from Famine Early Warning)

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Abstract

An effective early warning system is one which provides sufficient information to initiate actions to avoid the impacts of a threatened disaster. The paper takes a critical look at famine early warning and considers how place, time and user needs define the nature and operation of an early warning system. Critical elements for improving the effectiveness of early warning systems include: defining who is the early warning system client; including the potential victim in the warning system; producing warnings which are understandable and useful; organizing data and analysis based on geographically defined requirements; clarifying early warning and response information responsibilities; and clarifying the criteria used to select countries or regions to be covered by famine early warning.

1 Introduction

Early warning receives a great deal of attention but can produce mixed results. The successful warning of drought in Southern Africa in 1993 contrasts with inaccurate warnings of drought and food shortages due to the recent El Niño event in the same area.

The problem is not just an African one. There were few public warnings about El Niño's impact on Indonesia's food security. Famine in Irian Java did attract attention, but so late that the only possible response was an expensive and not totally effective distribution of food. Only when the unrelated (but compounding) economic crisis developed did attention focus on famine and food security issues across all of Indonesia.

This paper is based on the premise that there is room for improvement in the performance of famine early warning systems. This position is based on field experience, although supported to a degree by research (Field: 160, Buchanan-Smith et al. 1992; Hussien et al. 1993)[1].

The purpose of this paper is to identify ways in which famine early warning can become more a effective and efficient part of efforts to deal with threatened famines and related food security problems. The approach taken is grounded more in experience than theory. As a basis for analysis, the paper considers famine early warning from a geographical perspective, looking at how place, distance, and human factors affect the way famine early warning should operate.

Those who run famine early warning systems do so under considerable constraints, and are often well aware of the limitations facing their systems. This paper is not intended to cast doubt on their commitment to make early warning work, but intended to contribute to making complex famine early warning systems work better.

[1] International Federation of the Red Cross...: 29–31 discusses some of the points raised in this paper from a slightly different perspective, and comes to some of the same conclusions.

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2 Some Observations on Famine Early Warning

2.1 Income and Famine Early Warning

Why do famine early warning systems cover some countries and not others? There seems to be a correlation between personal income and the need for famine early warning. Countries with high average per capita income are not covered by famine early warning systems. Some, but not all, of those with low per capita average income are.

One can suppose that, if fewer resources are available per capita, then external assistance can play an important role in dealing with threatened famine. The same lack of resources means potential victims cannot easily communicate a timely alarm of an impending famine. This, in turn, leads to the creation of externally-financed early warning systems, to raise the alarm early enough for famine-preventing assistance to reach the victims. Still, not all countries with low per capita income are covered by dedicated famine early warning systems.

Thus, the question arises why some low per capita income countries "qualify" for famine early warning and others do not. Is this simply a logistics issue: inaccessible poor countries need famine early warning to ensure timely delivery of assistance? Or are there other factors, such as governance, political systems, or donor policies, which "qualify" some countries for coverage but not others?

Answering this question is important, as in the case of Indonesia, where per capita average income has dropped dramatically and food security and famine are now serious problems. If Indonesia did not qualify for early warning coverage before the current crisis, should it be covered now? Is there a need for a system to warn of the possible need for famine early warning, so that famines do not develop out of sight of the exiting systems?

2.2 Just Warning?

Is famine early warning intended as a standalone warning system, or as part of a response operations information system? Saying there may be a problem is a lot easier than saying what should be done about it, and keeping up a flow of information over weeks, months or years.

An argument for keeping these two functions separate is that the credibility of early warning may be put in doubt if those doing the warning could benefit from the response. On the other hand, if early warning is kept separate from the response effort, the early warning systems are not accountable for their output.

A strong argument for combining early warning and operations information systems is that both use many of the same sources of information, methods and technologies. Combining the two is more cost-effective and allows for a more seamless transition from warning to response. As well, by linking warning with outcome, the warning effort becomes accountable.

And this may be part of the problem. Those supporting early warning systems, most often external parties, may not be able or interested in responding to every warning. In fact, Buchanan-Smith, et al., concluded that the lack of a response capacity, not the lack of early warning systems, was the greatest problem facing more effective famine response in parts of Africa.

Famine early warning systems do generally provide limited information about response needs, but it is often so vague as to be of limited operational use. Vulnerability assessment systems have been developed to bridge the gap between warning and response information requirements (see Boudreau for one approach). Unfortunately, these systems fall considerably short of the normal requirements for an emergency operations information system.

Whether better warnings and response would result from combining the two functions needs to be considered. From a field perspective, a system which only deals with the easier and shorter task – warning – is not all that useful.

2.3 Audience and Proximity

Who really is the audience for the early warning? For most famine-related events, those closest to the event are the first to become aware of a potential problem: after three weeks without rain, a farmer is the first to see that his millet crop is wilting. This farmer needs no "warning

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of possible moisture stress due to below average rainfall which might lead to food production shortfalls and possible negative impacts on local food security", as a typical early warning message might read.

In reality, most famine early warning messages are of little use for those closest to the problem. These people already know something is wrong. And are probably already doing something about it.

Is it too extreme to suggest that much of the current complex of famine early warning systems may have little direct relevance for potential famine victims themselves?

Indirectly, of course, famine early warning is a critical step in providing external assistance to help the (potential) famine victims. Thus, famine early warning remains important. But if this early warning is of more importance to the external actors who may be expected to respond to the warning than it is to the potential victims, how can one ensure the assistance triggered by the early warning is actually needed and wanted by the potential victims? A famine early warning system that triggers a useless response is no better than one that fails to trigger a response when it is needed.

The answer is that the views and requirements of the potential victims need to be incorporated into the early warning process. But accomplishing this in a system which may, in reality, be focused on external needs, is a major challenge.

2.4 Perceptions and Warnings

To be effective, warnings have to be understood. A common problem is that they are not[2].

This is more than a problem with technospeak. Often, those providing warning have a different view of the problem than those who are to be warned. A drought-affected farmer may be worried about finding work, while the early warning system is concerned with increased food prices.

There are several complementary ways to deal with this problem. One is to educate the potential victims about the meaning of the messages they might receive. Another is to formulate the messages using common terminology, even if this terminology is not always technically correct. A third approach is to reformulate the basis for developing warnings into one which reflects local perceptions of the potential problem.

Formulating understandable warnings is not much of a problem if the messages are only for external organizations, which share the cultural and social values of the system operators. Creating the message becomes much more complex when it is to be provided across cultural, social, economic and linguistic boundaries.

Providing useful warnings in the latter case requires a well founded understanding of perceptions and beliefs of those to be warned. This cannot be developed without contact with the intended recipients of the warning messages. It requires a relatively close linkage between the early warning structure and those to be warned. Whether famine early warning systems are capable, from a policy or operational standpoint, of developing these linkages is a significant question.

2.5 Lead and Lag

A common problem in disaster management is the lead-lag of event and response. Early in a disaster, events take place before they can be minimized or avoided through assistance efforts. As assistance increases, the gap between impacts and response is reduced to a point where the assistance leads impacts, ultimately putting an end to the emergent phase of a disaster.

The key to minimizing the lead-lag problem is having the right assistance at a potential disaster site before or as soon after the disaster begins as possible. The closer resources are to the disaster, the faster they can be activated and the quicker the lag minimized and the emergent phase completed. Resource mobilization can involve stockpiles and other resources. But it also includes the victims' own self-help efforts and resources, which are (logically) closest to the disaster.

However, this poses two problems. As noted, the audience for early warning systems may not actually be the potential famine victims. In this case, mobilization needs to be coordinated by

[2] See Parker and Handmer for an overview of literature on early warning messages.

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another system, with the risk that mobilization is delayed while this separate system is brought into operation.

Second, since the potential victim is close to the potential problem, the time available from warning to response is limited. If useful information is included in warning messages, they need to reach an area of operations quickly. This requires either high speed communications, if the warning organization is distant, or operation of at least part of the warning system at the level of the potential victims. The latter fits well with the concept of empowerment, but does not fit well with warning systems focused on external organizations, or ones divorced from response operations.

Again, the lead-lag problem raises questions about the usefulness of early warning systems. If the systems are to provide only warnings to external organizations, their overall role in addressing the lead-lag problem at the core of responding to famine is limited. If these systems are to have a greater usefulness, they need to devote more resources and effort to making the potential victim a partner in the warning process.

3 Improving Famine Early Warning

The point of departure on improving early warning is deciding: **Who is the audience?** In the case of famine early warning, if the audience is an external party, one must then address the question of: **Is the potential famine victim to be involved?**

If the potential victim need not be involved, then the early warning system can be a simple operation to determine if specific conditions exist which could lead to a famine. Once these conditions are met, further steps to address the potential disaster become the responsibility of a separate famine response operation.

Of course, the logic is strong for including the potential victim in the early warning system. Involving the victim, even if the system is primarily intended to initiate external assistance, has two major advantages. First, it serves to bridge (or at least define) differences in the external and local views of what may constitute a famine and what to do about the problem. While not all differences can be resolved, simply being aware of them reduces the chance that assistance will be triggered when it is not needed, and that unrealistic expectations do not develop due to a lack of communication between victims and assistance providers.

Second, including the potential victims in the early warning process provides a "reality check" between events on the ground and what is being reported by the warning system. This is important, as no warning system is 100 percent reliable. But this is also a two-way street: external parties can use the connections to verify information from third parties, as well as receive feed-back from the potential victims. This connection across space serves to improve the overall credibility of the early warning process and the quality of any resulting assistance effort.

If the potential victim is part of the early warning process the system needs to **produce messages which are understandable and useful.** Doing this means understanding the perceptions and expectations of the potential victims, as well as delivering messages in a timely manner.

But the early warning system needs to go beyond the "it has not rained" type of message. Messages need to include information which supports the victim's own efforts to deal with the potential famine. Messages should focus on the practical, whether it be job opportunities or options for short term migration.

Whether or not the potential victim is involved, data and analysis for the early warning process need to be **based on time and space defined requirements** (Kelly). It is a waste of effort for a system serving external parties to focus on activities which cannot be implemented because critical information arrives too late or external organizations are too distant from the operations area to undertake action in a timely manner.

Similarly, there is a need to **clarify early warning and response information responsibilities.** Making early warning a module in the overall famine response effort makes sense. The combination is an efficient use of resources. The channels of communication with the potential victims, key to the operation of an effective response system, are a means which can be used to minimize any manipulation of the early warning process.

Keeping early warning and response separate may be mandated by those who fund a system.

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In this case it should be clear that the resulting early warning system has limited use and only a passing role in responding to a potential famine. In this situation, beefing-up early warning without a corresponding strengthening of response capacities will not contribute significantly to addressing the problems posed by famine and food insecurity (Buchanan-Smith, et al.)

Finally, there is a need to **clarify the criteria used to select countries for coverage by famine early warning.** It appears that, in most cases, a country only "qualifies" for famine early warning once it has had a famine. This "once burned..." approach may be effective the second time around, but places famine early warning in a reactive context. And reactive famine early warning is probably not very useful if the real intent is to assist potential famine victims avoid disaster.

4 Summation

This paper has identified several important issues in the operation of famine early warning systems and suggested how the process of famine early warning can become more effective and efficient. In each of the five examples an effort was made to look at famine early warning as a spatial event, where place, distance, time and human factors affect the way famine early warning should operate.

The resulting recommendations on improving famine early warning also focus on spatial issues. These recommendations can be summarized as suggesting that: (1) early warning needs to be better integrated into famine response and (2) have a closer link with the potential famine victims.

This second point needs equal billing with improving the mechanics of famine response. It seems that much of the complex of famine early warning systems do not systematically incorporate feed-back from the objects of the systems, the famine victims themselves. This lack of victim involvement flies in the face of the concepts of empowerment and working with the disaster victims (see International Federation of Red Cross...:145–146). Without bring the human factor – the victims – into famine early warning, there is little prospect that other steps to improve famine early warning will have any sustainable impact.

Finally, the degree to which the suggested improvements in famine early warning also apply to other types of disaster early warning needs to be considered. On the one hand, famine early warning may have developed in a special context and has little in common with, the little to learn from, other early warning activities.

This view ignores the global reach of famine problems and the similarities of the spatial challenges – place, distance, time and human factors – which define famine and other early warning efforts. Famine early warning clearly has things to teach, and learn from, other early warning systems. Geography provides a useful framework within which this learning and sharing can take place, to the ultimate benefit of the victims of all types of disasters.

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Agrometeorological Information System for Mitigation of the Effects of Drought in Hungary

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1 Introduction

Drought can only be considered as a relative phenomenon which originates from precipitation deficiency and occurs in high as well as low rainfall areas. Drought is a normal and recurring feature of virtually all climate regimes affecting most countries to some degree. Drought differs from other natural hazards. It has a slow onset and it is often difficult to define the boundaries of the affected area or its severity. Furthermore the impacts of drought are less obvious, often occurring in several economic sectors and in larger geographic areas.

Since the affected areas are very different, several drought definitions have been developed and applied, which can be grouped into the following types: meteorological, hydrological, agricultural and socio-economic. While meteorological drought is expressed solely on the basis of dryness or precipitation deficiency, the other definitions are more concerned with the effects on water flows, agriculture or economy and society; reflecting the fact that impacts of drought are not limited to agricultural production but other sectors of the economy such as water management systems, transport and industry can also be affected.

In dealing with drought issues it is crucial to be able to quantify drought severity. For this purpose several drought indices have been developed. Every drought definition has to be region specific since atmospheric conditions are highly variable from one area to the other. On the other hand, however the need for comparative drought measures resulted in more general indices and definitions which in turn produce comparable values in every region.

2 Severe Droughts in Hungary in the Last Decades

Since the beginning of the 1980s Hungary has witnessed the occurrence of spell of intense droughts, which caused significant damages and losses to the Hungarian agricultural sector. According to records and observations, the longest dry spell in this century happened between 1983 to 1995, and only few years, like 1986 and 1989 can be regarded as years when temperature average and precipitation amount and seasonal distribution were close to normal. Although 1996 and 1997 happened to be a cold and very wet year, the period 1983–1995 still remains the longest dry spell in history. By the way the last winter and early spring has one of highest temperature and lowest precipitation values.

The significant droughts of the late 1980s and 1990s coincided with political and economic changes and the transition of the economy

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from a centrally planned system to a market-based economy. This structural transformation occurred also in the agricultural sector, characterised by the break-up of small family farms and cooperatives and an increase in the number of small family farms. The productivity of agriculture was further affected by the governement reduction in state support.

3 Change in the Frequency of Hungarian Drought Phenomena

Since drought occurs in high as well as low rainfall areas, rainfall amount alone is therefore not an adequate measure of drought. The Palmer Drought Severity Index (PDSI) is one of the best-known and popular measures of meteorological drought (Palmer, 1965). It is based on the average hydrologic accounting and relates the actual situation to the long-term average and can be used to evaluate both dry and wet conditions. Although it has limitations, it is a useful technique for tracking long-term moisture anomalies and for evaluating drought frequency. It is a standardised measure of water availability, thus the values of different locations are comparable. PDSI values generally range from a +4.0 (extreme wetness) to –4.0 (extreme drought).

Szinell et al. (1998) at HMS have concluded a thorough analysis of drought characteristics in Hungary. A long series of PDSI values (more than 110 years) have been calculated for fifteen stations in Hungary. The following categories were applied to evaluate drought severity: drought is moderate if PDSI values <–2 extends over more than 50% of Hungary, severe if these values are PDSI values <–3 extend over 33% of the country, and extreme if PDSI values <–4 cover at least 20% of the nation. These categories, while somewhat arbitrary, were selected because more serious droughts have a lower probability of affecting larger areas. The values show that moderate and severe droughts occurred almost continuously during most of the 1980s and at the beginning of the 1990s. Wilcoxon test was used to detect whether or not the occurrences tend to concentrate at the end of the tome series. The results of this test clearly show that all three categories of the test statistics have significant values. This indicates that droughts occur more frequently in the recent period. However, the occurrence of extreme droughts is less frequent, although their concentration in the 1980s is clear (Fig. 1).

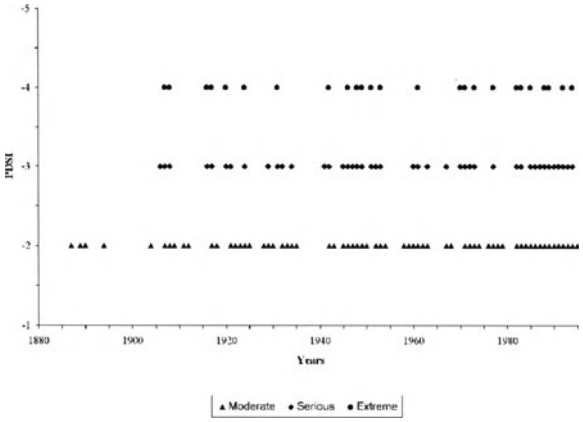


Fig. 1. Droughts in Hungary

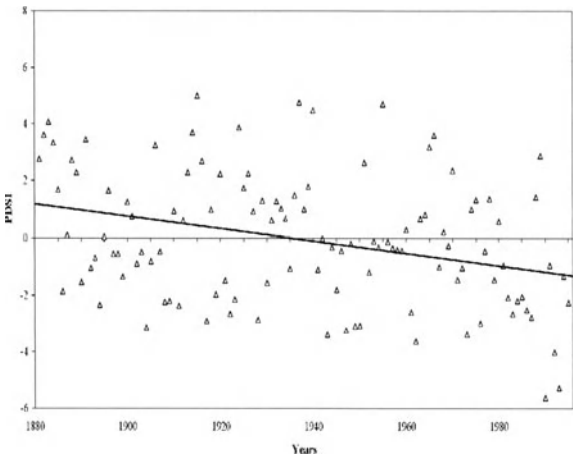


Fig. 2. PDSI values in August at Budapest

A linear trend line was fitted to the PDSI values to explore the overall tendencies. We found that all the stations are undergoing a general drying tendency for a given month. This tendency is proved by the significant decrease in PDSI values, which ranged from –1.3 to –2.4 PDSI/100 years. One example is presented for Buda station in Fig. 2.

Despite the great variance, all the cases were significant at 1%, and this resulted in the fact, that the mean value was shifted from a slight water excess to water shortage. Results show a scarcer occurrence or even a disappearing of wet and extreme wet years. In the case of Buda-

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pest the three smallest value (August, 1990, 1992 & 1993) occurred during the last five years. Briffa et al. (1994) in their analysis indicated similar results within the Danube basin, the PDSI values display a decreasing trend (i.e., a drying tendency).

4 Danger of Climate Change

One possible consequence of the prospected climate change is the change in the frequency of extreme meteorological and climatological events of which drought is one. The slow onset of drought makes its recognition and location more difficult and often hampers appropriate actions. Most of the time, droughts result in significant economic losses in particular areas. It is, therefore, advisable to encourage monitoring of drought, preparedness and vulnerability studies regarding drought impacts.

5 The Challenge of Increased Drought Frequency

5.1 Infrastructure Development at the Hungarian Meteorological Service (HMS)

Significant developments in the infrastructure of the HMS took place over the last years. The spread of automatic weather stations, computer networks, workstations and the appearance of data archive based on ORACLE and its coupling to our GIS system, the revolution in the quality and quantity of weather forecast provide a good background for the early warning of drought. This year an experiment on the usage of long range forecasts for an early prognosis of drought was initiated. The automatic weather network serve not only the problem of drought but help to identify other extreme meteorological events and disasters (high precipitation, flash floods, storms...).

This well detailed weather information and the development of an agricultural weather information delivery system is imperative to help farmers cope better with climatic hazards, with special emphasis on drought. HMS decided to continue investigations to find the appropriate field for implementation of different drought indices. I was then decided to alter and improve the agrometeorological information system of HMS. Efforts were made to increase the international cooperation in the field of drought. HMS gives priority to providing well detailed drought information (spatial distribution, intensity, possible damages) to the decision makers as well to the producers.

5.2 Cooperation with the National Drought Mitigation Center (NDMC)

Given the changes in the Hungarian economy and increase in drought frequency, it is extremely important that substantial changes in the Agrometeorological Information System be implemented. The HMS began reorganising this system and, in 1995, initiated a cooperative project with the NDMC located at the University of Nebraska-Lincoln, USA.

A further goal is the development if a drought management plan as a management tool for drought mitigation. These drought preparedness plans are being developed in several states of the USA (e.g. Wilhite 1996, 1997) and have been shown to be an effective way to reduce the impacts associated with drought. In this effort, application and adaptation of international experience will be most efficient.

5.3 Comparing the Drought Indices

It is also important to evaluate the performance of several drought indices in a drought situation, for which comparative case studies can be accomplished. The evaluation includes the index potential for use in early warning conditions and identifying the different effects of drought on hydrological features, ground water table, yield and state economy. Several drought indices like PDSI, Standardised Precipitation Index (SPI) were compared with several time scales, relative soil moisture and evapotranspiration and precipitation indices. The Standardised Precipitation Index (SPI) was also used, since the SPI has been widely applied at national, regional, and local levels throughout the United States. One of the big advantages of the SPI is its multiple time scale capability that allows monitoring of different water resources.

Time series of the SPI at different time scales and locations are examined and compared with

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the Palmer Drought Severity Index. Although the PDSI has no official time scale, its highest correlation is with the 6–12 month SPI in the territory of Hungary. The three indices: soil moisture, evapotranspiration and streamflow appear to be most related to the 3-month SPI. Other hydrological components, such as reservoir and ground water levels, are correlated with longer SPI time scales. Meanwhile the calculated soil moisture and evapotranspiration indices also correlate well with streamflow levels, which illustrates why a combination of indices are important as part of a drought monitoring system. By the way the relative evapotranspiration shows a high connection with the yield of several cultivated plants. It appears necessary to use more drought indices to get a real picture of a given situation. We hope to find some objective thresholds of drought indices for evaluation and analysis of the given situation, probable dangers and damages assessment and in the near future.

5.4 Reorganisation of Agrometeorological Information System of HMS

With the increased number of farms, it became difficult to disseminate agrometeorological information to producers in an efficient manner. Furthermore, these private farmers were not well acquainted with the products of the HMS. With the changes that have taken place in agriculture in recent years, it has become apparent that the method of disseminating information to farmers must be revised. Two ways being considered are: (1) development of a village advisory system that would be maintained by the Hungarian Ministry of Agriculture (HMA) and (2) creation of an irrigation advisory system, also partly supported by the HMA. This second approach may be a more viable option because the provided information is closely related to irrigation planning.

Provision of agrometeorological information was initiated in 1969 by the establishment of the Agrometeorological Bulletin issued by the HMS. This bulletin was issued for ten days periods and was disseminated by post. Recently, a new structure in the information delivery system has been implemented. The form of the Agrometeorological Bulletin has been changed. It was formerly distributed as a printed document. It is now mainly distributed by fax. Users call an automatic fax machine that sends out the four-page Bulletin. Payment is made via the increased phone bill. Another way to distribute the Bulletin is via BBS lines, but HMS still additionally sends out printed copies.

The content of the Bulletin includes a report on drought, forest (and agronomical) fire risk as well as plant diseases information. However, we also intend to include additional information on plant phenology and crop protection. The content is flexible according to the actual situation. Soil moisture and relative evapotranspiration maps are available for inclusion which can serve as valuable information for irrigation planning in dry conditions.

Our intention for the near future include initiating acooperation between the HMS and irrigation advisors. Within this framework, the HMS would provide information that would be used in irrigation management as a tool to assist in the mitigation of drought impacts. Farmers can learn to cope better with drought through the application of appropriate and timely irrigation advice. This service would include provision of calculated evapotranspiration, fiels capacity – actual soil water content, crop water requirement and crop coefficients to the irrigation advisors on a daily basis. Possible ways of disseminating this information is via fax or Internet.

6 Help to Decision Makers

Policy responses of governments to drought can be classified into three broad types: pre-impact programs to mitigate the future effects of droughts (e.g. early warning system), post-impact reactive actions by governments in response to the occurrence of drought and finally the preparedness plans, which are intended to reduce the long-term vulnerability to drought and are usually developed on larger (national) levels. Until recently, there has been little effort devoted to preparedness, the reactive approach has been preferred. It would therefore be useful to collect ideas and applied methods which could then augment the variety of actions already known by national services.

More recently it has been emphasised that the study of drought problems should also incorporate its impacts on the economic and so-

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cial systems and underline the fact that the importance of drought lies in its wide-spread impacts. Because of the diversity of these impacts, they are difficult to quantify, although the policy makers and decision makers need to have information on the possible and anticipated consequences of the actual situation. Therefore a study should envisage the different aspects of drought and evaluate their probable impacts on the basis of their result. It should then incorporate meteorological, hydrological and agricultural accounting and description of the actual situation from the point of view of their possible consequences.

HMS could supply several forecast and agrometeorological information which could be used as early warning in the politics. Nowadays HMS are able to give detailed information to the decision makers: analysis of present weather situation, soil moisture conditions, short or medium range weather (precipitation) forecast, drought indices, irrigation water demand, forest fire (ignition) indices, yield forecast for maize, wheat or potato and some information on the possible altering in height of the water table (wells), surface streamflows.

7 Conclusions: Committee for Coordination of Drought Mitigation

The complexity of the drought phenomenon commonly results in lack of coordination, although numerous coping strategies are known and applied. Drought is an extreme climaticologic event which affects many sectors of a nation's economy. Therefore, much scientific inquiry has been dedicated to drought-related research (e.g. Wilhite 1992; Riebsame et al. 1991). HMS plan to call into existence a Drought Coordination Committee to increase the cooperation among the policy makers (ministries), research centres, hydrological institutes, water authorities, rural development institutes, universities, and the academy of science. This committee could help to work out and find the common political intention and scientific tools for anearly warning system and to mitigate the effect of drought. On the other hand the committee could coordinate the information dissemination in a wide extent to all affected groups of society.

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CHAPTER 4.25

Early and Dynamic Warning: An Integrated Approach to Drought Management

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1 Warning Integral to Disaster Management

Natural disaster management strategies view warning as a basic component. The limits of warning can be determined only in the context of the essentials for response to a disaster. Warning, in the case of drought, serves no purpose if it does not encompass the various manifestations of drought impact. As is well known, drought is a continuously evolving condition, spanning a time frame comparable to no other disaster. In most cases, its onset is gradual and its impact extends beyond the period and place of occurrence. The temporal and spatial dimensions of drought govern the warning process as well as effort. The timeliness of the warning in a drought situation can result in the desired outcome, only if the content of the warning is relevant to the sectoral concerns unfolding at the ground level from time to time. An integrated approach is thus called for in the establishment of warning systems for drought management.

2 Determinants of Warning

Let us briefly turn to the determinants of effective warning; namely, content, purpose, target and means. Warning is not merely to inform about the probability of occurrence of a disaster but also to prepare the society to meet its impact. Therefore the content of the warning must be related to the many manifestations of drought impact such as food scarcity, declining incomes and drinking water shortage. The purpose is obviously to trigger response initiatives. The warning message has to be targeted towards sections of society, who have to gear-up for the challenge. The appropriate channels are the institutions, procedures and methods by which the warning message can reach the targets. *It is, thus, evident that the dimensions of disaster impact determines the framework of the warning systems.* In order to establish an effective and meaningful warning system for drought, it is, therefore, necessary to have a clear insight into the occurrence and the impact of drought.

3 Dimensions of Drought

Unlike sudden onset disasters, drought has certain peculiar features. It has spatial, temporal and situational dimensions in its causation, vulnerabilities, impact and response management. Drought can be viewed as a condition created by an abnormal lack of water impinging upon the normal water needs of a society to support life systems, comprising plants, crops and living creatures. It can be:

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- meteorological – caused by the lack of rain or precipitation.
- Hydrological – caused by the absence of water, surface and ground water or,
- agronomic – caused by a disruption to agricultural operations due to an absence of rain/uneven distribution of rain/prolonged dry spells/pest & disease attacks on plants and consequent loss in agriculture output.

Commonly, drought, to a meteorologist, reflects a deficiency of rainfall in relation to the normally expected value in a season, a month or even a week and to an agricultural scientist, it implies inadequate moisture for the plants affecting their growth precipitated by insufficient rainfall and adverse evapotranspiration. Crop failure is a concomitant of drought conditions and this may be caused by the hydrometerological behaviour in a local area or outside, in the catchment of any irrigation system feeding that area or due to ecological phenomena. As such, could a warning system for drought be focused on local development or phenomena only? Certainly not, the spatial dimensions of causation must be taken into consideration in the formulating of the warnings.

The temporal dimensions of the event relate to the climatic behaviour within a growing season, its historical behaviour prior to the relevant time, the contiguity of drought spells and development in the area. The extent, timing and the dispersal of precipitation are equally important in determining failure of different crops. The resource endowment of an area such as soil fertility, irrigation, land use, cropping and farming systems inform the contours of vulnerability. The status of irrigation and communication infrastructure, the generation of skills and employment opportunities etc. influence the drought impact. A clear appreciation of the vulnerability aspects of drought would be a prerequisite to set the framework and parameters of the warning system.

4 Drought Impact

The impact of drought on a society depends on the level of development. With a highly resilient agricultural sector, the impact of drought could be significantly reduced to prevent a substantial decline in the living conditions of a society. The pace of recovery is also determined by the status of economic development. The impact of drought is multidimensional and encompasses primary and secondary efforts. Primary effects are, (1) decline in food availability, (2) impairment of the quality of life due to adverse conditions such as to drinking water, health, nutrition etc., (3) impairment of agricultural economy, (4) loss of plant and animal life, and (5) environmental damage. Secondary effects are, (1) economic loss, (2) indebtedness of vulnerable groups, (3) depletion of resources, physical and financial, for future economic activity, (4) population shifts.

Depending on the particular vulnerability of different sections of society, the drought impact varies. Further the variability of causative factors over time and space has a tremendous influence on the degree of drought impact; since the main impact of drought conditions are on agricultural and allied activities, the duration between two seasons and the contiguity of drought occurrences contribute to the severity of drought. It is, in this context, that the long-term warning messages could mould and strengthen response initiatives.

5 Response Management

The response management is three dimensional with measures for:

- reducing the vulnerability of area and population,
- reducing vulnerability of the economy, and
- strengthening social structures.

An effective and comprehensive drought management strategy has to strive for, (1) stabilisation of crop production and farm activities, (2) promotion/sustenance of non-farm activities, (3) preservation of resources and physical assets such as cattle for future agricultural activities; (4) improvement of infrastructure, (5) maintenance of quality of life through provision of drinking water, health and nutritional services, and (6) ensuring flow of income to affected population.

These initiatives translate into concrete measures such as:

- contingency crop planning and supply of seeds,
- water budgeting,

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- mobilisation of resources/effort for better utilisation of water, surface & underground,
- provision of drinking water,
- nutritional assistance,
- fodder development and animal health care, and
- improvement of community resources such as percolation tanks, irrigation works, roads, forests etc.

6 Integration of Sectoral Warning Messages

For the fulfilment of these objectives, the drought warning system should encompass specific sectoral warning systems to provide the necessary input for the formulation of response. Sectoral responses need different lead times which have to be taken into account in an effective warning system and, therefore, provide for integrated messages.

7 Early Warning – Long-term Issues

The commonly held perception that warning is only in respect to an imminent event is not appropriate in the case of drought. The vulnerability of an area to drought is not merely the consequence of events in the immediate term but also of developments in the longer term. Focus on longer term aspects is equally crucial for determining the drought – proneness of areas. One could argue that initiatives in this realm will be subsumed in the developmental thrusts of a society; this may or may not be so. If this argument is inevitably true, there would not have been any need for the declaration of the IDNDR! In the world of competitive demand for resources, drought management concerns need to be continuously articulated to invite appropriate interventions. In this context, the importance of warning systems cannot be exaggerated. Institutional arrangements for long-term monitoring of climate changes, land use evolution, environmental degradation, irrigation development, groundwater exploitation, health and nutritional status, diversification of economic activities and institutional development have to focus on present and emerging vulnerabilities of areas. Periodical findings of research institutions in the field of agriculture, climatology, hydrology and health provide the necessary insight and inputs for the intervenors to formulate measures to counter vulnerability.

To illustrate the point, Indian experience has shown that area development on watershed basis reduces the production loss under drought conditions by 50%, increases crop productivity by 50 to 100% and improves the surface water availability and ground water storage. Similarly environmental improvement and farm rain management practices, such as contour bunds and inter-bund land treatment and mulching, would result in improved and extended availability of moisture to the crops in dry-lands. Changeover to less water consuming crops, adoption of drought-resistant and shorter duration varieties, changes in the soil fertility profile and land use, have implications for reduction in drought impact. The warning system should therefore have to reckon with these changes over time.

Long term climate behaviour has implications for agricultural activity and cropping pattern. Changes in the pattern of precipitation and temperature gradients would warrant agronomic changes. Since precipitation and its distribution determine the moisture availability at different phenological stages of crop growth, a proper assessment of changes in these factors would help in reducing drought vulnerability of areas by evolving suitable cropping systems and practices. Meteorological observations, remote sensing imageries and land use surveys contribute to greater appreciation of the changes and provide insight into the unfolding scenario as to drought vulnerability. It is not only in the acquisition of such scientific knowledge but in the application of such inputs by a society that assures for the success of a warning system in ushering proper response.

The status of ground water use and scope for further exploitation and availability of drinking water constitutes legitimate concerns of an advisory on drought proneness. Periodical assessment of emerging health and nutritional vulnerabilities are necessary to determine the interventions to mitigate drought impact on the affected population.

Ecological changes in the area and vicinity, and environmental phenomena have bearing on vulnerability to drought and deserve long-term monitoring and evaluation. Environmental degradation over time is closely linked to the onset of drought conditions in various parts of

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the globe. The drought – induced famine in North Africa is more attributable to desertification of Sahel, since there is no evidence to suggest a decline in rainfall over the past 100 years. Deforestation reducing the recharge of subsoil water contributes to moisture stress in soils thereby creating drought conditions in the Caribbean Islands and Haiti. The US 'dust bowls' in 1930s are believed to have been caused by the spread of wheat farms on prairies of Great Plains. In Soviet Union, the substitution of cereal crops for the natural ground cover of the Central Asian steppes in 1950s led to desertification and drought in the mid 1960s. Despite the very high precipitation for about 6 months in a year, the foothills of Western Ghats in Kerala in India experience water stress in post winter period, mainly because of deforestation and tea plantations and the consequent reduction in the soil absorption of surface flow. Geo-environmental studies would provide the necessary warning of emerging drought proneness of areas in relation to stability of food production and economic activities and water availability.

8 Early and Dynamic Warning – Short-term

It is more in the realm of current concerns that the efficacy of warning systems gets tested as to timeliness and accuracy. The multidimensional impact of drought necessitates special arrangements for warning of risks and challenges in different sectors. The prime concerns in a drought situation relate to agriculture, drinking water and income distribution to the affected population. Drought is a gradually unfolding disaster and its impact can change dramatically depending on the rainfall pattern. Agricultural operations and choice of crops are adopted to this pattern. Irregularly distributed precipitation and long dry spells rather than slight variations in the quantum of rainfall are more likely to affect crop production. A prolonged early dry spell following summer could cause severe water shortage and fodder scarcity. Late rainfall in a cropping season could provide hopes for a food crop in the succeeding season or remove drinking water shortage. Meteorological forecasts should, therefore, provide clues to climate or rainfall behaviour over the entire cropping season; the medium and short term forecasts covering dry spells and nature of precipitation could guide agricultural operations such as sowing and fertiliser application and facilitate undertaking of contingency measures to save crops from moisture stress. Accuracy of these forecasts would determine the effectiveness of contingency crop planning. Short term meteorological forecasts spanning homogeneous regions help in a rational use of irrigation and ground water and in budgeting the available water for sustaining various crops and different uses.

The conditions of crops and their failure are largely determined by the rate of evapotranspiration in different areas. Data from centres monitoring this phenomenon and remote sensing imageries are used to know in advance the condition of crops and emerging drought impact and help undertake emergency interventions such as priority in water allocation and enhancing ground water exploitation.

Early warning systems tend to focus on meteorological monitoring and food security surveys. But as already pointed out, other sectors also need attention for effective monitoring. Independent monitoring of surface and underground water bodies helps in the assessment of water availability and in its allocation for different purposes. Monitoring of prices of commodities in different markets, sale of cattle and incidence of rural indebtedness help forecasting the emerging scarcities of food and fodder, needs for support to income generating activities and for employment generation. Increase in the number of cases of illness reporting at hospitals would highlight nutritional deficiencies and health hazards facing a community and call for immediate intervention. Crop outrun estimates, mid-season and end-season, help in the assessment of severity of impact in an area and determine the need for income generation initiatives.

If compensatory cropping programmes and fodder availability enhancement programmes are to succeed, availability of input such as energy and petroleum products and seeds would have to be ensured at very short notices. Success in these area is possible only through streamlined sectoral arrangements for monitoring and forecasting emerging scenarios on real time assessment. Where the long range forecast points to the possibility of drought incidence, agencies/authorities in different sectors would

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need to be activated to monitor developments and report on emerging abnormalities. These could, then, be evaluated and formulated into a warning, if there is imminence of drought conditions or an alert to usher in precautionary initiatives. The multi-disciplinary monitoring has to be continuous and make real time assessments to focus on emerging challenges like particular crop failure, fodder or water scarcity food insecurity and to provide advice on contingency measures such as crop substitution, fodder development, nutritional supplementation and prophylactic health measure.

To sum up, a drought warning system will have to monitor, and make projections as to:

- Rainfall and climate behaviour, long, medium and short term,
- Agronomic assessment of evapotranspiration and crop condition,
- Status of surface and underground water bodies,
- Drinking water availability,
- Movement in commodity prices,
- Migration of labour,
- Rural indebtedness and employment situation,
- Incidence of illness and malnutrition reflected at hospital,
- Availability of agricultural inputs, energy and petroleum products, and
- Fodder availability, cattle migration and cattle sale.

9 Timelines

Warning is timely if it provides enough notice for streamlining response, it is dynamic if it relates to the changing profile of challenges over time, whatever be the span. Premature warning might detract from automatic institutionalised response to emergencies and result in the denial of an opportunity to recover if drought situation improves in a subsequent period. A very early warning might provide labour migration from an area too early; this may jeopardise agricultural operations for compensatory crop production, rendered possible by subsequent late rainfall. The political and social implications of warning of drought highlight the need for circumspection, objective procedures, and a proper evaluation of scientific inputs and objective data.

10 Institutional Arrangements

Institutional arrangements could provide the frame work for formulation and dissemination of warning. The political and administrative set-up of countries would dictate the nature of such arrangements. Generally, these should provide for a multi-disciplinary body with the participation of all sectoral agencies of monitoring developments prior to drought occurrence and those involved for response management; this body will be responsible for receiving information and issuing warning advisories. The other imperatives would relate to control rooms at various levels during the vulnerable period, designation of nodal authorities for coordination and a stream lined management information system.

11 Indian Experience

An integrated approach towards long term and short term content of drought warning has been evolved over time in India, and has contributed to the success of drought management. It will be useful to dwell on some of the elements of these strategies to provide a direction to the establishment of suitable drought warning systems elsewhere.

11.1 Drought Reduction Initiatives

Integral to the drought management strategy is the identification of drought vulnerability of areas. Based on the findings of a National Commission on Agriculture, India launched a Drought Prone Areas Programmes to build up the resilience of such areas. Over a period of time, several programme such as afforestation, creation of irrigation works, evolving drought-resistant varieties of crops and introduction of appropriate cropping systems, special nutrition programme and employment generation of agricultural labourers have been initiated. To improve dry land agriculture and the capacity of marginal lands for this purpose, watershed development programmes have been launched. The emphasis in drought relief employment has been on the creation of drought-proofing and community assets. Diversification of economic activities was encouraged through special assis-

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tance programme targeted at small farmers and agricultural labourers. Of particular significance are the promotion of dairying and poultry activities, which have contributed to the stabilisation of rural incomes. Agricultural research stations and agricultural development centres (Krishi Vikas Kendras) provide an early view of emerging vulnerability and suitable response at the local level; these institutions further provide assessments of crop condition and recommendations on contingency measures. A standing mechanism of the Central Water commission at the national level and similar arrangement at the state (regional) levels provide the necessary insight into the hydrological aspects and warning as to long term and short term measures. Decentralised administration and devolution of funds make local initiatives possible.

11.2 Dynamic Warning

The approach adopted by the Indian Government in managing the 1987 drought fully exemplifies the virtues of the dynamic warning mechanism. The main cropping season in the country depends on the South West monsoon from June to September, when nearly 70% of the total annual precipitation is received. When the long-term meteorological forecasts of drought were received in May, 1987 the national Govt. commissioned reconnaissance visits by Senior officials to make an early assessment of emerging challenges. It formulated an Action Plan of contingency measures including alternate cropping strategies, water budgeting, seed supply, fodder development, nutritional supplementation effort etc. The major concerns at this time were saving of sown crops and fodder on account of continued dry spells forecast. A committee of high powered experts continuously monitored on a weekly basis the ground level situation throughout the country and put out warnings of emerging problems and advisories on contingency measures. When meteorological forecasts hinted at rains later in the monsoon, initiatives for compensatory fodder development and crop production programmes in the post monsoon period were quickly undertaken. This helped in restricting the decline of 3% in the annual foodgrains production realised in 1986–1987. Warnings about declining reservoir levels led in August 1987 to an acceleration of programme of energisation of pump sets and focus on supply of petroleum products for undertaking, on a wider and intensified scale, ground water exploitation for saving crops and avoiding a drinking water scarcity. Acknowledgement of the inability of normal agricultural operations to employ labour on account of continued dry spells and feed backs on distress situations provided timely warning to authorities to commission employment generation programmes in needy areas from August 1987 itself as against January, when needs for real employment normally manifest. Simultaneously, the need for augmenting food supplies was addressed through the public distribution system and regulated releases of buffer stocks of essential commodities.

The dynamic monitoring and warning mechanisms helped in preserving the essential economic and social fabric of the rural areas that the country could realise a record winter agricultural production and recover sufficiently quickly to register a significant growth in agricultural production in the subsequent normal monsoon of 1988.

12 Conclusion

Thus, the complex and multidimensional impact of drought warrants a clear understanding of the parameters of warning relevant to an area. The spatial and temporal dimensions of drought impact necessitate an integrated warning system, monitoring and assessing developments. Since the objective of warning is to provide inputs to response management, continuous evaluation of emerging challenges and occurrences is necessary for providing real-time input to intervenors to structure and modify initiatives for mitigation. To achieve this, apart from sectoral agencies, there is a need for a central/coordinating arrangement to assess and formulate timely and specific warnings and disseminate the same for effecting proper response. Horizontal, spatial and temporal integration of monitoring and warning activities and real time reassessment of feed back would be integral to an effective drought management strategy.

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IVd Monitoring and Early Warnings Related to the El Niño Phenomenon

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Monitoring and Early Warning Systems Related to the El-Niño Phenomenon – An Overview

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The presentations in this followed the given outline, except for the last presentation by Akentyeva and Kobysheva on 'climatic forecast of natural disasters and calculation of hazard of damage to economics' which could not be given since the authors did not attend the IDNDR Conference. Thus all presentations were invited presentations, focussing on the breakthrough in seasonal climate variability predictions. For the first time, mankind can use physically based predictions of climate variability that are probabilistic but have useful skill up to several seasons ahead especially in areas affected by the El-Niño/Southern Oscillation (ENSO) phenomenon. The first presentation, by the convenor of the session, highlighted the basis of this breakthrough, the new observation system across the tropical Pacific, augmented by drifters, tide gauge stations and satellite altimeters. Improved coupled ocean atmosphere models assimilating the full meteorological and oceanographic observations given in real time are the leading tools for the climate anomaly predictions.

The second presentation by D. Anderson from the European Centre for Medium Range Weather Forecasts (ECMWF) gave a status report on the hitherto most advanced global climate variability predictions of up to two seasons. The recent major ENSO event 1997/98 has been well captured, including its global consequences for temperature and precipitation. The centre also issues probability distributions for the forecasts, i.e. attaches a confidence interval to the forecasts based on the seasonal predictions over the last two decades run in a hindcast mode.

The third presentation by N. Plummer from the Australian Bureau of Meteorology reported on the Australian multi – year expertise in up to 3 months forecasting using empirical regressions and model-supported forecasts. The skill of the forecast, is in the range useful for the farming community but its base, simple indices, does not capture the full skill that exists when global observations are assimilated into numerical models. The involvement of agricultural expertise when issuing the forecasts makes the Australian example especially attractive.

The fourth presentation by H. Kondo from the Japanese Meteorological Agency underlined again the need for upper ocean observations when trying to produce skilful seasonal climate variability predictions. H. Kondo showed promising El-Niño sea surface temperature anomaly predictions using the coupled ocean/atmosphere model at JMA, and outlined Japanese attempts to improve the observational base through new observations in the South-East Asian seas.

The fifth presentation, by C.F. Rapelewski from the International Research Center (IRI) for Climate Predictions, based in USA, added the applications research domain as an important component of climate variability prediction research. He also showed the first information available to the public (website from the IRI) on the status of the climate system, the seasonal forecasts, and the impacts of climate anomalies, to be issued and improved continuously.

Summary

Many countries, especially those in ENSO-affected areas can now use seasonal climate variability predictions for timescales up to about two seasons. This breakthrough has largely been due to a 10 year project of WCRP, the Tropical Ocean/Global Atmosphere (TOGA)

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study. The major challenge, besides improving the forecasts through, for better understanding of monsoons, is the involvement of user groups at early stages in order to fully exploit the value of long-term forecasting of climate anomalies which has brought a new dimension to early warning (e.g. droughts, floods, etc.). There is now a chance for more rapid development in areas hitherto suffering greatly from large natural climate variability.

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Towards Operational Prediction of El Niño by a Coupled Ocean – Atmosphere Model

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3 Recent and Ongoing Research Activities Towards Operational Prediction 371
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1 Introduction

The 1997–1998 El Niño has turned out to be one of the largest events in history in terms of the anomaly of sea surface temperature in the Pacific equatorial area. The atmospheric general circulation in and around the Pacific tropical area has been greatly affected by this El Niño and thus its possible direct or indirect influence extends over a number of abnormal weather or extreme events, as are shown in Fig. 1 for the period from Summer 1997 to Spring 1998. In the later part of 1997, dry weather prevailed in Indonesia and Australia, higher temperature in India and Southeast Asia, high temperature with dry weather in the north western part of South America, heavy rainfall in the southern part of the U.S.A. and in the northern part of Mexico, etc. Even the heavy rainfall and high temperatures in the eastern parts of equatorial Africa in late 1997 might have been a result. Various devastating disasters such as floods or long-lasting forest fires, especially those in Indonesia are consequences.

These disasters remind us how important it is to get accurate information on El Niño and particularly early warning through prediction. Recently, in addition to statistical methods, dynamical ways by coupled atmosphere-ocean models have been introduced in several institutions on a research and/or operational basis. The Meteorological Research Institute (MRI), the El Niño Monitoring and Prediction Centre and other relevant divisions of the Japan Meteorological Agency (JMA) have been developing such a model by coupling a global atmosphere model with an ocean model. This paper is intended to firstly show an analysis of the last El Niño conducted by the above Centre and secondly report our recent and ongoing research activities towards operational prediction of El Niño, being planed to launch from October 1998.

2 The Analysis of the 1997–1998 El Niño

Figure 2 shows the monthly mean sea surface temperature (SST) in November 1997 in the Pacific (above) and its anomaly from the climatological average for the period of 1961 through 1990 (below). The former fails to show the usually much lower SST off the coast of Peru than that in the western equatorial Pacific. The latter clearly delineates the extent of large values from the coast of Peru to the most part of the equatorial eastern Pacific. Figure 3 shows the time series of the cross sections of temperature anomaly distribution along the equator. The warmer region extending to the western and central parts around a depth of 100 m through 150 m in February 1997 moved eastward as time passed. In November 1997, the contrast of a significantly warmer anomaly region in the eastern part and a colder anomaly region in the western part became evident. In order to enable consistent statistical and climatological records, the JMA has been using a definition for El Niño under the term "El Niño Condition" as follows:

> A condition when the 5-month running average of a monthly mean SST anomaly over the El Niño monitoring region (also called as NINO3 region, see Fig. 4) is continuously more than +0.5 °C for 6 months or more.

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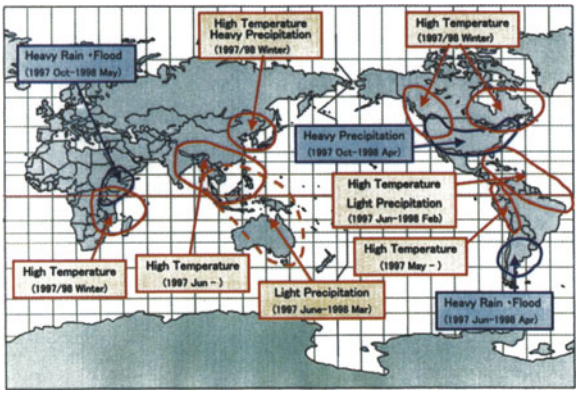


Fig. 1. Influences of El Niño event (1997 Summer – 1998 Spring)

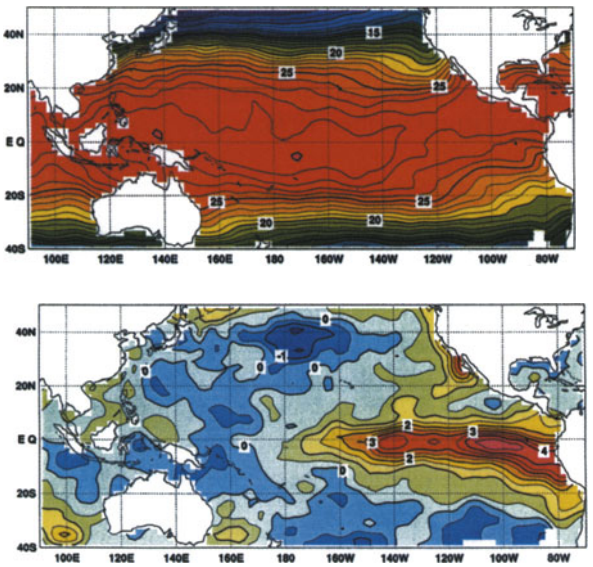


Fig. 2. Monthly mean Sea Surface Temperature (SST) in November 1997 (above) and its anomaly from the climatological average from 1961 through 1990 (below)

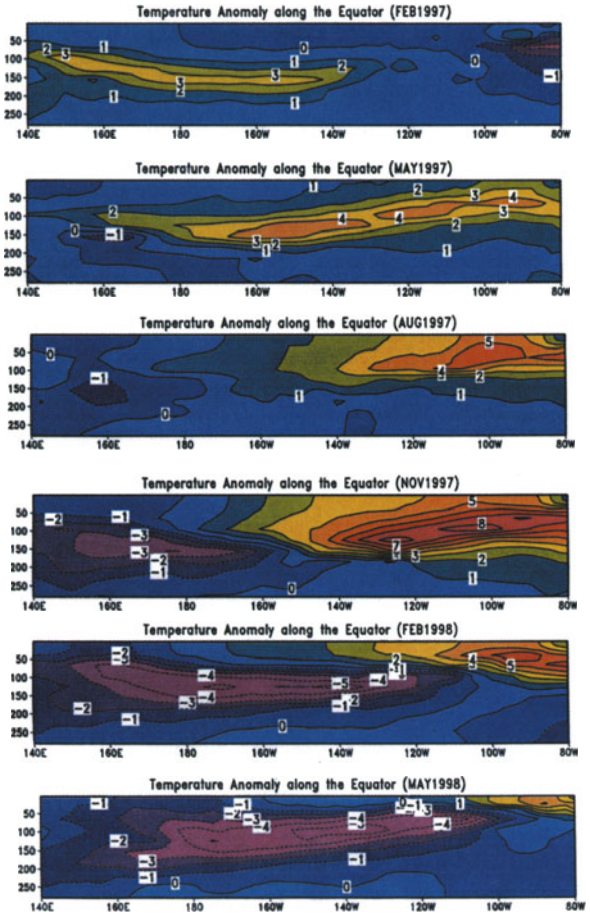
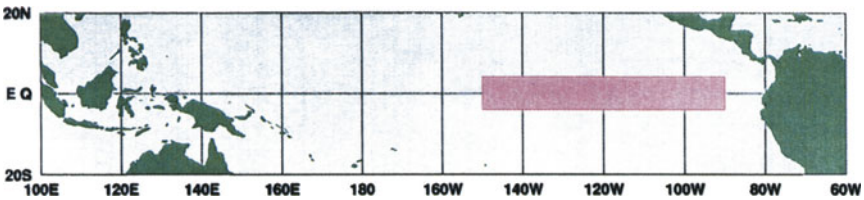


Fig. 3. Time series of the cross sections of temperature anomaly along the equator

Fig. 4. El Niño Monitoring (NINO3)–Region (4°N–4°S, 150° W–90° W)



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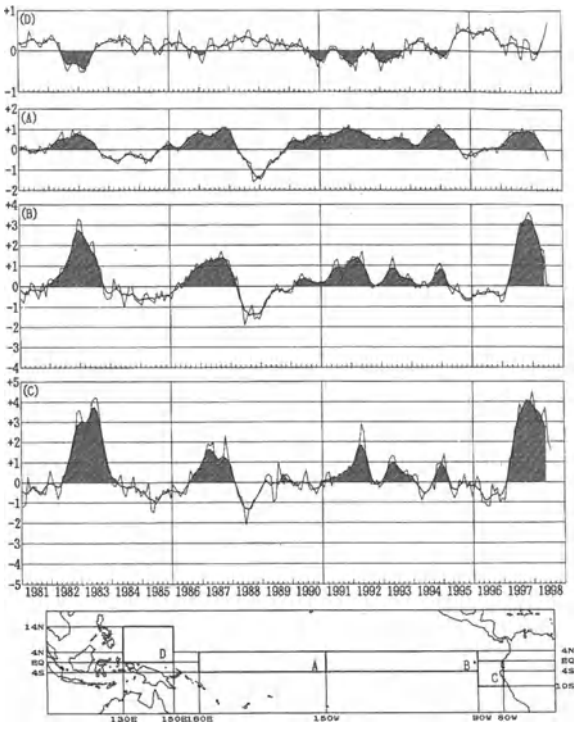


Fig. 5. Time series of monthly mean SST anomalies (°C) in the equatorial Pacific Ocean for the areas indicated at the bottom panel. Thin lines show the monthly means and thick lines their 5-month running means. Positive anomalies (A, B, C) and negative anomalies (D) are shaded. Anomalies are computed from the JMA climatological (1961–1990)

We also encounter the opposite extremity of the SST situation in the same region, which is called La Niña. Again we define the "La Niña condition" as follows:

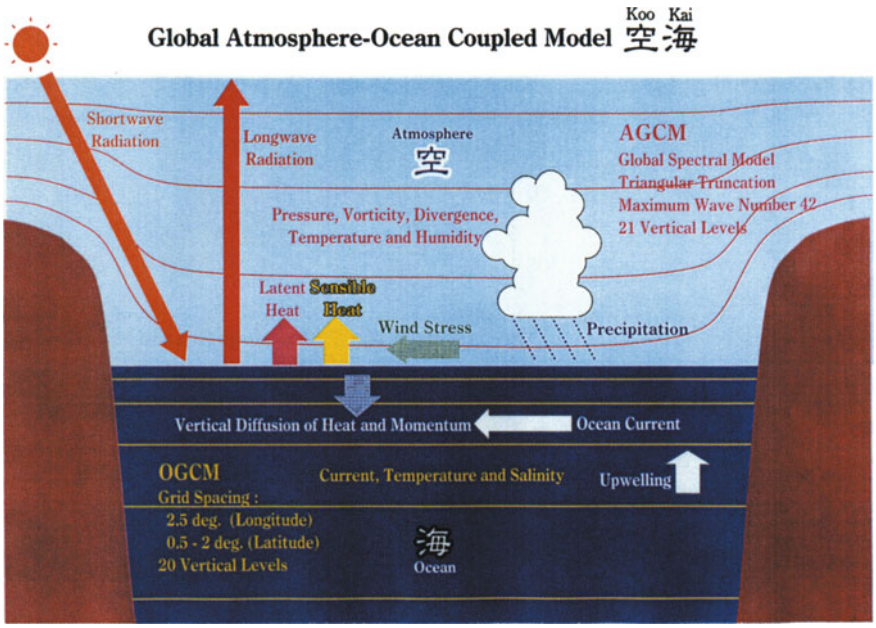
> A condition when the 5-month running average of a monthly mean SST anomaly over the El Niño monitoring region is continuously less than −0.5 °C for 6 months or more.

According to the above definition, 13 El Niño events have been recorded almost once every 4 years since 1949 from which data have been available. The thick line of (B) in Fig. 5 (p. 27 of the July 1998 issue of the Monthly Ocean Report published by JMA) shows a time change of the 5-month running mean value of the SST anomaly in the El Niño monitoring region which reached a maximum of +3.2 °C, while the thin line denotes monthly average of the SST anomaly which hit the highest value of 3.6 °C both in 1997. Apparently, this El Niño seems no less significant than the 1982–1983 El Niño.

3 Recent and Ongoing Research Activities Towards Operational Prediction

It is well known that a long-term oscillation of the sea surface pressure in the tropical Pacific and that of Tahiti correlates negatively with that of Darwin, Australia. This oscillation in the

Fig. 6. Global atmosphere-ocean coupled model.



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east-west direction has been called Southern Oscillation (SO) and is indicated by a parameter of Southern Oscillation Index (SOI), whose definition is based upon the difference between monthly anomaly values of the sea surface pressures in Tahiti and Darwin. Negative values of SOI dominate during El Niño. Thus the large scale atmospheric circulation is closely related to the change of SST over the tropical Pacific. The whole atmosphere–ocean system there is called the El Niño and Southern Oscillation (ENSO). In order to understand the process of ENSO, global scale considerations of the atmosphere and ocean are necessary.

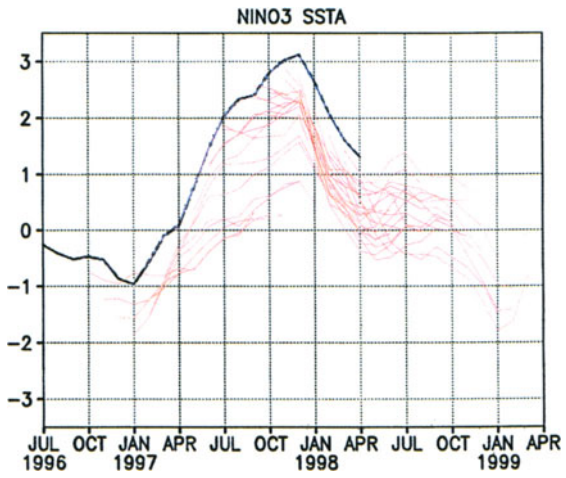
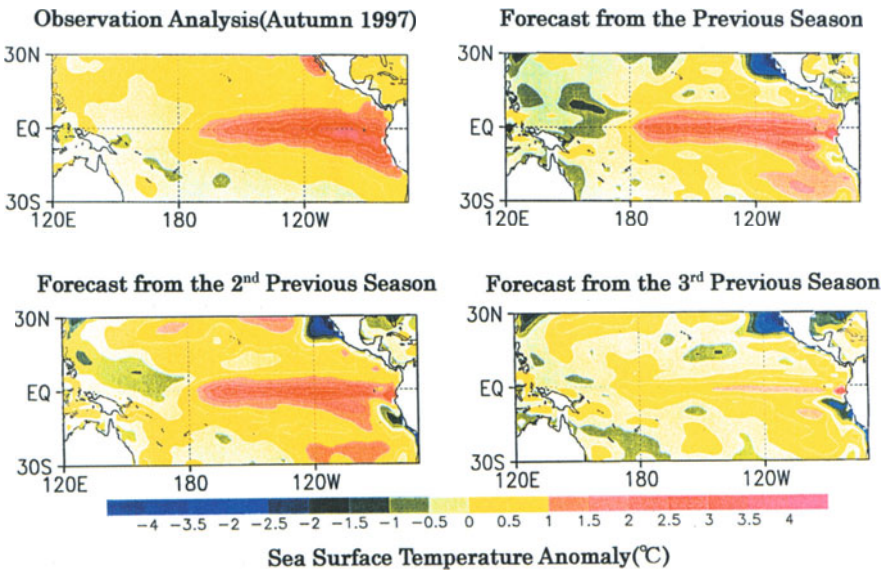


Fig. 7. Computed results (thin lines) for the 1997–1998 El Niño event (thick line indicates observed NINO3 SSTA)

To make active predictions in addition to statistical methods we, therefore, need to develop a global atmosphere-ocean coupled model. Figure 6 shows a schematic view of the model developed and dubbed as "Koo Kai." It consists of an atmosphere general circulation model (AGCM), a global atmospheric spectral model (21 vertical levels with 10 hPa as the top level and horizontal resolution of T42) derived from our operational numerical weather prediction (NWP) model and an ocean general circulation model (OGCM) with 20 vertical levels (bottom level: 4000 m), latitudinal resolution finer in the tropics (0.5° between 20N and 20S and otherwise 2°) and longitudinal resolution of 2.5°. Coupling of AGCM and OGCM is made once in every 24 physical hours with flux correction.

In order to run the model, data assimilation for the initialisation is vitally important. The atmospheric initial values are made by the objective analysis developed for the operational NWP model. As for the initial values of the atmosphere, the JMA has already developed an Ocean Data Acquisition System (ODAS) with the same ocean model described above for ocean data assimilation. Ocean data are obtained as SHIP or BATHY from research vessels and voluntary observing ships. In addition, vitally important data are obtained from TOGA/TAO buoys operated by NOAA/PMEL of USA in the equatorial region of the Pacific Ocean. Triangle Trans-Ocean Buoy Network (TRITON) buoys of Japan

Fig. 8. Observed and predicted SST anomaly



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Marine Science & Technology Centre (JAMSTEC) have recently been set in a western part.

We have made a number of experiments for the cases of past El Niño events. Figure 7 shows results of experiments for the 1997–1998 El Niño event. The thick line denotes observed time change of the SST for the monitored NINO3 region and thin lines show results from the 1-year El Niño forecast experiments starting from various initial times (once or twice a month). The tendency of the SST seems well predicted to some extent. Figure 8 shows observed and predicted horizontal anomaly patterns of SST. Again we see encouraging results. We also made experiments for the 1986–1987 El Niño case with reasonable results. However we have not yet obtained reasonable results for several El Niño events in the early 90s, maybe due to a different mechanism of events which our model has some problems in simulating.

4 Concluding Remarks

We know our model is not perfect, with various problems still left to be solved such as climate drift, parameterisation of physical processes (especially cumulus convection and diffusion in the ocean), further improvement of ocean data assimilation, etc. However, these difficulties will be dealt with step by step through real time operational model outputs. We consider it better to issue available information obtained through the existing model rather than to decline publication of the information due to its imperfect nature, at the same time reminding the users of the limit of the certainty of the prediction by providing some kind of evaluation. Based upon these results and consideration, we plan to launch operational prediction possibly as of October 1998. We are also considering to make the predicted El Niño information available to countries concerned.

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CHAPTER 4.28

Operational Seasonal Predictions in Australia

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1 Introduction – Basis for a Service

Efforts at climate prediction in Australia go back many decades but it is only since 1989 that the Bureau's National Climate Centre (NCC) has been publicly issuing Seasonal Climate Outlooks. These scientific predictions have arisen due to the development of "operational climatology" (analogous to operational short-range weather prediction) in Australia. Much of this has developed out of a greater understanding of the El Niño Southern Oscillation phenomenon.

Australian droughts generally accompany El Niño episodes (e.g. Allan 1991) and are associated with large negative values of the Southern Oscillation Index (SOI – the standardised difference in surface atmospheric pressure between Tahiti and Darwin). Years with little of the country in drought, or with significant areas with above average rainfall, tend to have large positive SOI values and are termed La Niña episodes. The El Niño Southern Oscillation phenomenon enhances Australian rainfall variability, as it does wherever it impacts on climate around the world (Nicholls et al. 1997). It also results in Australian droughts often being long-lived (Nicholls 1992) with many of these (and the extended wet periods) tending to last about 12 months. The heavy rainfall associated with a La Niña episode, although being variable across the country, tends to start early in the calender year and finish early in the following year and the dry periods associated with El Niña episodes tend to follow a similar evolution.

The Australian rainfall – El Niño Southern Oscillation link is most consistent over the east and north of the country (e.g. Pittock 1975; McBride & Nicholls 1983). Rainfall over the west of the continent is less strongly linked to the phenomenon but Nicholls (1989) identified a dipole pattern in Indian Ocean sea surface temperatures related to rainfall fluctuations in the central and southern parts of Australia. The El Niño Southern Oscillation phenomenon has a major impact on crop yields, native vegetation and wildlife over Australia.

El Niño related droughts have a significant impact on the Australian economy. During the period 1991 to 1995 the average production by rural industries fell about 10 per cent, resulting in a possible AUS$5 billion cost to the Australian economy. Drought relief provided by the Australian Commonwealth Government between September 1992 and December 1995 totalled AUS$590 million. Early warning of the development of an El Niño event is critical to the Australian economy.

2 Historical Evolution

The development of seasonal climate prediction extends over a long period of Australia's history. As early as the 1920s seasonal climate forecasts were generated in the Bureau of Meteorology following the work of Bureau scientist E.T. Quayle (e.g. Quayle 1929). The re-emergence of drought conditions in many areas of Australia in the mid – 1960s along with a renewed awareness of the extremely high varia-

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bility of Australian rainfall led to renewed interest in seasonal climate prediction.

The recognition of El Niño Southern Oscillation teleconnections prompted significant research in Australia in the 1970s and 1980s (e.g. Allan 1985; Allan et al. 1996; McBride & Nicholls 1983; Nicholls 1985a, 1985b; Pittock 1975). This activity provided the solid foundation necessary for effective development of the seasonal climate forecasts now routinely issued.

Outlooks initially remained reliant on correlation-type analyses or variants from these. More sophisticated approaches, based on multiple linear regression, 'SOI-phase' systems based on pattern analyses of the SOI (Stone & Auliciems 1992; Stone & Hammer 1992; Zhang & Casey 1992), and linear discriminant analyses (LDA) (Drosdowsky & Chambers 1998), contributed to generally improved seasonal climate prediction systems. Based on these approaches, useful and modestly skilful 'forecasts' have been produced on a regular basis for a number of years.

A more recent development has been the use of empirical orthogonal functions or 'EOFs' to isolate significant regions of global sea surface temperature (SST) that affect rainfall patterns in Australia (Drosdowsky & Chambers 1998). This system aims to provide improved forecast 'skill' for many regions in Australia, including improved predictive ability through the austral Autumn period and for southern and western regions of Australia that do not have strong relationships with phases of the SOI.

3 The Current Seasonal Climate Outlook Service and its Users

Information about past climate variability is in itself important in the management of climate risk but its value can be greatly enhanced if there is a seasonal climate prediction capability.

Seasonal Climate Outlooks are released near the beginning of each month for rainfall over the coming three-month period. They are available through the media, through the Internet (http://www.bom.gov.au/climate/ahead/) and through a poll fax service. From late 1998, the outlooks have been issued with a lead-time of about two to three weeks, and are based on SST patterns in the Pacific and Indian Oceans. More detail, particularly tabulated probability and analogue information, is currently provided in a monthly printed publication available by subscription.

The outlooks are prepared following a monthly meeting of scientists, usually including a representative of a state agricultural agency. The methodology employed continues to evolve but remains primarily based on refined statistical techniques. The skill, which relies largely on the influence of the El Niño Southern Oscillation, varies considerably in both time and space. The outlooks indicate those areas where there is a significantly increased probability of total seasonal rainfall being in either the upper or the lower tercile range. An example of a probability map issued to the subscribers is

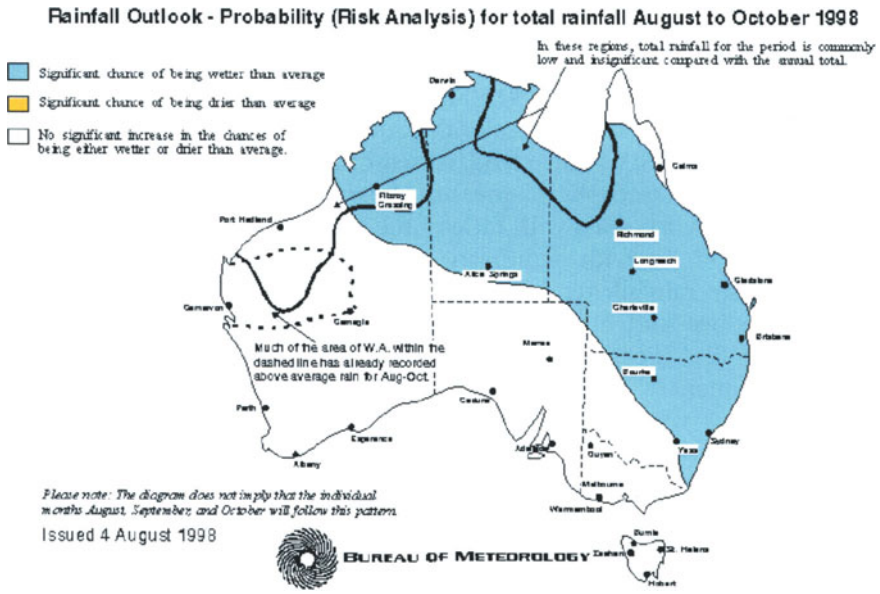


Fig. 1. The rainfall outlook for the period August to October 1998 as issued on 4 August. Much of the north and east of the continent was considered to have a significant chance of being wetter than average

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shown in Fig. 1. Surveyed rural users have indicated, in many cases, that a shift of ten per cent or more in either of these probabilities might be sufficient to modify their decision strategies. The majority of users are from the rural community, but there are significant numbers from water suppliers, forest managers, banks, and government departments.

Changes in content and presentation of the outlooks have resulted from user feedback. It has proved an elusive goal however, to present the probability information for the entire country in a map or graphical form that satisfies all user requirements. Furthermore, surveys have shown that about one user in three lacks the necessary understanding of basic statistics such as quantiles and probabilities to interpret such probabilistic predictions. These present significant challenges for the forecast providers.

4 Communication: Some Lessons From the 1997/98 El Niño Event

From May 1997 the Bureau had been providing early warning of a likely El Niño event in their outlooks. Rainfall was below average throughout much of 1997 and early 1998 in southeast and eastern Australia. However, the impact of the 1997/98 El Niño event was not as severe on Australia as had been the case in other severe events, notably the 1982/83 episode. Furthermore, significant areas of the continent experienced wet conditions during August to October 1997, in marked contrast to previous El Niño events.

Some suggestions that the Bureau had been exaggerating its confidence in the predictions came as a surprise to those involved in their preparation and dissemination. There was a wide gap between what the Bureau was attempting to say (i.e. an increased likelihood of drier than normal conditions) and the message received by users (i.e. definitely dry conditions expected, perhaps the worst drought in living memory). Part of the reason for the communication gap may come from users and forecasters interpreting 'likely' in different ways (Fischoff 1994). Those involved in preparing the forecasts and media releases intended this to indicate that dry conditions were more probable than wet conditions, but that there was still a finite chance that wet conditions would occur (Nicholls & Keston 1998). However, many users interpreted 'likely' as 'almost certainly dry, and even if it was not dry then it would certainly not be very wet'. The abundance of media reports on the El Niño, many suggesting grave consequences in many parts of the world, appeared to reinforce this interpretation amongst the broader Australian community.

Nicholls and Keston (1998) describe the use of the Bureau's outlook service to reduce the danger of bush fires in southeastern Australia during 1997/98. An intensive media campaign was initiated to alert people to the possible danger from bush fires because of the dry and hot conditions that often accompany El Niño events. Although several days in February and March 1998 actually had conditions very conducive to bush fires (and were similar to conditions in 1982/83), fire damage to residential property was limited even though considerable forest areas were burnt. At least part of the reason for the relatively low level of damage was the publicity campaign that evolved from the interactions between forecasters and users (rural fire authorities). It is important to note that this 'partnership', i.e. between the Bureau of Meteorology and fire authorities, was conducted without the media acting as an intermediary.

It is crucial for organisations and individuals to develop improved methods for delivering their message through the media. In a media analysis study to investigate media reporting on climate-related information (particularly El Niño) between April and December 1997, Walsh (1998) provided recommendations for the Bureau's National Climate Centre in their dealings with the media. These included: the development of a proactive media strategy and clear communication objectives with consistent messages; train staff in media relations; research target users; possibly employ a media liaison/communications officer; provide education seminars for key opinion leaders and media; and allow extra time in dealings with non-specialist journalists.

5 Future Developments

The service will continue to evolve in its presentation, content, and methodology. Probability information is difficult to convey in a con-

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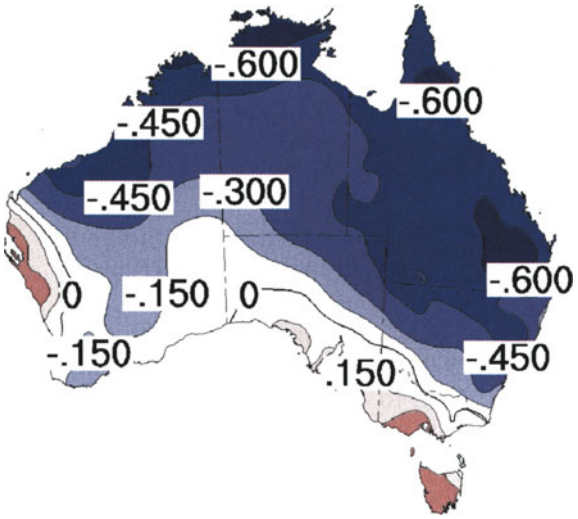


Fig. 2. Plot of correlation coefficients between the Southern Oscillation Index and daytime maximum temperatures in Austral summer. The period of record was 1950 to 1995

cise manner and so further changes may occur in the physical layout and diagrams inside the subscription booklet. The content will also expand with the introduction of seasonal temperature outlooks within the next six to 12 months. Figure 2 shows that there are large areas of the continent where the SOI is strongly correlated with daytime maximum temperatures in Austral summer. There is also scope to increase the level of detail associated with the analogues of the SOI.

However, the most significant changes are likely to occur in the underlying methodology. The Bureau of Meteorology Research Centre (BMRC) will continue to look for possible improvements and variations in the statistical techniques currently used. This may involve increasing the number of SST empirical orthogonal functions used, altering the way they are selected, or testing the viability of different SST indices. BMRC is also developing a fully coupled ocean-atmosphere general circulation model (GCM), which in the medium term (say around five years) should largely replace the current statistical methods. NCC is presently testing the accuracy of some international GCMs for predicting seasonal conditions in Australia.

Acknowledgement

Thank you to Dr. David Jones (BMRC) for providing the SOI-Maximum temperature correlation analysis in Fig. 2.

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ECMWF Seasonal Forecasting System: Performance and Evaluation

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1 Introduction

In 1997 and 1998 there were many reports of anomalous weather conditions in different parts of the globe: the droughts in Northern Australia, Papua New Guinea and Indonesia, the associated smoke pollution in the Malaysian and Indonesian region, hurricanes battering the west coast of Mexico, abundant rain on the coastal plains of South America in places where it hardly ever rains[1]. Why? Although the weather always seems to be anomalous somewhere, 1997/98 seem to be more anomalous than most.

The key lies far from our shores, in the vast expanses of the tropical Pacific, where the so-called El Niño returned with a vengeance equalling and in some respects possibly exceeding the El Niño of 1982/83, which at that time was the most violent El Niño on record. There is a tendency to blame any and all unusual weather conditions on El Niño. This is not justified. Even without an El Niño there would be weather disasters, but there is little doubt that its effects are almost global. Even here in Europe, half a world away from the source of the climate disaster, there are possibly El Niño effects (Fraedrich 1994; Barnston, 1994). Although it becomes hard to ascribe any one weather anomaly to El Niño, over the years, observations and modelling studies including those at ECMWF, have gone some way to clarify potential climate teleconnections.

One conceptual model of weather is that of a series of events which are (for practical purposes) unconnected: the weather next week is essentially independent of the weather this week. An example of such a model is an unbiased coin. If such a coin is tossed several hundred times, one would expect to find short runs of one face or other, say five heads in a row, purely by chance. If the heads are thought of as inactive weather systems, then such a run of heads might correspond to drought conditions. There is no point in seeking a physical cause for such a run. The 'drought' is simply the outcome of a series of chance processes and as such it is unpredictable. But weather patterns may not always be purely stochastic. Suppose the coin were slightly biased. Then a sequence of tosses would still throw up heads and tails in pretty much random ways as before, but a more careful analysis might reveal that there were slightly more heads than tails, which in our simple analogue, would correspond to below average rainfall. Individual weather systems may still be chaotic, but the statistics governing them may be perturbed in a deterministic and predictable way. In middle latitudes where we are living the bias from El Niño is likely to be fairly small, although in extreme events it might be stronger. But closer to the Pacific, the bias will be much stronger to the point where in some cases the coin is heads on almost every toss. In major El Niño years, there might be no rain to speak of for months on end, as happened for example in parts of New Guinea in 1997.

There are reasons for believing that some aspects of climate variability might be predictable on the seasonal timescale. Firstly, the lower

[1] R. Brugge, personal communication.

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boundary conditions of the atmosphere such as sea surface temperature (SST) or soil moisture may have a longer memory than the atmosphere and hence be at least partly predictable. Secondly there is a fairly comprehensive ocean observing system now in place in the equatorial Pacific which can measure upper ocean temperatures from the surface to depths of 500 m. Finally models of the atmosphere and ocean have improved. To be sure these are still flawed and require extensive further refinement but they are good enough to use in developing a coupled system. Since it is the slower timescale in the ocean that brings predictability, any attempt to predict El Niño, or seasonal changes in general, must involve both atmospheric and oceanic models.

Seasonal forecasting does not allow exact predictions, even for seasonally averaged values, but it should be possible to describe the probability distribution for weather, and hence calculate probabilities for any specified event. Our plots of the probability of above average temperature or rainfall (see later) are just one example of the sort of product that can be made; other possibilities might be the probability of mean temperature above a specific value or a quintile threshold, the probability of the number of rain days exceeding a certain value, the probability of either the mean maximum or absolute maximum temperature reaching a certain value, the number of heavy snowfall events, etc. The probabilistic nature of the forecasting makes verification a difficult issue, particularly because so far we have only a small number of cases to study. For cases where the (forecast) probability distributions are not much shifted from climate, then it is hard to know whether the forecast was good, unless perhaps the observed weather is very extreme. An essentially null forecast such as this might be of use, of course, if one could be confident that it implied that extreme weather would definitely not occur – but testing would have to cover many years to establish this. On the other hand, if the forecast is for a strong shift in the weather patterns for a particular year, then this provides a good opportunity to test the forecast system. It is still true that we are not able to predict exactly what will happen, but the test as to whether the observations lie within the predicted range becomes more powerful. In 1997 and 1998 our system has been forecasting strong shifts in global weather patterns, largely associated with the exceptional El Niño (discussed further below). This means that the last two years are a very good period over which to assess the performance of our system. A fuller assessment will require the completion and analysis of forecasts covering a much longer period of time; this will be provided at some stage in the future.

2 The Seasonal Forecast System

The atmosphere model component has a spectral resolution of T63 and a corresponding 1.875 degree grid for physical processes, while vertical resolution is 31 levels. The ocean resolution in the extratropics is about 2 deg but is increased in the tropics to 0.5 deg in the latitudinal direction, so as to resolve the equatorial waves which are important for ENSO. The two models are coupled globally and without flux corrections. The atmospheric and land surface initial conditions are taken from the ECMWF operational analysis. An analysis of the ocean state is made using the forced response of the ocean and assimilating surface temperature analyses and all available sub-surface thermal ocean data. Salinity is currently not analysed.

The forecast strategy is to couple directly the two components of atmosphere and ocean and integrate forward from the initial conditions. This inevitably leads to a drift in the climate of the coupled system, due to systematic errors in the component models. Such biases can be corrected for after running a model integration by removing the drift as estimated by a set of forecasts for an earlier period (Stockdale 1997): it is large, comparable with the size of the signal we are trying to predict. This drift correction is included in the plots we show later of forecast SST anomalies; it does not affect the evolution of the coupled model itself. Extensive experimentation for the 1980s and especially the 90s shows that our system has useful predictive skill.

The forecasts we present here come from our near-real-time experimental system, where a coupled forecast is run each day out to 200 days. (In the earlier phase, only 3 forecasts were made each week.) Over a month an ensemble size of 30 members is created which allows us to sample the chaotic part of the sys-

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tem, as will be discussed below. We do not yet sample the uncertainty arising from incorrect ocean initial conditions or from model error. The forecasts are performed about two weeks after the nominal start date to allow for ocean data acquisition.

Forecasts within 35 degrees of the equator are available to all on the web at http://www.ecmwf.int. Member States may access the full global products on http://w3ms/ecmwf/seasonal/index.html, but should be aware of the limitations of forecasts in the extratropics, especially over Europe. Any prediction must be probabilistic in nature. Our web pages give two maps for each predicted field, the probability of occurrence and a measure of the amplitude. The fields currently posted are the integrated rainfall, the surface pressure and the 2 m temperature valid at 00Z, together with plume diagrams of the Sea Surface Temperature (SST) in Niño3, (a key region in the central east equatorial Pacific).

By taking sufficiently large ensembles, statistical tests can be used to distinguish whether an apparent signal is in fact significant. For this purpose we create an estimate of the climatological distribution of e.g. rainfall using forecasts for the years 1991–1996. The ensemble has typically 30 members, and the reference climate is made up of 114 members (19 integrations for each of 6 years, all starting in the same calendar month). We only plot the points which are significant at a certain level, typically 95%. Areas in which the signal is not significant at the chosen level are left blank. There are usually large areas where no signal shows. In 1997/98, plots in mid latitude show much more extensive areas of colour, far beyond what might be expected under the null hypothesis of no signal. The 95% significance level is related to our confidence that the probability distribution for e.g. the rainfall is shifted, not to our confidence that the actual realisation of the rainfall will have an anomaly of the predicted sign.

3 Chaotic Processes in the Coupled System: Limits to Predictability

The years 1997/98 are of special interest because of the strong El Niño conditions in the Pacific. In December 1996, a weak cold anomaly was present in the east Pacific. By May 1997, the El Niño warming had appeared. The forecast anomaly for May, created by averaging the forecasts starting at different days in December is quite similar to that which was later observed to occur i.e. the onset of the El Niño was well predicted (Stockdale et al. 1998). The amplitude of the El Niño in May 97 was not particularly large. It was not until December 1997 that it peaked. So our forecasts made in December 1996, which only looked 6 months ahead were not yet indicating a huge El Niño. Whether we could have predicted a huge El Niño one year ahead is a mute point.

It has long been realised that the atmosphere is highly nonlinear (chaotic) on the timescales of weather and that individual weather events are unpredictable beyond a few days. It is typically assumed, however, that the ocean does not react too much to this high frequency variability but acts as a filter and responds only in some smoother sense. Because of the feedbacks between ocean and atmosphere, different integrations of the coupled system would be expected to show some divergence of SST, but the importance of this for e.g. six month forecasts has remained unclear. Partly because of computer constraints, the rate of divergence seems never to have been tested with a coupled forecast GCM, although estimates have been made in other ways (Kleeman & Moore 1997; Stockdale et al. 1994; Eckert & Latif 1997).

Extensive experimentation with our coupled system has shown that the rate of divergence, even in the tropical Pacific, can be surprisingly large. We illustrate this in Figure 1, showing three forecasts initiated for 21, 22 and 23 December 1996. The ocean state is the same in all three: only the atmospheric state changes. The plots show the predicted monthly mean temperature anomaly in May 1997. There is a substantial spread in predicted SST between the ensemble members: all show the overall warming, but there are differences of the order of half to 1 K over quite large areas. Differences outside the tropics are also large, as expected, although there is some measure of both consistency and skill in the North Pacific.

This variability in tropical SST is a result of chaotic processes mainly of atmospheric origin. It indicates a limit to predictive skill beyond which we cannot go since the differences between panels a, b and c arise simply from different synoptic atmospheric events which are

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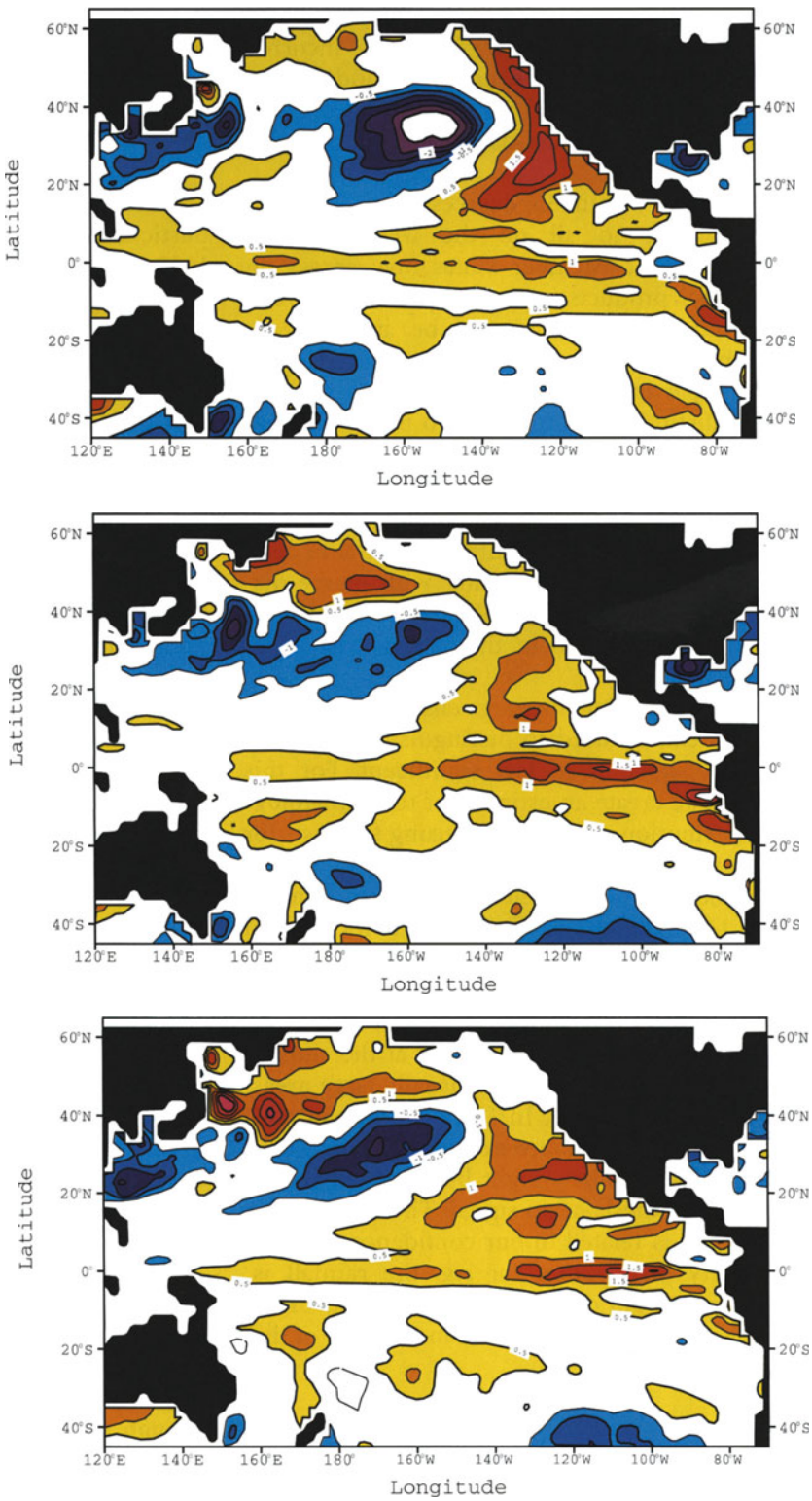


Fig. 1. Predicted SST anomalies for May 1997, from forecasts with atmosphere initial conditions from 21st December (a), 22nd (b) and 23rd (c). Contour interval is 0.5 K. Despite the identical ocean initial conditions there are significant differences between the plots showing the influence of differences in atmospheric initial conditions. None the less all show the same basic El Niño development

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unpredictable beyond a few days. There will be other limitations to predictive skill: the model is not perfect, nor are the ocean initial conditions known precisely. With better models and better observing systems, one can anticipate that these latter limitations will be reduced in the years to come though undoubtedly not eliminated. The chaotic nature of the atmosphere imposes, however, a limit beyond which forecasts cannot be improved.

A full and thorough evaluation of the skill of the seasonal prediction system has not been conducted so far. However, some preliminary remarks are appropriate. Results are shown here for both the recent 97/98 El Niño and also for earlier years of this decade. We will consider the Pacific SST predictions first as they are a sine qua non for other atmospheric fields.

4 The 1997/98 El Niño in the Pacific

The year 1997 saw one of the biggest El Niños ever recorded, the anomalous SST reaching peak values in Dec 1997/Jan 1998. May 1998 saw a precipitous decline in temperatures in the central equatorial Pacific which by early June had ceased to be warm. A weak cold phase is developing, sometimes known as La Nina. Plots of the ocean thermal structure from our ocean analysis system are given in Figure 2. Panel a) shows the sea surface temperature anomalies at the beginning of January of this year, while panel b shows them at the beginning of July illustrating the rapid decay from warm anomalies of 5 K to cold anomalies of -2 K. Panels c) and d show the temperature anomalies in the upper 400 m along the equator for the same times. The black vertical bands indicate the equatorial land masses which separate the three ocean basins. The temperatures in the subsurface ocean have changed by an even greater amount than at the surface, from a warm anomaly of 11 K to a cold anomaly of -6 K. In January 1998, even though the surface and subsurface temperatures were very strongly above average in the east, the subsurface temperatures were cold in the west. This cold anomaly spread slowly eastward over the following 6 months to reach the surface in June. A seasonal forecast system must be capable of forecasting the development and demise of such a large El Niño event. How well did we do?

In Figure 3, forecasts of Niño3 are shown for six different start months. The thick heavy line shows the observed value of Niño3 SST. One can see that the overall ability of our system to forecast Niño3 SST's in 1997/98 has been good, better indeed than might have been expected. There have been times, however, when the forecasts have been less good. Some of our worst forecasts of Niño3 SSTs were those initiated in April 1997. All members of the ensemble in this case underpredicted the growth of the anomaly as panel b shows. In March 1997, a major Intraseasonal Oscillation with associated Westerly-Wind-Bursts came out of the Indian Ocean into the west Pacific where large amplitude oceanic Kelvin-type waves were generated. These waves were strongly present in the ocean model initial conditions for forecasts initiated in April: it is surprising then that the model underpredicted the Niño3 SST. The reasons for this are not clear but there is some suggestion that the coupled model failed to amplify the signal when it reached the east Pacific. The other panels of Figure 3 show that forecasts from December 1996, and July 1997 were spot on, while those from October 1997 slightly over-predicted the anomaly. Those initiated from January 1998 show a very tight ensemble and indicated a very rapid decay of the El Niño. In fact Nature showed an even faster decline. The final panel predicts that cold conditions will last throughout the rest of the year.

Because the forecasts of the evolution of El Niño were good, it makes sense to analyse the results further and to look at the model predictions for fields other than SST and to consider the predictions globally. The predictions for the tropical Pacific made in October 1997 for the subsequent 6 months were thought to be unlikely to be grossly wrong and therefore we had more confidence for this period than would be the case in non El Niño years. An important issue at that time was, 'Will El Niño in the Pacific have a pronounced effect on European Winter climate?' Our forecast system gave a pretty categorical indication of mild conditions for Europe, although we have not verified that this was a consequence of El Niño. Figure 4a shows the probability of above average 2 m temperature for December, January, February forecast from October 1997. Deep red colours indicate high probability of above average temperature, while deep blue colours indicate high probabil-

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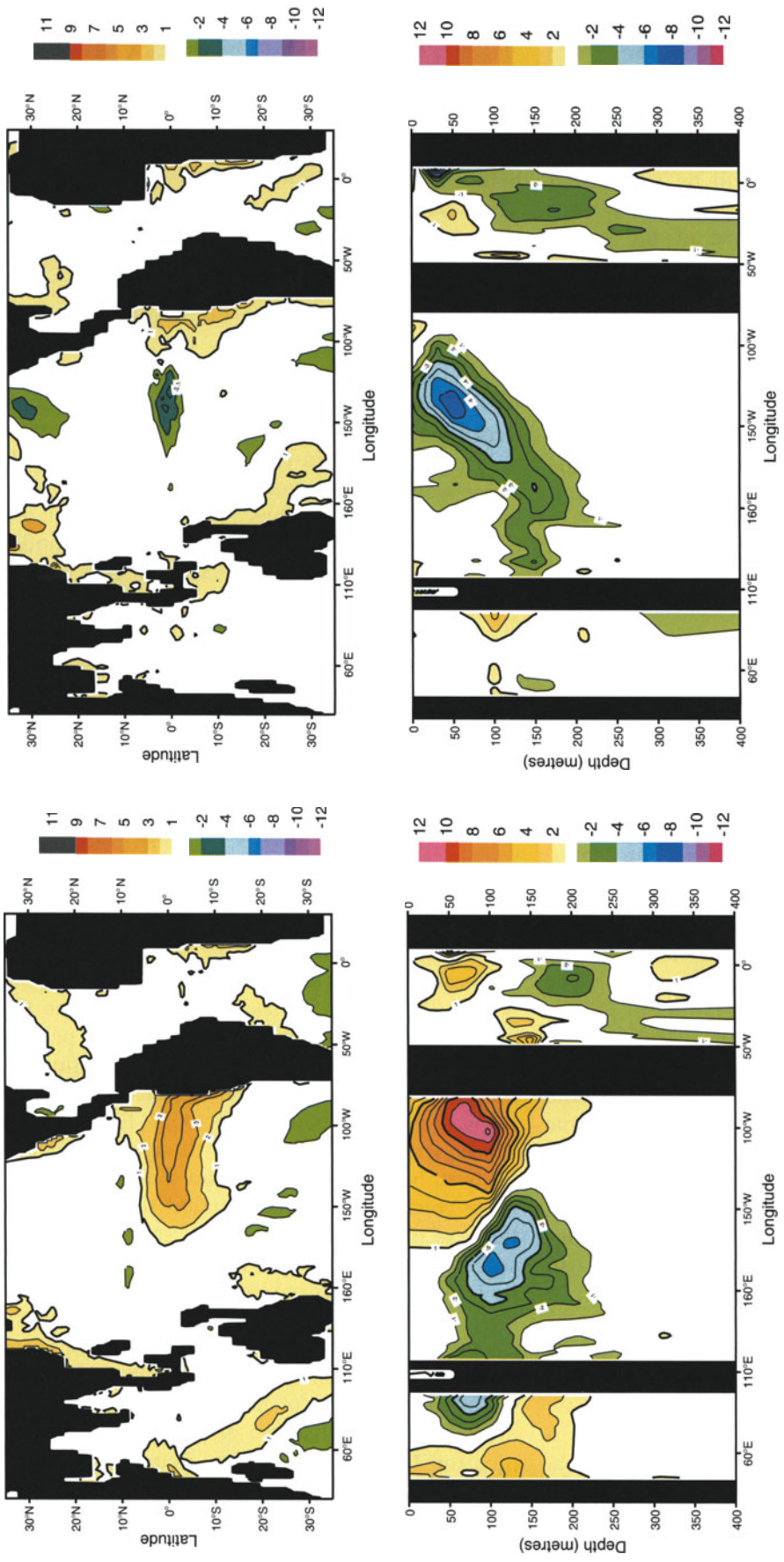


Fig. 2. Plot of sea surface temperature for a) the beginning of January, 1998, and b) the beginning of July 1998. Vertical sections of thermal anomalies along the equator are shown for the same times in c) and d). These figures show the large changes which have occurred in the space of 6 months from the peak of the warm phase of El Niño to the developing cold conditions in July. The subsurface anomalies may not alter the SST immediately or locally. Indeed these anomalies may propagate thousands of kilometres before they alter the SST. Nonetheless it is important to carry this subsurface information in a model as it may be the propagation of subsurface anomalies such as these which give the system predictability

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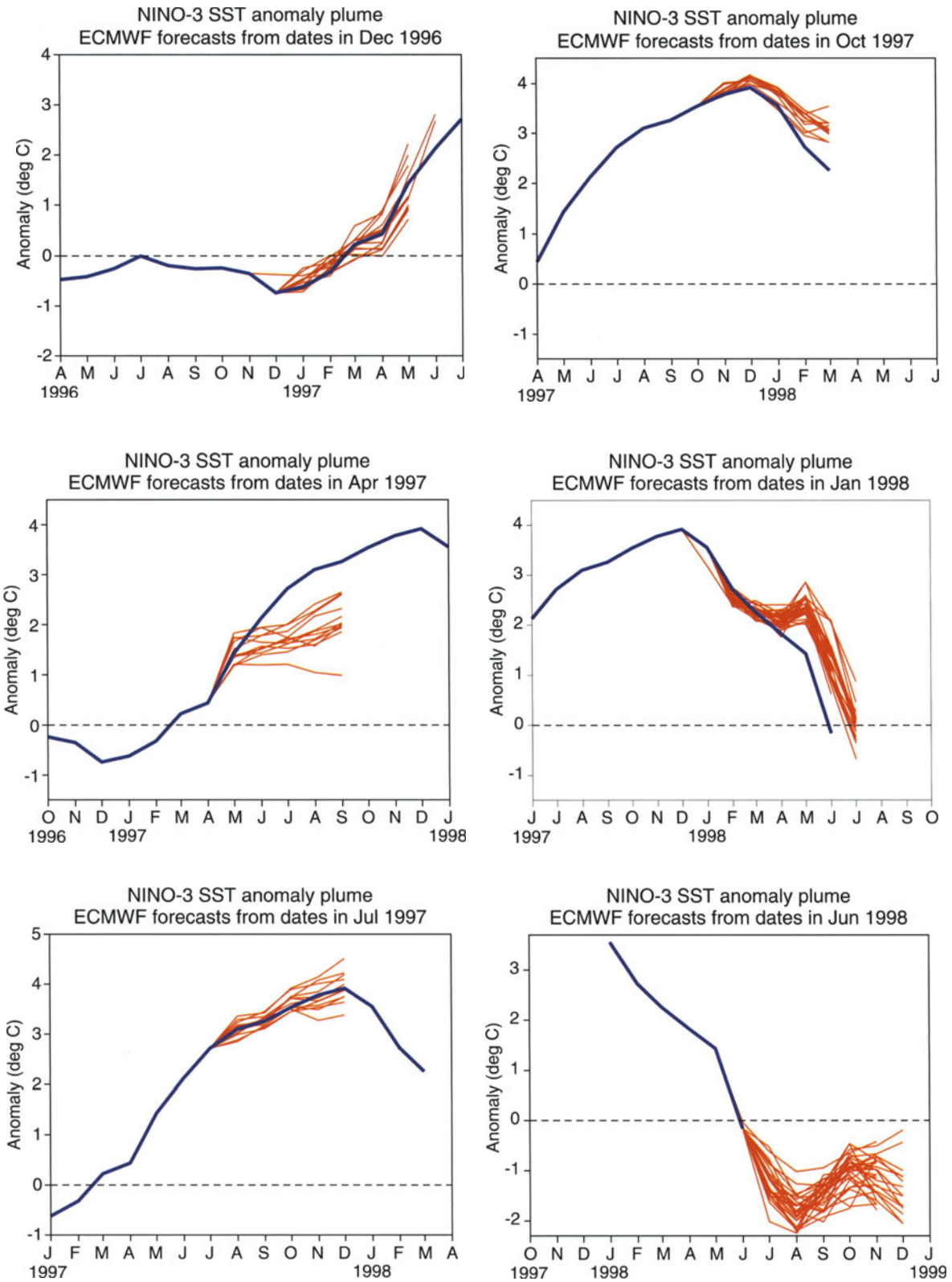


Fig. 3. Plot of Niño3 SST values as predicted for 6 different start months. The forecasts from Dec 96, July '97, October '97 were all good. Those from April '97 underpredict the ENSO growth

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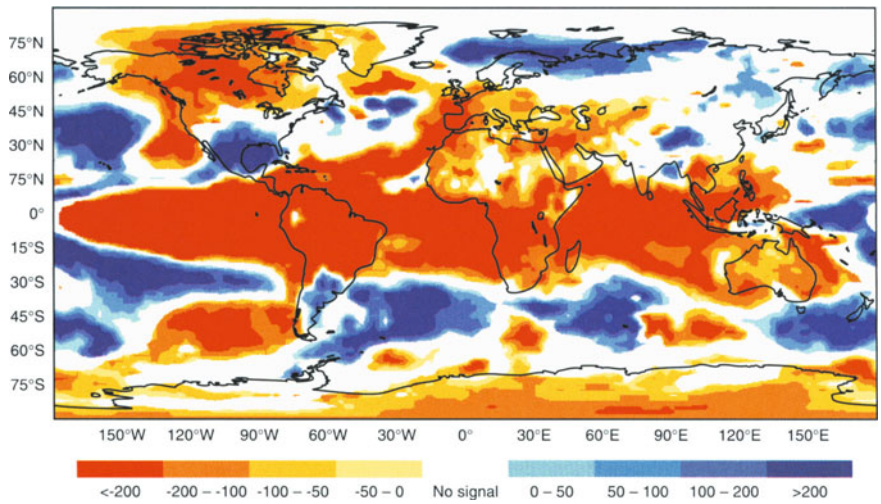


Fig. 4a. Probability forecast of 2 m temperature for the winter of 1997/98 for forecasts initiated in October '97. Deep red colours indicate high probability of above average temperature. Deep blue colours indicate high probability of below average temperatures

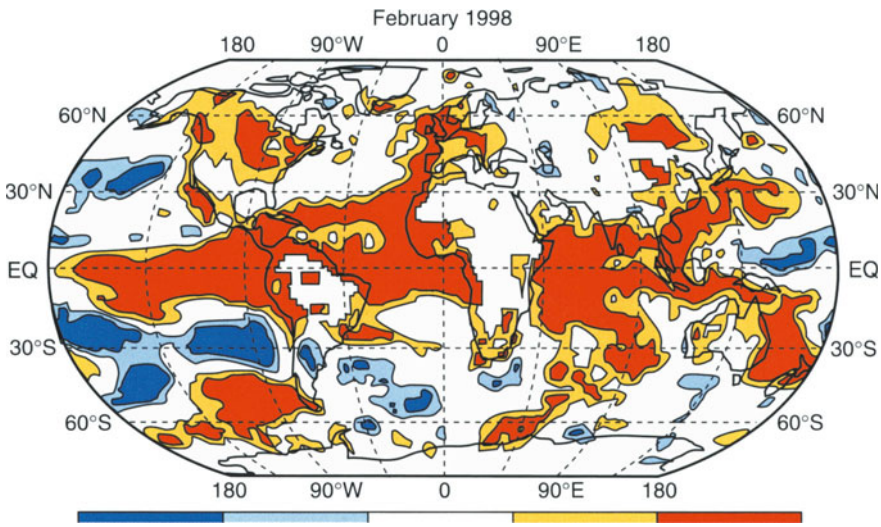


Fig. 4b. Probability forecast of observed temperature anomalies represented as percentiles. From the Climate Analysis Center

ity of below average temperature. Panel b shows the observed anomalies of temperature for February 1998 but is representative of the earlier winter months. It does not correspond exactly to the forecast product, showing percentile behaviour, but indicates the very unusual warm conditions of the winter of 97/98. The similarity of this map and the probability map shown in panel a and in particular by the warm tropical Atlantic and the broad sweep of warmth from the southern Caribbean east/northeast to Europe is striking. North America was also warm in both predictions and observations. There are apparent disagreements in the Southern United States where below average temperatures were forecast in panel a, but none observed on panel b. In fact this region was cooler than normal though not as cool as forecast. There is no warm anomaly over Brazil in the analysis, but this just indicates lack of data rather than the absence of an anomaly.

We also predict the probability for rainfall anomalies. Rainfall is a more chaotic variable, less likely to be skilful and more difficult to verify because of its small scale chaotic variability, but we include it because of its potential importance. Detailed verification on a country by country basis is unlikely to be meaningful, but in the tropics the broad-scale patterns of drought over the Indonesian region and over Amazonia are well forecast, though here too they differ in detail (Anderson 1997, 1998).

Figure 5 shows the anomalous height of the 500 hPa surface for DJF 97/98 from the coupled

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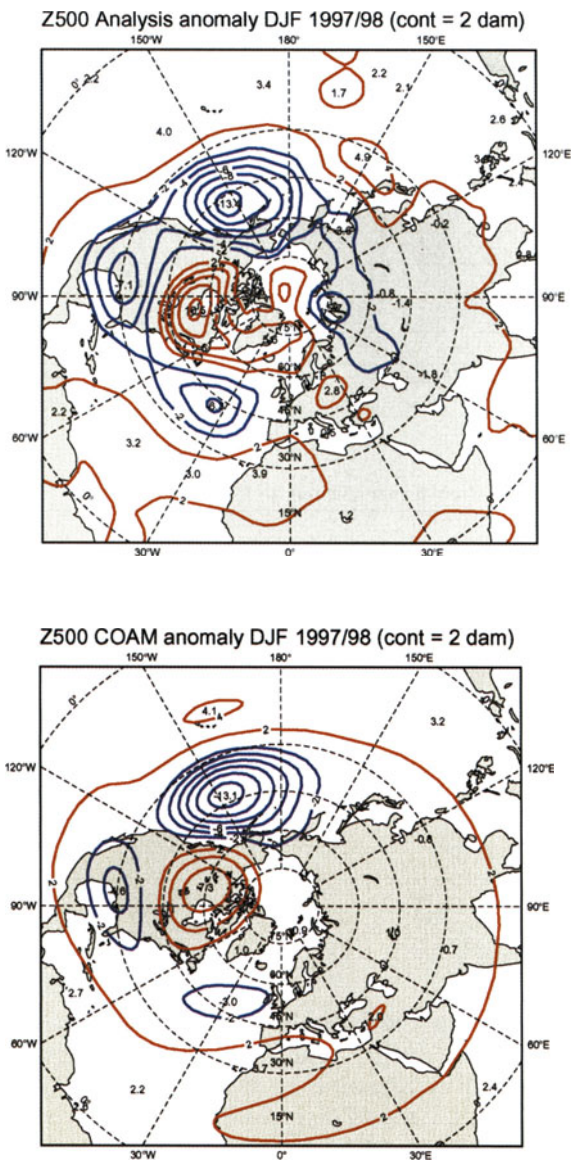


Fig. 5. The anomalous height of the 500 hPa surface for DJF 97/98 from the coupled model prediction from October 1997 (right) and the verifying ECMWF analysis (left)

model prediction from October 1997 and the appropriate ECMWF analysis. The ensemble mean forecasts from the coupled model did a splendid job of predicting the anomaly in the region of the Aleutians, a pretty good job over the United States but less well over the European region. The centre of the low over the Atlantic was reasonably well located but its amplitude was only half that observed. This could be because of model error, discussed below, but could also reflect the lack of perfect predictability which would be expected even in a perfect system.

Is the level of skill shown typical or only attainable in windows of opportunity associated with large El Niño or La Niña's (Livezey et al. 1997)? If one looks for a different year, say 1994/1995, one finds that the forecast ensemble mean is much less able to represent the observed anomaly pattern, and in this sense the forecast is less skilful. (In another sense, the lack of a consistent signal in the forecast ensemble might be an accurate indicator that the future is undetermined). This low level of skill is typical of the model forecast performance during the period 1991–96. A substantial cause of this could be relatively low levels of predictability in the Northern Hemisphere flow during these years. However, ensemble integrations of the same atmosphere model using observed SSTs generally have better skill scores than the coupled integrations, and predictability estimates from the internal spread of the ensembles also suggest that better forecasts should be possible. Two significant causes of forecast error are uncertainty in the ocean initial conditions, and error in the coupled ocean-atmosphere model.

We expect significant errors in the ocean initial conditions in the key region of the equatorial Pacific, and we expect the errors to be worse prior to the mid 1990s. It is only in the last year or two that the equatorial Pacific TAO array has been fully operating and providing good wind and ocean thermal data. (The TAO array consists of approximately 60 buoys anchored to the sea bottom, with instrumentation capable of measuring the ocean thermal structure at 10 levels between the surface and 500 m and transmitting this data to satellite and then onto the GTS. In addition surface winds are measured and transmitted 3 times per day and also put on the GTS.) Our analysis of ocean initial conditions depends not just on in situ ocean data, but also on the forcing given to the ocean by the atmosphere. Variations in the quality of the wind stress and heat and fresh water fluxes provided by the ECMWF operational atmospheric analysis system give cause for concern, and probably also contributed to lower forecast skill in the early to mid 1990s. ERA-40 should give a more consistent set of forcing fields, which will help us produce improved analyses for the 1990s in the future.

One way to assess potential skill is to suppose one had perfect knowledge of the SST, and

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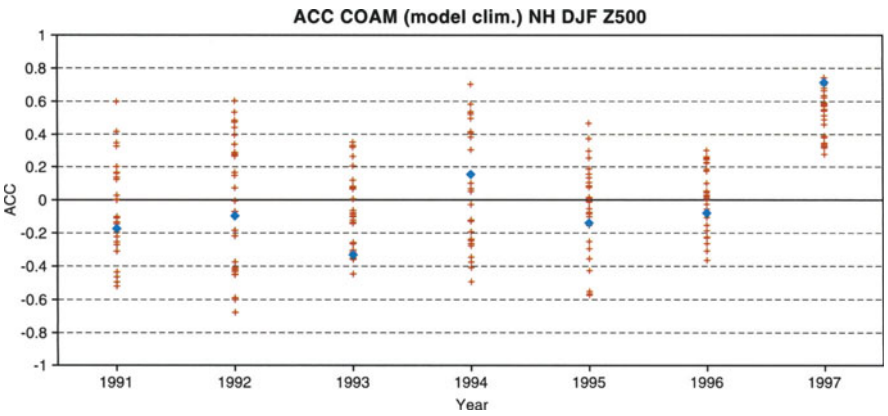


Fig. 6a. Anomaly correlation of the individual ensemble members for the period 1991–1998 (crosses) and of the ensemble mean (diamond) from the coupled integrations

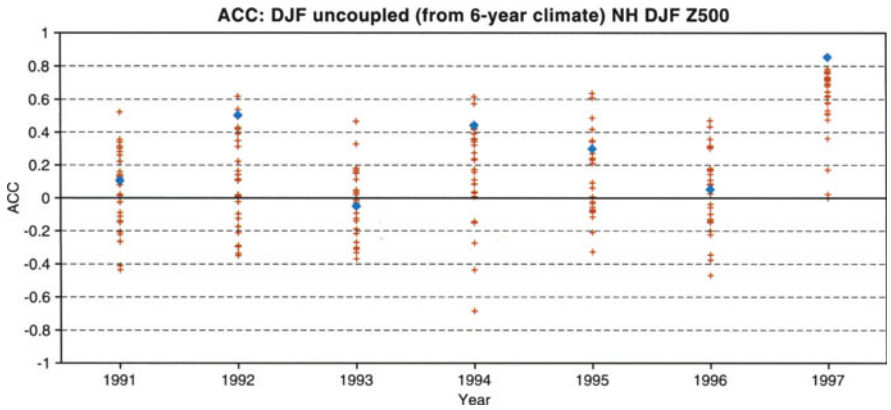


Fig. 6b. As 6a but using observed SSTs

by making ensembles of integrations of an atmospheric model with prescribed SSTs quantify the extent to which the observed atmospheric response is reproducible. This has been done for the years 1991–1998 using the same version of the atmospheric model as is used in the coupled system. A comparison of individual and ensemble-mean skill scores (500 hPa height anomaly correlation coefficient) for both coupled and uncoupled forecasts is shown in Figure 6, for the northern hemisphere. The ensemble mean skill is shown by the diamonds. It can be seen that the ensemble mean forecast from the uncoupled runs with prescribed SSTs are systematically more skilful than the coupled forecasts (for the latter, only 1997 showed skill). For the uncoupled runs, the anomaly correlation skill scores were positive over the northern hemisphere in 5 out of 6 years, (and positive over Europe in 4 out of 6 years).

Figure 6 also shows that there is a large spread in the skill of individual ensemble members, emphasising the effects of chaotic processes in middle latitudes, even for seasonally-averaged quantities. The fact that the ensemble mean skill is higher than that of an individual member in 1997/98 may seem a little surprising at first sight. The observed pattern can be thought of as a combination of a part which results from slowly evolving boundary conditions and a part from chaotic processes. The former is predictable in this model scenario with prescribed SSTs, the latter is not. Averaging over the ensemble will tend to reduce the chaotic part which in general will not correlate well with that observed.

In both the coupled and uncoupled integrations, the systematic error in middle latitudes is large, comparable in magnitude to the inter-annual signal which one is trying to predict. For example in the European region, the systematic error in the height of the 500 hPa surface is $\sim$13 dam, whereas the anomaly for 1997/98 was only 6 dam. Small wonder that the skill over Europe is limited. Preliminary results from perfect model scenario whereby one mem-

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ber of the ensemble is chosen at random and taken as truth, and against which other ensemble members are then evaluated, shows that skill levels are considerably higher than those currently attained. Such analysis has been done both for the coupled model for the period 1991–1997 and for the PROVOST integrations using prescribed SSTs covering the period 1979–1993. This highlights the need to reduce systematic error in the model and to improve ocean initial conditions. In the extratropics most of the systematic error in the coupled system comes from the atmospheric model.

In conclusion, the coupled system has done a good job of predicting equatorial Pacific sea surface temperatures for the recent El Niño event. There were at least two times when the forecasts were less than perfect. One was for forecasts for May-July of 1997 when the model under-predicted the rapid rise in Niño3 SSTs, the other was for forecasts for May-June of 1998 when the model under-predicted the rapid decline in Niño3 SSTs. Forecasts for tropical rainfall and temperature have generally been good for the recent El Niño. There is some indication of skill in the extratropics too. However, systematic error in atmospheric model integrations using prescribed SST and in the coupled integrations is large and this undoubtedly degrades any potential skill. Perfect model simulations indicate that the current system is operating considerably below its maximum potential. To improve the system requires a concerted effort to reduce the systematic error, much of which originates in the atmospheric model. Improvements in ocean model resolution, physics and initialisation are also needed. This involves improvements to the analysed fluxes of momentum, heat and fresh water, as well as a more comprehensive ocean observing system and more sophisticated ocean data assimilation schemes. Substantial work is also required to develop appropriate seasonal forecast products. Progress is expected in all of these in the years to come, but an optimal seasonal prediction system is still some way off.

Acknowledgements

The model integrations were partly carried out on a VPP300 machine donated by Fujitsu Limited. This work was supported in part by the European Commission. The Seasonal Prediction Project consists additionally of J. Alves, M. Balmaseda, C. Brankovic, L. Ferranti, T. Palmer, and J. Segschneider, who all contributed to the work on which this paper is based.

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IVe Early Warning Systems for Severe Weather Phenomena in mid and High Latitudes

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Services from the Norwegian Meteorological Institute Can Reduce the Effects of Disasters – Both Natural and Man-Made

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1 Introduction

Norway is a country which is strongly exposed to weather. Extreme weather events, often lead to loss of life and damage to property. Main economic activities in Norway such as fisheries and oil exploration are very sensitive to weather conditions. In the far north and in wintertime, conditions can be almost 'hostile' for many normal activities, such as communication (air, sea, rail and road). Furthermore, vital services such as the supply of electric energy to the Norwegian society can be interrupted due to extreme weather. Many of these activities, can only function well if good meteorological services are available and reliable.

2 DNMI and Prediction of Extreme Weather Conditions

The purpose of activities performed by the Norwegian Meteorological Institute (DNMI) is expressed in the Royal Decree of 10/2–1995:

> "The Norwegian Meteorological Institute provides the public meteorological services for both civil and military purposes.
> DNMI shall provide services for the authorities, commerce and industry, institutions and the general public, for protection of their interests, for protection of life and property, for planning and for protection of the environment."

In this paper, we claim that DNMI's services to society can reduce the effects of disasters, – both natural and man-made. Making this claim, we think mainly of situations that can lead to disasters in the Norwegian society or in its areas of responsibility and where meteorological conditions plays a vital part.

The cornerstone in these services is the output from Numerical Weather Prediction (NWP) models. Up to 48 hours, forecasts come mainly from DNMI's operational NWP model HIRLAM (HIgh Resolution Limited Area Model). For longer forecast periods, access to output from other weather-centers NWP models are assured through agreements and strong data transmission lines; f. ex. ECMWF (European Center for Medium range Weather Forecasts) and UK Met. Off.

Tailor-made 'tools' for different disaster situations have been developed at DNMI and the meteorologists on duty are regularly trained in the use of these specialized tools. Links have been set up for exchange of information and use of these meteorological products in decision-making processes. DNMI's personnel often take part in this process, to explain the significance of the meteorological information for the development of the disaster situation and its management. We can list:

1. *Extremely strong low-pressure* developments can lead *to winds of hurricane force.* Predicting these developments and informing society about potentially destructive accidents so that those most affected can take proper

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precaution, is a vital task for DNMI. In extreme situations, '*state of emergency*' for certain districts can be declared and DNMI's weather predictions and warnings of extreme weather conditions will set the premises when these decisions are taken (see more below).

2. *Heavy precipitation* combined with *strong snow-melt* in springtime (change in weather to a period characterized by relatively warm and windy airmasses) can *trigger flooding* conditions if other factors combine in the right mix. Predicting the strength of these changes and informing the hydrologists in charge in the decision-making team, is vital for taking the right decisions at the right time.
3. *Strong wind* and *snowfall* in wintertime can *disrupt vital communications*, both for traffic in air, at sea, with rails and roads. Good and reliable weather predictions are vital for sending out warnings and for the responsible authorities to take precautionary actions.
4. *Wind, precipitation* (*snow*) and *changes in temperature* in wintertime can prime the conditions for *snowslides* (*avalanches*). In a country with Norway's topography, snowslides occur frequently in winter and spring. They usually follow predictable tracks almost every year and seldom causes great accidents. But in certain situations the snowslides may occur at unexpected times and places. To predict these conditions and send out warnings to those most probably affected is a challenge to DNMI's services.
5. *Strong low-pressure* developments can lead to *high tides* and *storm surges*, causing large damages in coastal areas. Prediction of these situations and sending out warnings in due time can be very important so that precautionary actions can be taken to secure life and property.
6. *Dry and warm conditions* (less precipitation then normal for a long period of time in the summer season) can lead to *high risk for forest fires*. Warnings are usually sent out with the weather forecasts when the risk is high in certain areas.
7. *Accidents* with *oil-related* activities resulting in *oil-spill* and *marine pollution* can lead *to damage to property and environment in coastal areas*. Predicting the transport path of these marine oil-spills is vital for right and timely precautionary actions to be taken and for the best use of available resources.
8. *Nuclear accidents* (Chernobyl) and releases of radioactive substances to the atmosphere can cause problems and have large consequences far away from the release point. Even though Norway does not have large nuclear installations on its own territory, neighboring countries have and nuclear accidents are regarded as one of the largest environmental risks to Norwegian area of responsibility. A state of high preparedness is needed for DNMI to be able to predict the pathway of these airborne pollutants in serving the needs of the 'Norwegian Nuclear Preparedness Organization' (see more below).

We will now go into more detail of the situations listed under points 1 (*extremely strong low-pressures*) and 8 (*nuclear accidents*) and show how DNMI's services fits into the organizational framework responsible for handling the emergency situations that may arise in these situations.

3 Extremely Strong Low-pressures

In the early hours of January 1, 1992, a 945 hPa low approached the Norwegian west coast from the southwest (see Figures 1 and 2). In connection with the back-bent occlusion on the southern side, hurricane force winds were encountered over a fairly large area. The coastline from Stad (62.33oN, 5.27oE) to Ørland (63.70oN, 9.60oE) was hardest hit. Many weather observing stations recorded a sustained mean wind speed of 30 m/s or more, with gusts of at least 50 m/s (Breivik et al. 1992). The wind and rain caused enormous havoc; buildings, boats and land areas to an amount of about 1.7 billion Norwegian kroner (USD 200 millions) were ruined. Every fifth family in the region hit by the storm was affected, with the number of recorded damages being almost 40 000 (Ohm 1993). Although statistical material is sparse, it is estimated that such an event has a return period of approximately 200 years (Roebber 1989; Aune & Harstveit 1992). This makes the storm the largest natural disaster in Norway in modern time.

The storm, which had an almost 'explosive' development, was generally well predicted by

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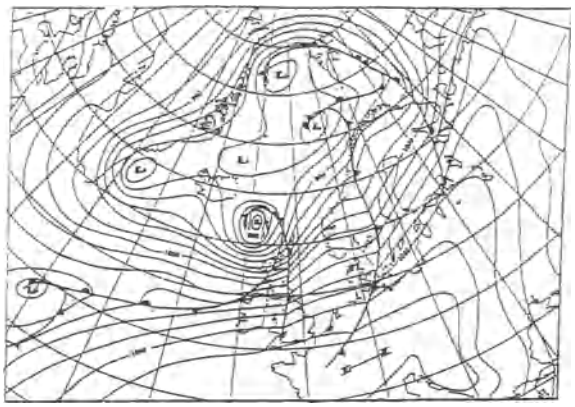


Fig. 1. Surface map showing MSLP and position of front, valid 00 UTC 1 January 1992. (From Breivik et al. 1992)

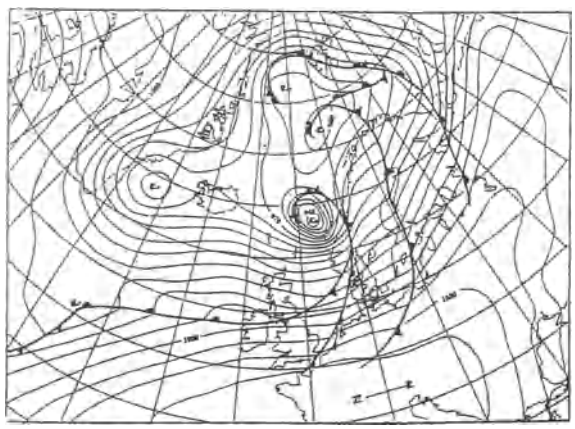


Fig. 2. Surface map showing MSLP and position of front, valid 06 UTC 1 January 1992. (From Breivik et al. 1992)

the operational numerical weather prediction (NWP) models. In Norway, mainly four models were used at that time for operational weather forecasting: DNMI's LAM50S (Limited Area Model with 50 km grid squares), the British UKMO-global and fine mesh models and the ECMWF (European Center for Medium range Weather Forecasts) model. Among these models the last two did particularly well in predicting both the position of the storm and the intense winds on its southern side (Breivik et al. 1992).

This enabled the meteorologists on duty to forecast extreme weather conditions for an extended area of Western Norway and allowed warnings to be given well in advance over radio and television. We do not know if everyone in the most affected area did take precautionary actions to the extent possible, but most people did and property and life were saved. (No loss of life occurred in Norway in this storm event, but 3–6 people died due to accidents in repairing damages that resulted from the storm.)

As a result of the havoc caused by the storm, trees fell over and damaged electric power lines and the electricity supply to a large district was cut out. Kristiansund and the surrounding area with a population of about 30 000 people lost its electric power for more than a week. Since most people in Norway use electric energy for heating their houses in wintertime, this was a difficult situation for most people in that district, especially for sick and elderly people.

4 National Preparedness Plan

The experiences from this storm and a storm of almost similar force occurring a year later, resulted in an initiative from DNMI to work out a national plan for preparedness on forecasting extreme weather, issue warnings and on how such situations should be handled. The working-group, consisting of people from the Ministry of Police and Justice, Ministry of Administration and Planning and from DNMI, delivered its report in November 1994 and the plan were implemented soon after (DNMI 1994).

Since this plan is a backbone for DNMI in its activities to forecast extreme weather and issue warnings, we will quote some sections from this national preparedness plan:

4.1 Purpose

This preparedness plan shall help both society and individuals to act in such a way that life and property are secured and the extent of damage due to extreme weather events are reduced. The plan makes it clear when 'extreme weather' warnings shall be issued, to whom it shall be delivered and who has the responsibility to communicate to official authorities and the general public. The purpose is to make unique, simple and secure communication between DNMI, those responsible and those affected in different preparedness situations.

4.2 Extent

Warnings of forecasted extreme weather conditions shall cover:

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- Wind
- Storm surge
- Snowslides (avalanches)
- Extreme precipitation
- Weather conditions which can result in flood.

There is given definitions and criteria for when warnings on 'extreme weather' conditions are to be issued.

4.3 Responsibility

DNMI is responsible for sending out warnings on extreme weather conditions. DNMI's warnings shall include situations which can result in flood.

The warnings are sent to: Main Rescue Center North (HRS nord) - and - Main Rescue Center South (HRS sør).

DNMI has the responsibility to inform Norwegian Broadcasting Corporation (NRK).

4.4 Local radio stations

The role of the local radio stations in crisis situations is defined in an agreement between the Prime Minister's Office, Norwegian Broadcasting Corporation (NRK), Norwegian Telecommunication Company and Norwegian Association of Local Radio Stations.

The County Chief Administrative Officer or Chief of Police decides if the situation is such that the Authorities have a need to communicate directly to the public in a district and to send out extraordinary information to save life and/or reduce the extent of damage that may arise.

5 Experiences with the Functioning of the Plan

The national preparedness plan for extreme weather warnings has now been in use for nearly 4 years. Both in real weather situations and in realistic exercises the plan has been tested and both the authorities responsible for crisis management and the general public are very satisfied so far. The plan seems to have filled a need. A leading principle is that crises/disasters should be managed on a regional level from the decision-making point of view. Also for DNMI the plan functions well and is a structured framework for sending out warnings on extreme weather conditions. Frequent and direct contact with the decision-makers (County Chief Administrative Officer, Chief of Police, etc.), enables DNMI to better understand their needs for information in crisis management.

It is stated in the preparedness plan when actual warnings of extreme weather events shall be issued. A guideline has been that it is better to issue one warning too often and be prepared for a predicted storm (if the probability seems high, even though it does not develop extreme weather conditions) - then not send out warnings at all. But too many warnings that "the wolf is coming!" can lead to a credibility problem. This ends in a difficult balance situation for the weather forecaster - of too many or too few warnings.

6 Nuclear Accidents

The Chernobyl accident in April/May 1986 showed that Norway was badly prepared for this kind of emergency situation (NOU 1986:24A). We experienced this event at a safe distance from the site of accident (so we thought), Norwegian territory was affected by high concentrations and large depositions of radioactive pollutants released to the atmosphere as a result of the accident.

Scientists and institutions who had relevant information on the subject, felt frustrated because there was no clear answer to the question: Where and how should their information be delivered, assessed and synthesized? (NOU 1986:24A). The authorities had no clear and unique strategy on how to inform the general public. Media gave a confusing and often misleading picture of the situation and an information crisis developed (NOU 1986:19). In addition, there was no atmospheric transport/dispersion model implemented in an operational environment ready to simulate and forecast transport/deposition of the radioactive pollutants based on real-time meteorological data. This was the situation not only in Norway, but in most other countries in Europe as well (Smith & Clark 1989).

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Norway is much better prepared to handle such an emergency situation today (NOU 1992:5). A new centralized administrative structure has been set up, consisting of representatives from most national institutions who have relevant expertise for the management of this kind of emergency situation. This new structure was named 'Norwegian Nuclear Preparedness Organization' and is under the leadership of Norwegian Radiation Protection Authority (NRPA). The Nuclear Preparedness Organization is given wide responsibility for crisis management: It can request resources to analyze and assess the situation, make decisions and implement the decided measures and inform the general public through radio and television. Special importance has been given to having a well prepared information strategy in crisis management.

In this organization DNMI plays an important part in answering questions like: Will the Norwegian area of responsibility be threatened by the accident? Where and when will the effect first be noticed? Can we expect harmful concentrations and depositions of radioactive substances? To be able to answer such questions, a real time dispersion model implemented in an operational environment is needed to give the decision-makers updated analysis and prognoses of the atmospheric transport/dispersion of the radioactive pollutants (NOU 1992:5).

Such a model – SNAP (Severe Nuclear Accident Program) – with the capability of predicting the transport, concentration and deposition of the emitted radioactive substances, has now been developed and implemented for operational use at DNMI (Saltbones et al. 1996). The results from this model can rapidly be transmitted to the decision support system at NRPA, where it can be displayed and used together with other relevant information to help the decision-making team to make right and timely decisions.

SNAP is now fully operational at DNMI, which means the meteorologists on duty can start simulations at any time – day and night. Every week DNMI personnel run simple training exercises on how to respond in case of nuclear accidents. SNAP is also a useful tool in special studies to assess the threat to our country from nuclear installations abroad. Figures 3 and 4 shows examples of output from SNAP for a hypothetical release at Kola Nuclear Power Plant in Russia (Saltbones et al. 1997).



Fig. 3. The map shows the 'mass concentration' in the cloud in the atmospheric boundary layer 48 hours after the release started. The lines represents values for the mass concentration: 1, 3, 10, 30, 100, etc. * 10–12 g/m^3. In the sea out of Møre, we find values in the range (30–100) * 10–12 g/m^3. North of Finnmark the values are three times as large. (From Saltbones et al. 1997)

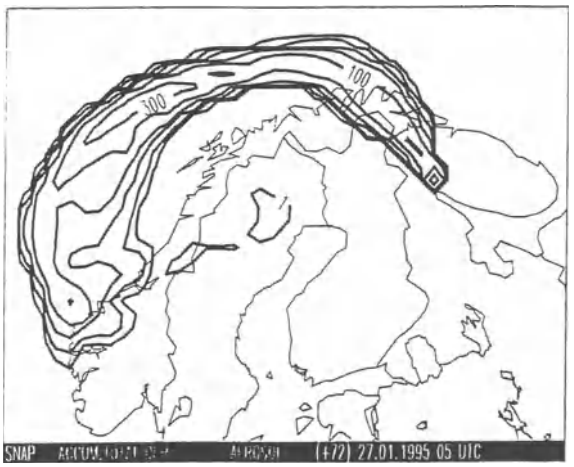


Fig. 4. The map shows the total deposition (wet + dry) at 72 hours after the release started. The isolines represent values for the deposition: 1, 3, 10, 30, 100, etc. * 10–9 g/m^2. We find high values close to the source ~(1–3) * 10–6 g/m^2 for a limited area. This is the result of both wet and dry deposition. Out over the sea west of Lofoten we find a large area where the values for the deposition are in the range (0.3–1) * 10–6 g/m^2. This is typically the result of wet deposition. The overall impression of this deposition field is dominated by the wet deposition. (From Saltbones et al. 1997)

7 Conclusions

In this paper we have given examples of disaster situations where DNMI's services are useful contributions in crisis management. The experiences from the storm of January 1, 1992, led to

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the implementation of a more structured framework where DNMI was given the responsibility of issuing warnings on extreme weather conditions. The list of different situations which can lead to weather-related disasters is long and include both natural and man-made events. A state of high preparedness is essential for successful crisis management and DNMI's contributions are an important premise for that end.

To be able to do the job properly, the personnel on duty at DNMI's operative weather-center must be well trained in the use of the special crisis procedures and in the use of the 'tools' for providing the meteorological products needed to support the decision-making process. The key word here is communication, – both in a technical sense and in explaining the significance of the meteorological information for the development of the disaster situation to the decision-maker. Feedback from the end-users of DNMI's services in crisis management stress the importance of this direct contact between the meteorological experts and the decision-making team. This is regarded as essential for successful crisis management.

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The Early Warning and Forecasting System (EWFS) for the Reduction of Serious Atmosphere-Hydrosphere Disasters

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Abstract

The Early Warning and Forecasting System (EWFS) for the Reduction of Serious Atmosphere-Hydrosphere Disasters is expounded in this paper. The system can operate in real-time, has achieved obvious economic and social benefits, and was established about 6 years ago. The system concentrated initially on heavy rain-floods and typhoons.

EWFS consists of a pre-warning servicing system, an information system of disaster reduction, a synthetic database, disaster forecast and assessment, countermeasures for disaster reduction, and local demonstrating systems in six provinces and cities.

In the recent few years, EWFS has been operating in real-time, and has achieved more than 1 billion RMB economic benefit in the reduction of disaster losses, and has also achieved obvious social benefits. EWFS was established as a better base for modern China's Preventing and Reducing Disaster Set-up (CPRDS) and China's Centre of Disaster Reduction (CCDR). This scientific system has been awarded the National Prize and the first class Prize of CAS.

The system is a highly scientific and technological system for disaster reduction, and can operate in real time. It opens up new ideas on disaster reduction.

Total losses resulting from Chinese natural disasters is about 3–6% of Chinese General National Production (CNP) which becomes an important factor, as it restricts rapid and sustained development of society and the economy of China. Atmosphere-Hydrosphere Disasters are concentrated on primarily for preventing and reducing disasters in China, because their losses represent about 60–70 % of Chinese total losses (Wang 1995).

In modern disaster prevention and reduction, the most urgent work is to establish China's Preventing and Reducing Disaster Set-up (CPRDS) by extensive use of modern new technology. When we establish the CPRDS, an operating demonstrating scientific system is the CPRDS's pioneer. If the scientific system was demonstrated successfully, it will inspire us to establish CPRDS and CCDR (Wang 1993).

About 6 years ago, based on CPRDS's recognition of the serious consequences of atmosphere-hydro disasters, and more mature atmosphere-hydro science and technology; the Early Warning and Forecasting System (EWFS) for the Reduction of Serious Atmosphere-Hydrosphere Disasters was established. The system initially concentrated attention on heavy rain-floods and typhoons. In summer and autumn of 1994 and 1995, the system operated day by day in real-time, and it carried out disaster monitoring, forecast warning, assessment and countermeasures etc. A new system of disaster reduction was opened up, and it resulted in obvious social and economic benefits (Wang et al. 1996). Many foreign experts are paying attention to this system.

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1 Synthetical Scientific System of Disaster Reduction

Although general meteorological, oceanic, geological and water conservancy monitoring and forecasting systems have been established, and they play an important role in preventing and reducing disasters in China, they have serious shortcomings for preventing and reducing great disasters (Wang 1993). The serious shortcoming are that the great disasters represent sudden change and synthetics. So we must establish modern China's Preventing and Reducing Disaster Set-up (CPRDS), and apply all established engineering, systems and equipment of disaster reduction, to monitor, forecast and warn of serious disasters, and produce rapid response to or reduce disasters (Wang 1995).

EWFS is the demonstrating system of the new set-up. Its main objectives are heavy rain-floods and typhoons which represent the most serious disasters in China. In order to extensively apply meteorological, oceanic, and water conservancy systems, monitoring and warning occur on a daily basis in real-time, and forecasts and assessments are issued 1–3 days in advance. All the above activities directly serve central and local government departments responsible for preventing and reducing disaster. It is successful.

EWFS consists of 6 parts and 2 sub-systems, as shown in Fig. 1. There are pre-warning serving system of heavy rain-floods and typhoons, information systems for disaster reduction, a synthetic database, a disaster forecast and assessment system, a countermeasure system for disaster reduction, and local demonstrating systems in Hubei, Sichuan, Henan, Jiangsu, Guangdong provinces and Shanghai city. Two sub-systems are: an information input system of serious disasters, and a distribution system of new products for EWFS (Wang et al. 1996). The system is introduced as follows:

This system collects all different kinds of text graph and image data related to serious disasters from meteorological, water conservancy, oceanic and disaster situation systems by using remote network, local network, satellite, radio and wire communications methods in real-time (Liang et al. 1996).

To give national meteorological forecasts, a pre-warning service system for serious disasters was established by applying special advanced platform techniques in the 1990's, opening up a lot of software, establishing special government lines, and perfecting the TV program production and distributing system (Wang & Wang 1996).

Information systems for disaster reduction collect a volume of real-time meteorological, water, conservancy, oceanic, remote satellite, disaster situation, and geographical information by using remote and local networks in China and abroad, and process disastrous information in real-time by the use of management workstations, real-time workstations, and assessment workstations, as well as synthetic databases (Liang 1996).

Synthetic database and assessment system: the synthetic database of this system is different to the general disaster database, which contains only historic data. Our synthetic database is a real-time database which can operate day by day. This therefore, represents a new step in disaster reduction. At the same time, it contains other social-economic data including social, economic, demographic and geographic data. This database can correlate great natural changes (i.e. hazards) with mankind society. In the assessment system, many methods of assessing disasters were studied, combining monitoring, pre-warning, real-time information, data and assessment of disasters in one system, and can be used for real-time disaster reduction (Li & Lu et al. 1996).

The countermeasure system of disaster reduction arranges the steps and actions relating to disaster reduction. We use all monitoring, pre-warning and assessment information or ideas, then present countermeasures to central governments by special lines or distribution systems. In the future, this part will be developed into the Auxiliary Decision Making System (ADMS) (Xu & Lu et al. 1996).

As most disaster reduction measures are carried out by local governments, we established six demonstrating systems in local regions. The heavy rain-flood disaster is the main emphasis for Hubei, Sichuan, Henan and Jiangsu systems; and the typhoon disaster is the main emphasis for Quangdong and Shanghai. The systems were built and operated in the above six provinces and cities, and achieved obvious successes.

Finally, the products of our system are distributed to ministries, departments, users and news agencies using government special lines

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or communication networks. These serve the government and the public, and provide social benefits.

2 The Characteristics and Achievements of the System

2.1 The Characteristics of the Scientific System

1. Initial real-time operating system of disaster reduction (it operated 100 days continually in summer 1995);
2. It can withstand serious Atmosphere-hydro disasters, and monitor or provide pre-warnings of them;
3. To forecast time, region strength and potential losses 1–3 days in advance of a disaster (in 1995, forecasted main disasters in middle and lower reaches of Yangtse river and north-eastern China successfully). This is a break through in disaster reduction.
4. To rapidly complete macroscopic assessment of serious disasters and provide information to disaster reducing departments;
5. Local systems of disaster reduction can be extended and utilised.

2.2 Main Achievements

1. A forecast and warning service system for typhoons and heavy rain-floods in China was studied and perfected.
2. Six local forecast and warning service systems for heavy rain-floods or typhoons (i.e. Hubei, Sichuan, Henan, Jiangsu, Guangdong and Shanghai) were studied and perfected.
3. An information system of disaster reduction for heavy rain-floods and typhoons was studied and established.
4. A synthetic database of disaster reduction for heavy rain-floods and typhoons in China was studied and established, and a lot of special databases were established.
5. Disaster assessment and countermeasures of heavy rain-floods and typhoons were studied.
6. 250 papers or reports were published.
7. A reduction in disaster losses of more than 1 billion RMB represents considerable economic benefit, according to statistical results of benefit certificates for disaster reduction;
8. Wide social benefit was obtained by using forecasts, warning services and disaster reduction measures of heavy rain-floods and typhoons to inform the public, the government and meteorological stations; the TV forecasting and warning service alone covers 700 million persons.

These achievements have been awarded with the national important achievement prize for "8–5" scientific and technological projects, and at the same time were awarded the first class of Scientific and Technological Progress Prize, Chinese Academy of Sciences in 1996. In 1997 it was awarded the second class of National Scientific and Technological Progress Prize.

3 Significance, Problems and Cooperation Purpose

3.1 Significance

To establish modern China's Preventing and Reducing Disaster Set-up (CPRDS) is an important strategy for guaranteeing rapid and sustained development of Chinas society and economy. Apart from significant non-engineering undertakings and scientific or technologic programs of disaster reduction, the first important thing is to establish "China's Centre of Disaster Reduction" (CCDR) (Wang 1993, 1995; China National Committee for IDNDR 1993). CCDR will combine all systems, large engineering and non-engineering undertakings, programs etc. to form the modern CPRDS (Wang 1991).

Although we observed some systems when visiting Europe, USA and Japan, etc., these are very different to our set-up. We must therefore establish our modern CPRDS by ourselves, to realise our strategy of disaster reduction. For this objective, it is very important to establish a scientific demonstrating system which has Chinese characteristics and correspond to the actual Chinese situation.

It is a positive move that this scientific demonstrating system was established and operated, and has obtained considerable successes. EWFS is a better base for CPRDS and CCDR, and its significance is great.

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3.2 Problems

- How to develop this scientific system into a professional system?
- How to perfect the Auxiliary Decision Making System (ADMS) and disaster reduction by using urgent preventing-combating-relief system?
- How to develop these demonstration disasters to apply to all important disasters?
- How to establish CPRDS and CCDR, and let them operate successfully; etc.?

3.3 The Cooperation Purpose

- To perfect this system;
- To establish this system in other countries, if it is needed, and perfect or improve it;
- To promote CPRDS and CCDR;
- To extend the above system to the world, and to contribute to IDNDR.

4 Conclusions

This system is an important achievement which was developed over the past 6 years. It is now at an advanced stage and has had provided active benefits; the system is a strong instrument and system for reducing serious disasters. We hope that China and the USA have the foresight and sagacity to cooperate to establish CPRDS, and to perfect an advancement for IDNDR.

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V Early Warning Systems for the Mitigation of Geological Hazards

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CHAPTER 5.1

Early Warning Systems for the Mitigation of Geological Hazards – an Overview

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4 Tsunamis 405

For all geological hazards, e.g. earthquakes, volcanic eruptions, landslides and tsunamis, hazard and risk assessments are needed as a basis for long-range planning, and for allocating resources for early warning systems. Warning systems must build on public awareness and commitment by public authorities. Decision making for disaster management could be substantially improved by better integrating information systems and paying more attention to specific, tailor-made products.

1 Earthquakes

- Transmission of earthquake data to threatened communities before seismic waves arrive is becoming more widely used in order to shut down or modify critical operations.
- Damping of earthquake shaking in buildings can reduce resonance and minimize damage.

2 Volcanic eruptions

- Numerous volcano monitoring efforts were undertaken during the IDNDR, with some successful predictions, most notably at Mt. Pinatubo in the Philippines.
- Volcano warnings have demonstrated the importance of involving all the sectors of society.

3 Landslides

- Landslides, avalanches and rock falls cause substantial damage in mountainous terrains
- Strategies for monitoring potential landslides involve the trade-off of proximity to the source area and a longer lead time against a better assessment of the threat and a shorter lead time.

4 Tsunamis

- An effective warning system operates for the Pacific Basin for distant source regions.
- Local and regional tsunamis pose a large threat, and usually arrive with little warning.

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Va Early Warning Systems for Earthquakes

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Earthquake Early Warning Systems: Current Status and Perspectives

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Abstract

As increasing urbanization is taking place worldwide, earthquake hazards post strong threats to lives and properties for urban areas near major active faults on land or subduction zones offshore. Earthquake early warning systems can be a useful tool for reducing earthquake hazards, if cities are favorably located with respect to earthquake sources and their citizens are properly trained to response to earthquake warning messages. The physical basis for earthquake early warning systems is well understood, namely, destructive S- and surface waves travel at about half the speed of the P-waves, and seismic waves travel at much slower speed than signals transmitted by telephones or radios.

At least three countries have earthquake early warning systems in operation: (1) Japan, (2) Mexico, and (3) Taiwan. These systems can provide a few seconds to several tens of seconds of warning for large earthquakes. With recent emphasis on real-time seismology, operators of many regional and local seismic networks are now upgrading their systems to reduce the time for issuing an earthquake notice from several minutes to under a minute, thus potentially making earthquake early warning a technical possibility. More significantly, a properly upgraded seismic network can provide a shake map within minutes after a disastrous earthquake, so that loss estimation from an earthquake can be quickly assessed to aid disaster response and recovery.

At present, the Seismic Alert System (SAS) in Mexico City is the only system issuing earthquake warning directly to the public. As it is appropriated for the International IDNDR-Conference on Early Warning Systems for the Reduction of Natural Disasters (EWC'98), we will discuss the societal experience of this system during the past few years.

1 Introduction

The present technology in seismic instrumentation and telecommunications permits the implementation of a computerized system for earthquake early warning. Such a system is capable of providing from a few seconds to a few tens of seconds of warning before the arrival of strong ground shaking caused by a large earthquake. This timely information may be used (1) to minimize property damage and the loss of lives in metropolitan areas, and (2) for

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real-time loss estimation to aid emergency response and recovery. The purpose of this paper is to present a brief review of the advances in earthquake early warning systems and to examine its current status and perspectives. As this paper is intended for a general audience, no technical details will be presented, but the interested readers can consult the extensive bibliographic references given at the end of the paper. Because the Seismic Alert System in Mexico City is the only system issuing earthquake warning to the public, we will discuss the societal experience of this system during the past few years.

In addition to this EWC'98 International Conference, four technical sessions on earthquake early warning systems were held in conjunction with the following international meetings:

The XXI General Assembly of the International Union of Geodesy and Geophysics in Boulder, Colorado, USA (see Lee and Shin 1995), The Eleventh World Conference on Earthquake Engineering in Acapulco, Mexico (see Lee and Espinosa-Aranda 1996), The 29th General Assembly of the International Association of Seismology and Physics of the Earth's Interior in Thessaloniki, Greece (see Lee et al. 1997), and International IDNDR Conference on "Modern Preparation and Response Systems for Earthquake, Tsunami and Volcanic Hazards" in Santiago, Chile (see Instituto Geografico Militar de Chile 1998).

The references cited above gave abstracts (and sometimes, extended summaries) of papers submitted. Complete papers for the Mexico session can be found in the Proceedings of the Eleventh World Conference on Earthquake Engineering on CD-ROMs.

In addition, several papers related to earthquake early warning were presented at the Union session on "Hazard Mitigation: Use of Real-Time Information" during the 1997 Fall Meeting of the American Geophysical Union in San Francisco, California, USA (see Ward and Cluff 1997). A progress report on "Real-time Seismology and Earthquake Hazard Mitigation" was presented by Kanamori et al. (1997) in the popular scientific journal, Nature. References to technical details will also be given as we discuss the issues below.

An earthquake early warning system can be constructed from systems for real-time monitoring. Such real-time systems have other applications, e.g., in tsunami warning and in monitoring volcanic eruptions. However, it is beyond the scope of this paper to discuss these topics.

2 Some Background Information

Cooper (1868) proposed the idea of an earthquake early warning system for San Francisco, California, more than one hundred years ago. In the mid-nineteenth century, there were frequent earthquakes near Hollister, California, about 120 km southeast of San Francisco. Cooper proposed to set up seismic detectors near Hollister and when an earthquake triggered them, an electric signal would be sent by telegraph to San Francisco. This signal would then ring a big bell in City Hall to warn citizens that an earthquake had occurred. At that time, scientists already knew that an electric signal travels much faster than seismic waves. Unfortunately, Cooper's scheme was never implemented. More than 100 years later, Heaton (1985) proposed a seismic computerized alert network for southern California, and Bakun et al. (1994) implemented an early warning system for aftershocks of the 1989 Loma Prieta earthquake using modern hardware in a scheme similar to Cooper's.

In the mid-1960's, China, Japan, USA, and USSR initiated extensive earthquake research programs. These programs emphasized earthquake prediction and some seismologists at that time were optimistic that earthquake prediction could be realized in 10 years. However, the ability to predict the time, place, and magnitude of an earthquake accurately remains elusive (U.S. National Research Council, 1991). More recently, Geller (1997) presented a critical review of earthquake prediction, and concluded that:

> Earthquake prediction research has been conducted for over 100 years with no obvious successes. Claims of breakthroughs have failed to withstand scrutiny. Extensive searches have failed to find reliable precursors.

It is now recognized that earthquake prediction is an extremely difficult problem to solve, because the earth is complex and we do not fully understand the earthquake generating process

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(Knopoff 1996, Evans 1997). Although earthquake prediction research is yet to attain its goal, increased funding from the 1960's has resulted in advances in many fronts in seismology, including the development of regional and local seismic networks (see for example, Lee and Stewart 1981).

We cannot ignore the increasing economic and human loss due to earthquakes because of rapid urbanization around the world. For example, recent earthquakes such as, the January 17, 1994 shock in Northridge, California, and the January 17, 1995 shock in Kobe, Japan, caused about USD 20 billion and USD 100 billion in damage, respectively; and over 5000 persons lost their lives in the Kobe earthquake. Therefore, in recent years some seismologists and earthquake engineers have turned their attention to developing and implementing systems that can provide early warning or rapid response to large earthquakes in order to minimize loss and to aid recovery.

3 Physical Basis for Earthquake Early Warning

The physical basis for earthquake early warning is simple: strong ground shaking is caused by shear (S) and the following surface waves (which travel at about half the speed of the primary (P) waves), and seismic waves travel much slower than electromagnetic signals transmitted by telephone or radio.

Figure 1 shows an example of a prototype system for earthquake early warning, which was implemented in Taiwan. Figure 1(A) is a map showing the geographic location of the Hualien Network and Taipei, capital of Taiwan. Figure 1(B) shows accelerograms recorded in Hualien and in Taipei from an earthquake marked by "*" in Figure 1(A). The amplitude of the Taipei accelerogram has been magnified 6 times relative to that of the Hualien accelerogram. The time scale is shown at the top of Figure 1(B). "O" stands for the origin of the earthquake, "P" for P-wave onset, and "S" for S-wave onset. In Hualien, the P-wave arrived in about 3 seconds, and the S-wave arrived in about 5 seconds after the occurrence of the earthquake. On the other hand, in Taipei

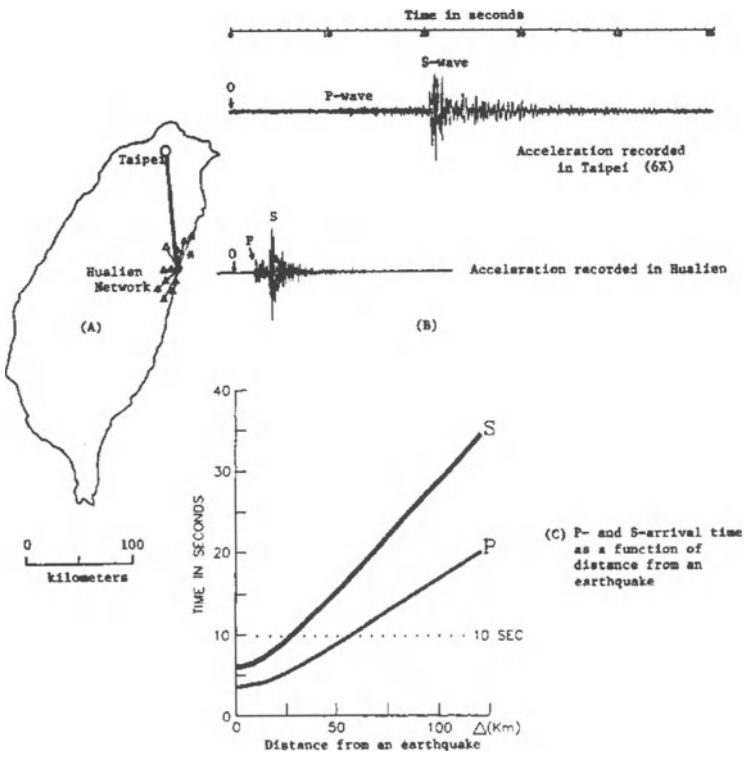


Fig. 1. A prototype earthquake early warning system in Hualien, Taiwan

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(about 120 km from Hualien) the P-wave arrived in about 12 seconds, and the S-wave arrived in about 21 seconds. In both cases, the amplitude of the S-wave is much larger than that of P-wave. Since the Hualien Network is capable of locating an earthquake and estimating its magnitude in about 10 seconds, a warning signal sent to Taipei by telephone circuit arrives just before the P-wave, and about 11 seconds before the larger S-wave.

To illustrate the above observation in general, we plot the travel time for P-wave and S-wave versus distance in Figure 1(C). We make the following assumptions of a typical destructive earthquake: (1) focal depth at 20 km, (2) P-wave velocity at 8 km/sec, and (3) S-wave velocity at 4.5 km/sec. If an earthquake is located 100 km away from a city, the P-wave arrives at the city in about 13 seconds, and the S-waves in about 22 seconds according to Figure 1(C). If we deploy a dense seismic network in the earthquake source area that is capable of locating and determining the size of the event in about 10 seconds, we will have about 3 seconds to issue a warning before the P-wave arrives, and about 12 seconds before the more destructive S-waves and surface waves arrive at the city. Here, we have assumed that it takes very little time to send a signal from a seismic network to the city by electromagnetic waves (e.g., telephone circuit) at nearly the speed of light (300 000 km/sec).

From Figure 1(C), it is clear that the above strategy may work for earthquakes located about 60 km or more away from a city. For earthquakes at shorter distances (say, 20 to 60 km), we must reduce the time for detecting the event and issuing a warning to about 5 seconds. For earthquakes within 20 km of a city, there is little one can do other than installing automatic shut-off devices for gases (for example) that can be triggered by the onset of the P-wave. Normally an earthquake that is more than 100 km away from a city does not pose a large threat to the city, because seismic waves would be attenuated by a factor of about 5 in general. There are exceptional cases due to unusual local site conditions, such as Mexico City, that will be discussed later.

4 Real-time Monitoring and Early Warning

There are two different approaches in implementing an earthquake early warning system. Nakamura (1988, 1996a, 1996b) used a single station approach, where seismic signals are processed locally and an earthquake warning is issued when ground motion exceeds the trigger threshold. Lee et al. (1996) used an array approach, where a central station processes signals from an array of stations and decides whether or not an earthquake exceeding certain threshold has occurred.

It was recognized in the 1960's that real-time seismic monitoring was critical to the earthquake prediction program. At that time, it usually took half an hour or more to locate an earthquake. In the late 1960's, J. P. Eaton, W. H. K. Lee, and S. W. Stewart demonstrated through a computer simulation that a real-time seismic monitoring system could be implemented to locate an earthquake within 1 minute (unpublished report submitted to the U.S. government). Two years later, an actual system was developed by this team at the U.S. Geological Survey (USGS) in Menlo Park (Stewart et al. 1971). Since then, numerous real-time monitoring systems have been developed and implemented worldwide.

In real-time monitoring, signals from seismic sensors in the field (either analog or digital) are telemetered to a central receiving station for processing. By real-time we mean that the results can be obtained within seconds or tens of seconds. In practice, there are several obstacles to achieving a quicker response. Large earthquakes normally occur at depth of a few tens of kilometers or deeper. It takes several seconds for seismic waves to reach the earth's surface where the seismic sensors are located, and several tens more seconds before sufficient numbers of sensors detect the seismic waves. In the experimental earthquake early warning system in Hualien, Taiwan, a 10-second or less response time has been achieved for earthquakes occurring inside or near the dense array with sensor spacing of about 2 km. However, such dense deployment of sensors is not economical to cover a large area in real practice.

In essence, a real-time seismic monitoring system consists of: (1) sensors deployed in the field, (2) telemetry, (3) a central receiving station where real-time data acquisition and processing are performed, and (4) if an potential

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damaging earthquake has been detected, then results are communicated via one or more communication channels to users. For an earthquake early warning system based on real-time seismic monitoring, we must achieve a response time that users can take actions before strong shaking arrives. Unfortunately, most urban areas of the world (except Mexico City and a few others) are not situated at a favorable distance from earthquake source regions for earthquake warning to be effective. Recent damaging earthquakes, such as Northridge and Kobe earthquakes, occurred in heavily populated areas, too close for any earthquake early warning system to be useful before strong shaking arrived.

It is interesting to note that the earthquake early warning systems in operation in Japan and Mexico were developed by engineers in response to a practical need. Whereas the real-time seismic monitoring systems developed by the seismologists are mostly for collecting data and for in-house research. This situation changed somewhat after the 1989 Loma Prieta, California earthquake. Rapid earthquake notification systems were developed in southern California ("CUBE", the Caltech/USGS Broadcast of Earthquakes, Kanamori et al. 1991) and in northern California ("REDI", the Rapid Earthquake Data Integration Project, Gee et al., 1996). These systems allow earthquake parameters to be broadcasted to users in a few minutes after the earthquake occurred. For the 1994 Northridge, California earthquake, rapid notification by CUBE was found very useful in emergency and recovery management (Eguchi et al. 1997).

Recently, Kanamori et al. (1997) summarized the progress on real-time seismology and earthquake hazard mitigation as follows:

> Recent advances in seismic sensor technology, data acquisition systems, digital communications, and computer hardware and software make it possible to build reliable real-time earthquake information systems. Such systems provide a means for modern urban regions to cope effectively with the aftermath of major earthquakes and, in some cases, they may even provide warning, seconds before the arrival of seismic waves. In the long term these systems also provide basic data for mitigation strategies such as improved building codes.

Real-time seismic monitoring is also critical for volcano studies. In particular, the IASPEI real-time seismic data acquisition and processing system (Lee, 1989; 1990) was used in the successful prediction of the Mount Pinatubo eruption in 1991 (Kerr 1991, Newhall and Punongbayan 1996).

5 Benefits of an Earthquake Warning System

An earthquake early warning system may provide the critical information needed (1) to minimize loss of property and lives, (2) to aid rescue operations, and (3) to assist recovery from earthquake damage.

The most effective use of earthquake early warning is to activate automated systems to prepare for incoming strong ground shaking. For example: slowing down rapid-transit vehicles and high-speed trains to avoid potential derailment, orderly shutdown of pipelines and gas lines to minimize fire hazards, controlled shutdown of manufacturing operations to decrease potential damage to equipment, and safe-guarding computer information by saving vital information and retracting disk heads away from the disk surface. All the above can be accomplished to a useful extent with a few seconds notification.

Although human response may take more than a few seconds, personal safety could be greatly enhanced if people were alerted: school children could seek cover under desks and workers could move away from hazardous positions. More importantly, early earthquake notification might reduce panic and confusion. The functions of a modern society, including civil and military operations, will be less likely to turn into chaos if an early earthquake notification is available and drills for appropriate actions have been performed. For example, the Mexico City Alert System (and associated programs to educate the public) demonstrated its usefulness during the September 14, 1995 earthquake (Espinosa-Aranda et al. 1995, 1996).

For an earthquake early warning system with sufficient numbers of well- distributed accelerometers (such as the realtime system in operation in Taiwan), we can estimate quickly the maximum expected ground-motion caused by an earthquake (i.e., a shake map), so that emergency response teams may be dispatched where they are needed most. In practice, such a shake map will be revised and updated as more infor-

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mation is received. In addition, an inventory of man-made structures and their vulnerability must exist so that loss estimation from an earthquake can be quickly assessed to aid disaster response and recovery. The usefulness of this approach is recognized, especially after the Northridge earthquake (Goltz 1996, Eguchi et al. 1997). Recently, the Federal Emergency Management Agency (FEMA) of the United States introduced a risk assessment methodology – Hazards United States (Hazus) to assist emergency managers in estimating earthquake risk in their jurisdictions (Nishenko 1998). The shake map produced by an earthquake early warning or rapid notification system is required for Hazus' approach in estimating loss after an earthquake disaster.

As noted before, few cities are favorable located so that an earthquake warning message can be effectively used before strong shaking occurs. Although Mexico City is favorably located for earthquake early warning, the experience of the SAS in Mexico City indicates that it is not easy to manage a public earthquake early warning system. Nevertheless, an earthquake early warning or rapid notification system is an important tool to provide the necessary information (e.g., a shake map) for effective earthquake mitigation and to monitor the seismicity after a disastrous earthquake.

6 Earthquake Early Warning Systems in Operation

We will now briefly review a few earthquake early warning systems that are currently in operation around the world. The two operating systems in Japan were developed under the leadership of Y. Nakamura and were designed to issue earthquake warnings for the railway operations (Nakamura 1996a, 1996b). J. M. Espinosa-Aranda and associates (Espinosa-Aranda et al. 1995, 1996) developed the Seismic Alert System operating in Mexico. Its purpose is to communicate an emergency message to the public in Mexico City. Two research-oriented systems have been implemented in Taiwan as a joint effort of the Central Weather Bureau, the Southern California Earthquake Center, and the U.S. Geological Survey (Lee 1995, Lee et al. 1996, Shin et al. 1996, Teng et al. 1997, Wu et al. 1997). We will also mention a few earthquake notification systems that are potentially capable of earthquake early warning, but whose main purpose is to provide rapid notification for emergency and recovery management immediately after a damaging earthquake.

6.1 Earthquake Early Warning Systems in Japan

For more than twenty years, Japan has benefited from an earthquake early warning system on their Japan Railway trains, including the "bullet" trains (Nakamura and Tucker 1988). This system consists of alarm seismometers installed every 20 km along the lines (see Figure 2). Currently, an intelligent earthquake warning system called UrEDAS is being implemented in Japan (Nakamura 1988, 1996a, 1996b). UrEDAS (Urgent Earthquake Detection and Alarm System) uses a single station instead of a network approach. An UrEDAS system detects initial P-wave motion of an earthquake and estimates its location and magnitude within about 3 seconds. Using the location and magnitude data, it then issues an alarm for the area of expected damage. By March, 1992, fourteen UrEDAS had been installed along the Tokaido Shinkansen line and a total of about 30 UrEDAS are now in operation (Nakamura 1996b).

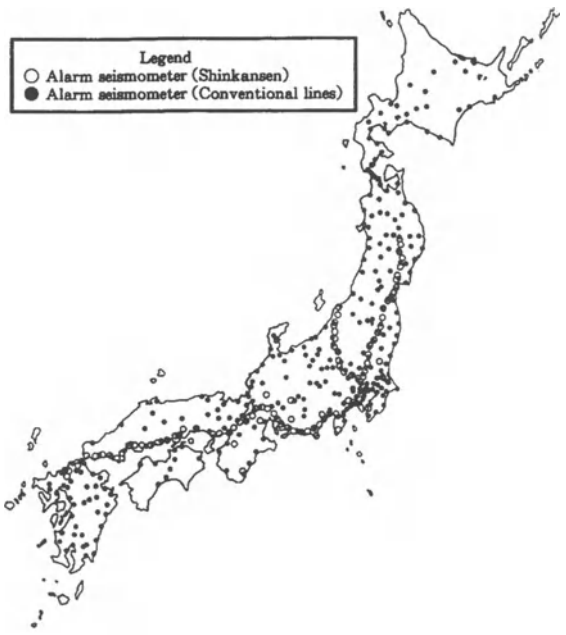


Fig. 2. Distribution of Japan Railway's alarm seis-mometers (courtesy of Dr. Y. Nakamura)

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During the January 17, 1995 Kobe earthquake, the alarm seismometers issued alarms within a few seconds one by one. All Tokaido UrEDAS (except at Gozaisho) judged the Kobe earthquake as harmless for the bullet trains and did not issue an alarm. However, the UrEDAS at Gozaisho, which is nearest to the bullet train line, did issue an alarm at about the same time as the older alarm seismometers. These results indicate that both old and new warning systems for the bullet trains functioned properly as designed.

6.2 The Seismic Alert System in Mexico

Mexico City suffers from considerable earthquake damages even though the earthquake sources are typically about 300 km away. The Michoacan earthquake of September 19, 1985 killed about 10000 people and left tens of thousands homeless in Mexico City. After the 1985 earthquake, a seismic alert system was designed and implemented by the Centro de Instrumentacion y Registro Sismico (CIRES) under the direction of J. M. Espinosa-Aranda. This system is named the Seismic Alert System (SAS), and it consists of four units: seismic detection, telecommunications, central control, and radio warning. The seismic detector system has 12 digital strong-motion field stations along 300 km of the Mexican coast at 25 km spacing as shown in the top portion of Figure 3. Each field station monitors the seismic activity within a 100-km radius and detects and estimates magnitude of an earth-

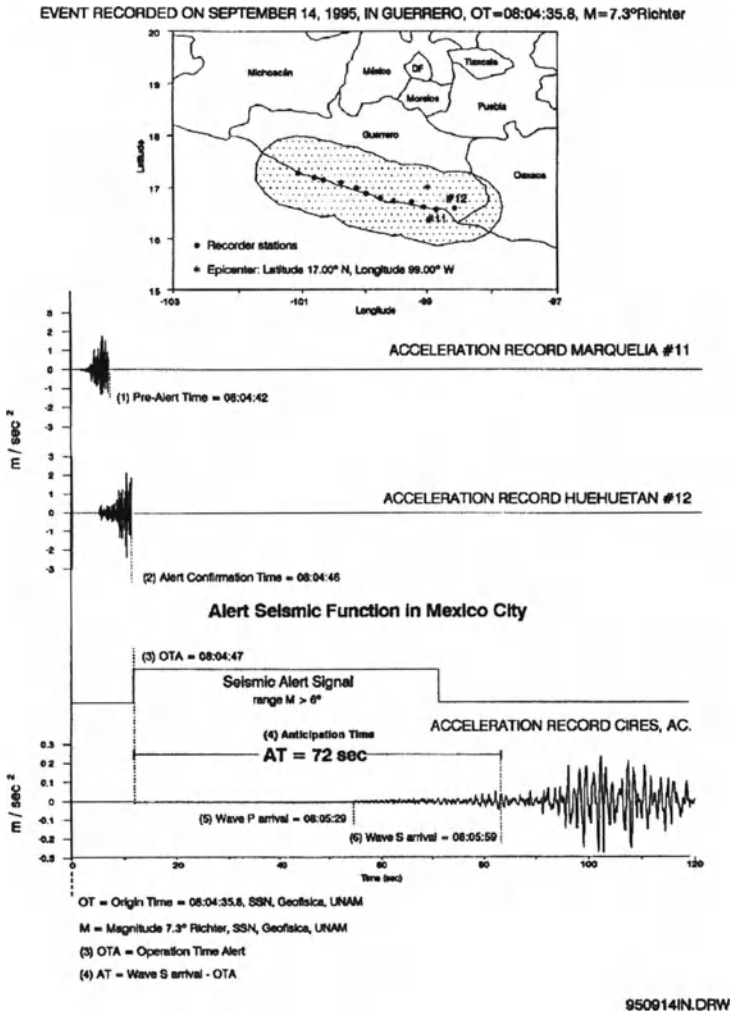


Fig. 3. Time diagram of early warning advantage in Mexico City, September 14, 1985

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quake within 10 seconds of its initiation. If the estimated magnitude is greater than 6, a warning message is sent via the telecommunications unit to the central control unit in Mexico City. A public alert signal is sent through the radio warning unit if two or more field stations confirm the occurrence of the earthquake.

The local magnitude is estimated for epicentral distances closer than 100 km, using an empirical relation embedded in each field station, this relation uses mainly the root mean square acceleration and its average evolution. The decision of emitting the early warning is taken by the central control system in Mexico City after receiving the estimates of other stations. During the operation of SAS, there have been some inaccurate magnitude estimations. To solve this, the empirical relation has been periodically adjusted using new earthquake data acquired by the system. Also, a minor adjustment to the central control unit enhanced the system by allowing general alerts only when at least two field stations estimate the magnitude of the earthquake as greater than 6.

In addition to implementing a practical earthquake early warning system, the Mexican group also paid attention to the utilization of the seismic alerts by the public. A comprehensive education program with drills was also implemented. The success of the SAS required support of the Mexican government and the cooperation of the public. Furthermore, Mexico City is favorably located with respect to earthquake sources so that there is sufficient time to react to earthquake warnings. Because the Mexico City system is the only earthquake early warning system in operation that is issuing an alert to the public when a large earthquake is detected, we will devoted a section on its societal experience later in this paper.

6.3 Earthquake Early Warning Systems in Taiwan

A strong-motion instrumentation program in Taiwan (to install an equivalent of 1000 three-component digital accelerographs) was begun in 1991 by the Central Weather Bureau (CWB). During the instrument acquisition, CWB was able to specify accelerographs capable of digital stream output so that they can be easily integrated into the existing telemetered seismic network.

In implementing the prototype earthquake early warning systems in Taiwan (Lee 1995, Lee et al. 1996, Teng et al. 1997, Wu et al. 1997), two approaches were explored. The first was to develop a dense telemetered accelerograph network (covering a very small area) with real-time data processing and communication, and the second was to expand the existing regional telemetered seismic network (covering the entire island) with modern accelerographs and real-time data processing and communication. In both cases, existing commercial hardware and the published IASPEI software (Lee 1989, 1990) were used to minimize the development cost.

A prototype system was implemented in Hualien, Taiwan, to explore the use of modern technology for earthquake early warning purposes. The prototype system consists of 12 remote three-component accelerometers telemetered digitally via 9600-baud telephone lines to the CWB Hualien Station. At the Hualien Station, the incoming digital signals are processed in real time and the results are telemetered to the CWB Headquarters in Taipei for control and display (Chung et al. 1995).

Another prototype system was implemented in Taiwan using the existing telecommunication facilities of the Taiwan Regional Telemetered Seismic Network (with 75 short-period, 3-component seismic stations) operated by CWB. This network uses only half of the bandwidth of 9600-baud telephone lines for telemetry. As first pointed out by T.L. Teng, the remaining half of the bandwidth of 9600-baud telephone lines can be utilized to telemeter data to CWB Headquarters without any increase in operational costs. With the availability of digital accelerographs capable of digital data stream output and the IASPEI real-time seismic monitoring hardware and software, CWB implemented a real-time, regional, telemetered strong-motion network for rapid response in Taiwan with very little additional capital and operational costs. A technical description of this system and its performance may be found in Shin et al. (1996), Teng et al. (1997), and Wu et al. (1997).

The main purpose for these two prototype systems in Taiwan is for research and development of methods and techniques for earthquake early warning. The results are not intended for immediate public release. The Taiwan Central Weather Bureau realized that with-

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out a strong program for educating the public on earthquake warning response, they are not yet ready to release earthquake warning messages to the public.

6.4 Other Systems

In addition to the systems described above, there are several other rapid response systems with potential earthquake early warning capability. We will just mention a few examples. A rapid response system is operating in Australia (Gibson et al. 1996). Since 1980's, the U.S. Geological Survey (USGS) in Menlo Park has an earthquake rapid response system for in house use. In recent years, the California Institute of Technology (Caltech) and the USGS have a "CUBE" (Caltech/USGS Broadcast of Earthquakes) system in operation in southern California (Kanamori et al., 1991). The University of California at Berkeley in collaboration with the USGS has a "REDI" (Rapid Earthquake Data Integration) system in operation in northern California (Gee et al. 1996, 1997). Since 1994, CUBE and REDI have collaborated to broadcast earthquake information for all of California (Kanamori et al. 1997).

More significantly, a multi-purpose system is being developed in southern California by Caltech, USGS and the California Division of Mines and Geology (Heaton et al. 1996, Mori et al. 1998). It is called the "TriNet" project and has the following objectives:

- To provide ground shaking data within minutes of a damaging earthquake so that the effectiveness of emergency response can be enhanced.
- To record ground motion data for research and for improving building codes.
- To develop a prototype earthquake early warning system.

7 Societal Experience of the Public Seismic Alert System in Mexico City

We will now turn to the Mexico City experience with a public earthquake early warning system in operation for some years. The effectiveness of a public earthquake early warning system demands both the ability to provide alert and to have an adequate population response. The issuing of the seismic alert is only one element in the process. The preparedness of city residents to respond is fundamental. Drills and education are very important to achieve the proper response to the earthquake alert signal. The magnitude 8.1 Michoacan earthquake of September 19, 1985 killed about 10000 people and injured 30000 in Mexico City. The heavy loss of lives was due in part to the soil conditions and structural characteristics of buildings, but also to lack of preparedness for rapid response in case of big earthquakes (Esteva 1998).

The development and implementation of the Seismic Alert System (SAS) has been sponsored by the Mexico City Government Authorities since 1989. The SAS began operation in August 1991 with only a few users. By the end of 1992, SAS was providing the early earthquake warning to some public elementary schools on an experimental basis. It was opened as a public service using the commercial radio stations in August 1993, after the successful SAS alert that gave early warning signals between 65 to 73 s in advance of ground shaking during two Guerrero earthquakes, (magnitude 5.8 and 6), on May 14, 1993 (Espinosa-Aranda et al. 1995). This administrative decision opened the challenge of how to prepare and educate a population of 20 million people in Mexico City.

The planning for the dissemination and education program of the early warning signal was conducted taking into account the opinions of public and private organizations of emergency response, government officials, lifeline administrators, disaster researchers and the general public. Six public deliberations were carried out in 1992 (Fundacion Javier Barros Sierra 1992), giving conclusions that were used to set up the education programs.

7.1 Disaster Prevention and Public Response Education Programs

The program for rapid response for public and private schools for children in Mexico City started after the September 1985 earthquakes. The Secretariat of Public Education proposed the practice of preventive actions and since 1992, response plans in the schools have been drawn up as part of the earthquake hazard re-

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duction. Evacuation drills at schools are held monthly and in some cases with greater frequency. Officially, the education program for rapid response has become a part of the Mexico City public school program. Earthquake education and response readiness training is carried out in all public schools of Mexico City. The Secretariat of Publication Education has instructed all Mexico City schools to listen to radio broadcast and to carry out the response procedures if the SAS generates a warning signal.

To reach the average Mexico City residents, the government of Mexico City developed and disseminated a brochure that explained the SAS to 2 million households at no charge. The brochure describes how the SAS works and gives instructions about how the residents should respond to an alert, as well as advice on preparedness activities, actions to take during an earthquake and after the shaking has ceased.

Additionally a radio spot has been transmitted repeatedly during the day by the radio stations. The announcement begins with the tone of the seismic alert and then continues giving some recommendations based on the instructions brochure. Also some additional literature has been published explaining the SAS basics, what magnitudes of earthquakes can be detected and which seismic zone is instrumented.

Despite these efforts to educate the average citizen, there has been lack of continuity in the dissemination of brochures and transmission of radio spots. The delivery of brochures was carried out only once, and radio spots were issued for only 11 months, starting in June 1993. Additionally, earthquake drills for the average city resident have not been carried out frequently. Systematic actions like training, field testing responses in advance of emergencies, updating plans and evaluating activities to enable timely response have been left to a few local community emergency response organizations. However, in January 1996, an Emergencies Act was approved by the Congress of Mexico City. Chapter II of this Act promotes the organization and training of civil response groups by the neighborhood associations.

7.2 September 14, 1995 Earthquake: Mexico City SAS Public Response

At 8:04 a.m. on Thursday September 14, 1995, a magnitude 7.3 earthquake occurred in Copala, Guerrero, Mexico, approximately 150 km east of Acapulco and 300 km South of Mexico City. There was considerable damage in coastal towns near the epicenter, although there was no major damage or casualties in Mexico City. This earthquake was felt strongly in Mexico City, amplitudes of ground motion were about 20% of those from the September 19, 1985 Earthquake (Anderson et al. 1995), with a maximum acceleration of about 73 gal recorded in Tlahuac.

This earthquake was quite significant, because SAS early warning was activated and the majority of AM-FM commercial radio stations in Mexico City broadcasted the alert signal to the public, 72 seconds prior to the arrival of the strong ground shaking as shown in Figure 3.

The earthquake occurred during the peak hour on a working day, at a time many people were already at or were going to their normal place of employment. Normally the METRO and public transportation is crowded. Standard hours for people to arrive at their jobs is at 8:00 or 9:00 a.m. All secondary schools and universities had already started classes at 7:00 a.m. Elementary schools start at 8:00 a.m.

During the September 14, 1995 Copala earthquake, there were 98 SAS user's radio receivers distributed in Mexico City. They are classified in ten categories depending on the estimated number and type of people covered. Eighty six SAS radio receivers were activated and 12 SAS radios receivers did not work because they were not installed at that time by the users: two in the radio stations, seven in government agencies and three in emergency response centers. The following report on public response was elaborated by means of a survey carried out by telephone with the users in charge of the SAS receivers to evaluate the benefits of the early warning issued. These results are summarized in Table 1.

Public Schools. Since 1992, the Public Education Department has been a participant in the SAS education program. The public education system includes nurseries, kindergartens, schools for handicapped, elementary and secondary schools, technical institutes and univer-

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Table 1. Mexico, City Seismic Alert System performance in the September 14, 1995, M=7.3 "Copala" Gro. Earthquake

User organization	Receivers activated	People warned	Comments
Public schools	26	1970000	Children reached directly by 28 radio receivers, plus those informed by listeners alert operators
AM/FM Radio stations	22	2000000	People listening to radio on peak hour
Subway METRO	2	400000	People traveling on peak hour
Housing complex el Rosario	1	10000	Residents of housing complex
Other	35	9000	Emergency response centers, Government agencies, Public buildings, Private schools, Universities and CIRES technical personnel
TOTAL	86	4389000	

sities. The total number of public school installations in the Mexico City area is 5943 with 2033000 students.

At the time of the Copala earthquake, only 26 public schools were equipped with SAS radio receivers. These 26 schools covered directly, represent 14200 children in 4 kindergartens, 16 elementary schools and 6 secondary schools. However, since the maintenance personnel in almost all Mexico City schools with no SAS receivers had been instructed by the Secretariat of Public Education authorities to monitor the radio stations and to trigger the alarm manually, the estimated number of children warned in the schools of Mexico City was 1970000.

The children in secondary schools were already in the classroom and the ensuing evacuations, according to education officials, were orderly and well coordinated. Most of the children in elementary schools were entering or about to enter the classroom, so they remained in the pre-designated safe places.

Private Schools. Only two private schools have the SAS receivers. The response at private schools without the SAS receivers is generally unknown. However, a comparative research about the response to the seismic alert was conducted on two private schools in Mexico City (Arjonilla 1998), one with the SAS receiver and the other without it. The children with the SAS receiver were less stressed during and after the earthquake than the children without it and could get back to classes almost immediately.

AM-FM Radio Stations. Twenty four radio receivers with special audio controls were installed in commercial AM/FM radio stations in Mexico City, before September 1995, to switch over the standard audio program from the radio stations to a 60 s prerecorded message for seismic alert. This message consists of a clearly identifiable special tone and the statement "alerta sismica, alerta sismica" (in English "seismic alert, seismic alert"). This statement is automatically broadcast without the intervention of human operators. The warning message does not contain any technical information, specific guidance for protective actions, description of potential dangers or severity of the earthquake. According to the Institute of the Mexican Radio, the estimated number of listeners in the morning between 6:00 to 10:00 a.m. is 10% of the population of Mexico City area, or about 2000000 people. It is expected that when a person hears an early warning, he or she can communicate the emergency to another person.

Although a large number of people presumably received the SAS alert, there have been no formal evaluation of its effectiveness. There are anecdotal reports of people who were listening to the radio, heard the warning, and took some action, but there are no studies or data about the people response in general.

Subway METRO. Upon receipt of a seismic alert, the Mexico City METRO commands trains to travel at reduced speed and stop at the next station, where they open the doors. However, neither the people in the trains or at the stations were informed of the seismic alert. The estimation of people traveling in the subway was about 400000 during the peak hours.

Housing Complex El Rosario. El Rosario is a densely populated public housing project inhabited by 200000 people. The area is characterized by low-rise, multi-unit apartment buildings constructed between 1960 and 1970 and surrounded by open areas and recreational facilities. El Rosario has a public audio warning

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system connected to the SAS. At this location, a system of high power loud-speakers is installed in a tower.

The audio seismic alert broadcasted to an estimated audience of 10 000 people in the El Rosario housing complex. The audio system functioned without problem at 8:04 on September 14, providing community residents time to evacuate their apartments. Residents indicated that they were frightened when the signal sounded but responded by turning off gas and lights and evacuating their buildings according to established procedures, with the assistance of residents assigned to direct people to pre-designated evacuation routes and outdoor assembly locations. There were no reports of panic behavior such as running, shoving, or other actions associated with extreme fear and flight reactions.

The next three categories appears as "Other" in Table 1.

Emergency Response Centers. The most important centers were covered, among them the Civil Protection Agency, the Mexican Red Cross, the Central Agency for Disaster Prevention, the Police Department of Mexico, and the Central Command of the Mexican Army. A total of 13 SAS radio receivers were installed. It is estimated that 2400 people were warned in these sites during the Copala earthquake. The emergency response centers of Civil Disaster Management office, Public Works Department and emergency services alerted their personnel. The police also were alerted and started a general inspection in the city to locate damages.

Government Agencies and Public Buildings. People who received the seismic alert signal in these sites are white collar employees with some training in evacuation procedures. The estimate of people warned is 3900 during the Copala earthquake.

Universities and CIRES Technical Personnel. Six hundred undergraduate students in the campus heard the audio warning signals sent by the SAS during the September 14 1995, Copala earthquake. CIRES personnel were warned in their homes by 6 radio receivers (which are used for continuous monitoring of the performance of the SAS system).

7.3 Mexico City SAS Technical Incidents

During the SAS public operation service after August 1993, the early warning system had three problems. The first incident was a missed alarm during the October 24, 1993 magnitude 6.7 earthquake. The second was a false alarm broadcast to the public on November 16, 1993 at 19:20 local time. The third incident was a magnitude 4.6 earthquake that struck in the Guerrero and Oaxaca coast on May 31, 1995 at 6:49:47 local time. A restricted early warning to schools was issued by SAS, but because a school-type SAS receiver had been installed by mistake in one radio station, the chief reporter announced on the air that a big earthquake was about to strike Mexico City. These incidents caused some panic and anger, but no person was hurt or injured because of the false or missed alarm.

There are several factors that determine the reliability to issue the early warning signal of SAS. The most significant are the reliability of the equipment and the reliability of the method of magnitude determination. An initial attempt to calculate the reliability of the equipment was made using the data from the operation results of the system from September 1991 to July 1993. In this analysis the statistics of failures observed in both hardware and software subsystems, the information about what components or subsystems are most failure prone, the sources of failures, schedule in maintenance, availability and mean time between failures were evaluated to determine the reliability of the equipment. This estimate was $R = 0.9764$ (Jimenez et al. 1993), and did not include the radio receivers of users that receive the early warning signal. When extended until May 1998, the reliability analysis was $R = 0.9950$. The reliability enhancement was due mainly to the completion of the redundant communication path between Guerrero and Mexico City. Also the reliability of the method of magnitude determination was evaluated by the Centro de Investigacion Sismica (CIS) de la Fundacion Javier Barros Sierra, with an initial result of $R = 0.89$ detecting and estimating earthquakes of greater than 6.

The public education, training and drills have permitted an adequate response from part of the public in Mexico City. The best response was from the public schools with a population

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of children with ages 5 to 15, which have the highest level of training and experience. But this good response of children depends on the continuous application of education programs for earthquake hazard reduction.

Today not all the guidelines and recommendations of the public deliberations for the SAS application (Fundacion Javier Barros Sierra 1992) have been carried out or been continuously applied. For example, the problem of educating the average Mexico City resident still remains. Although the 1996 new law for civil protection promotes more civil response groups and emergency preparedness, there is only a limited budget to promote these actions, so the problem still remains. The limited deployment of radio receivers in schools, public buildings and industry, at present has not generated controversy. As further deployment of the system proceeds, the system will be more complex and difficult to maintain with a limited budget. There will be greater social and economic consequences as critical processes and functions are unnecessarily curtailed or disrupted in a false alert or malfunction.

Contrary to speculations, when a SAS false alarm was issued on November 16 1993, to an estimated radio audience of 2 000 000 people, during rush hour in a city of 20 million people, common sense prevailed. Before that, an argument used against disseminating the seismic alert to the public was that many people could die or get badly injured because of panic. Although some people were already trained for disaster situations when the false alarm was triggered, the majority of the public was not, and nobody was killed or injured. This November 16, 1993 lesson, should be reviewed and publicly discussed, with the aim to promote drills for rapid response to the seismic alert broadcasted by the commercial radio stations. Until now no training for the general public has been performed to promote a proper response to a seismic alert issued by radio.

7.4 Remarks

Although the early warning for the Copala earthquake was successful, the problem of a warning in a scenario with an earthquake striking at night still remains. With the majority of people sleeping and the radios turned off there is no chance of taking the 60 second advantage. To solve this problem a project has been proposed to the government to implement an all hazards radio network that will operate in the public service band between 162.400 and 162.550 megahertz (MHz) which could be used to transmit earthquake early warning signals. A low cost alert radio receiver tuned to these frequencies has been developed and successfully tested. The audio of this device can be activated even if it is turned off. The cost of this radio receiver is about 40 to 80 US dollars and it could be used to receive other emergency information, besides a seismic alert. Unfortunately no dedicated frequencies have actually been allocated for emergency broadcast purposes.

The issue about the usefulness of a public earthquake early warning system has been answered in part by the September 14, 1995 earthquake. Major earthquakes which are likely to cause damage in Mexico City are from the Guerrero coast, and there is sufficient time for an earthquake warning. The SAS is a low cost project, but has a high benefit return for residents of Mexico City. The number of people reached by the early warning in this seismic event was about of 4 million persons, with almost 2 million of children responding adequately. From 1991 to 1997 the SAS project had a cost of $1.2 million U.S. dollars for development and installation and $400 000 per year for operation and maintenance.

Although establishing a warning effectiveness factor or measure is somewhat ambiguous, the experience of the September 14, 1995 earthquake demonstrated that the combination of adequate public education, training, drills and a properly issued warning, can reduce social damages in case of a major Guerrero earthquake. The education programs improved the capacity to respond to earthquakes. Residents of seismically vulnerable regions can be expected to respond to a brief warning in a controlled, rational and adaptive manner as was demonstrated by the performance of students in the Mexico City public schools. Timely warnings which are heeded save lives.

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8 Future Perspectives

For a city that is favorable located with respect to potential earthquake source regions, a practical system for earthquake early warning can be implemented at a modest cost of a few million U.S. dollars. Recent results from the Seismic Alert System in Mexico City are very encouraging. It is interesting to note that the development of earthquake early warning systems was first carried out outside the "mainstream" of earthquake research program of Japan and Mexico. Fortunately, the need of rapid earthquake information for earthquake response and recovery is well documented (Goltz 1996, Eguchi et al. 1997). In addition, Kanamori et al. (1997) have presented scientific and societal reasons for developing real-time seismology for earthquake hazard mitigation, including earthquake warning capability.

So far, only the Mexican SAS issues earthquake warning directly to the public. Because of different political, legal, and economic systems in different countries, it may be difficult to apply the Mexican experience to other countries. A false warning can cause large economic loss and legal battles in countries like the United States.

There are a few hundred regional and local seismic networks in operation around the world. With recent advances in real-time seismic monitoring, upgrading these seismic networks for rapid earthquake notification is a goal that can achieved with a relatively small cost, as shown in the Taiwan case. Many seismic networks have already recognized this potential and are working hard to achieve this goal. For example, Teng et al. (1997) showed that shake map, effective epicenter and effective magnitude could be achieved within about one minute for an upgraded telemetered seismic network in Taiwan. The TriNet project (Mori et al. 1998) is making major improvements for southern California earthquake monitoring. We believe that most existing seismic networks can be upgraded to provide useful information (such as a shake map) within minutes after a strong earthquake occurred. However, to use this information effectively (especially as earthquake early warning messages) requires collaboration of seismologists, earthquake engineers, and emergency response managers, and education of the public. Implementing an earthquake early warning or rapid information system is very desirable for many urban areas of the world that are threaten by earthquakes, because it stimulates the public to consider the critical issues involved in earthquake hazards mitigation, including education, planning, and response.

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Earthquake Disasters: Prediction, Prevention and Early Warning

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1 Introduction

Five years before the 1985 Mexico earthquake (M8.1), Gerhard Berz, a German geophysicist working for a major reinsurance company, made an accurate estimate (within ± 5%) of the damage expected to occur from this earthquake. When the disaster finally struck, he had an accurate picture of what had happened. He arrived on the spot and paid off his clients within a week. The government of Mexico, however, was completely taken off guard. It took almost three days for an organized official response.

In that same year there was also a destructive earthquake off the coast of Central Chile. A seismic gap had been previously identified in this segment of the Nazca Plate. Warned by the foreshock sequence, researchers from our Institute travelled to Chile to survey the future epicentral area and to set up recording instruments weeks ahead of the earthquake. Much of the local population similarly took sensible safety precautions. Even though there was no official warning the number of casualties was relatively low for an earthquake of magnitude 7.8.

It strikes me as remarkable that such experiences are not accepted as valid instances of early warning or of earthquake prediction. Why not? Were they flukes, or should they be regarded as exceptional?

In this paper I argue that in a relevant sense, earthquake prediction exists and is being widely practiced in engineering, in urban planning, and in the insurance industry. I propose that earthquake prediction is not so much a scientific problem as a public issue. Conflicting political views about the nature of disasters are involved.

2 Discrepant Views About Disasters

A widespread critical view has been expressed among disaster researchers, in the sense that there is a self-serving Western approach that tends to foist emergency relief, economic aid and technical assistance upon defenseless Third-World populations. In particular, science, technology and administration have become suspect as official responses to disaster. Earthquake prediction has come under attack by fundamentalists who claim that seismic processes are essentially unpredictable. Finally, the International Decade of Natural Disaster Reduction (IDNDR) has been criticized as being more revealing of "how the rich nations feel" than of what the stricken populations actually need.

All this may sound like a lot of nonsense, but it contains a grain of truth. Neither the governments nor their critics have thought of asking the populations at risk. How welcome is international relief really? I have participated in over a dozen emergency missions in various countries after as many destructive earthquakes, and I have yet to hear of anyone complaining about relief. More often, it is claimed that international assistance is not actually reaching the victims. But the donor nations do not control the distribution of emergency sup-

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plies. Communications are poor even in normal times, as in the Napo, Ecuador earthquake of 1987 (M7.3), with ist epicenter in the Amazon Basin. In the 1970 Yungay, Peru disaster it took two or three days for supplies to reach the upper Santa valley by road from Lima airport. I saw tons of blankets, medicines and assorted supplies lying around on the runway waiting for transportation. Some of this was possibly sold for profit by unscrupulous politicians and administrators, but much of it was spoiled due to the lack of timely means of conveyance. And the type of assistance was not always appropriate: blankets – fine for Yungay – are at a low priority in the hot lowlands. But I did not hear anyone faulting relief as such.

After the 1985 earthquake the government of Mexico caused an uproar at home and abroad by initially refusing all international aid. The government quickly changed their mind. Today a square in the razed downtown section of Mexico City has been named after "International Solidarity". Sadly, the efforts by foreign emergency teams achieved little, as there is no effective technology for rescuing people from collapsed reinforced-concrete high-rise buildings. A few dozen victims were rescued alive, but by neighbors and local volunteers, not by foreign rescue workers.

Were these disasters predictable? Let the reader judge. The town of Yungay was built on a sloping river terrace created by a prehistoric mud avalanche from Mt. Huascarán. The town was razed by an essentially identical avalanche on May 31, 1970. These avalanches are locally known (and very well known) as *huaycos*. Glaciers in the tropics (latitude 9° south) are notoriously unstable. The earthquake broke off a ledge of ice from the top of the Mt. Huascarán glacier. A mixture of ice, water, rock and soil raced down the mountain at high speed. Where the ravine makes a sharp turn the slurry banked and spilled over the lateral moraine. Yungay was located just beyond the moraine. It was covered with mud so that the tops of four palm trees stuck out to signal the location of the town square. There were no survivors in Yungay.

The earthquake was located in a seismic gap. Furthermore, the disaster could have occurred independently of an earthquake. Unstable glaciers can be monitored. High-altitude townships located in the path of avalanches can be relocated. Looking at the barren flat mud where a flourishing tourist town of 25 000 people had once stood was a distressing sight.

Those who claim that earthquakes are unpredictable have been successful, to the extent that they have helped reduce the budget for earthquake research in some countries. But is this a wise saving? UNESCO used to field emergency teams after major earthquakes. I was a member of such a fact-finding team in Yungay and again in the 1987 Ecuador earthquake. But the project has been discontinued. Moreover, leading scientific journals such as the *Bulletin of the Seismological Society of America* no longer publish descriptive articles about earthquake disasters. Characteristically, the only full-length technical volume on the 1985 Mexico earthquake was published in Tokyo in Japanese.

Claiming that earthquakes are unpredictable may sound reasonable at first sight. The earth is a self-organized complex system, and earthquakes are chaotic nonlinear phenomena. However, absolute unpredictability is a myth. Natural systems are characterized by a *limited predictability* (Nicolis, 1989). Chaotic attractors provide the archetype of such systems: they are potential information-generating devices. In other words, *predictability* is relative. Absolute unpredictability is not found in the real world. Nonlinear self-organized systems are endowed with finite predictability times.

There are plenty of examples. Weather prediction is a limited reality, but it works. There is limited volcanic prediction. There is limited hurricane prediction, limited flood prediction, even limited wave prediction in the North Sea. And let us not forget Gerhard Berz and his limited but highly effective prediction of future damage in the Mexico earthquake. If earthquakes were fundamentally unpredictable no statistical forecasting would be possible.

3 How Early is "Early Warning"?

As seismologists, we are largely to blame for the current confusion about prediction. The precise time of a future earthquake will always elude us, if time is measured to the nearest second. But if we are talking about years or decades (which is more reasonable), we may have something to say.

Scientists and engineers know that ground motion in earthquakes is bounded. There is a

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theoretical upper limit of 2 g in terms of ground accelerations. This is not fantastically high: any automobile can handle it. Thus there is no scientific reason in the world why structures cannot be made 100% earthquake-proof!

Then why does this idea sound controversial and subversive? Should the public continue to accept buildings which openly admit to incorporating a nonzero probability of failure in an earthquake?

In ancient Mexico earthquakes were not particularly feared. They were attributed to the sun and the stars stumbling in their journey underground, after setting in the west and before they rose again in the east. This was a perfectly coherent scientific theory at the time – it was as good as those accepted in Europe. Earthquakes were not dangerous because dwellings were made of light materials, and pyramids were quite stable. Such structures could take 2 g of ground motion in most cases.

So why should Mexico City be suddenly more vulnerable to earthquakes than, say, Denver, Colorado? Are we perhaps in the presence of some Western cultural prejudice? Or is Mexico City doomed, because of its supposedly unique soil conditions, to suffer from earthquake damage forever? But this was not so in Aztec times. Moreover, in the 1985 earthquake the ancient Colonial churches and monuments were notoriously spared, while modern high-rise buildings collapsed all around them. Such reflections tend to place the onus of the disaster controversy where it belongs: upon the problem of vulnerability.

The victims of the 1985 Mexico earthquake were not Third-World peasants. They were middle-class urban citizens who had made the mistake of buying or renting supposedly earthquake-proof apartments in modern reinforced-concrete high-rise buildings designed and built by professionals. Moreover, the Mexican peasant could now afford to move to California though not necessarily because of earthquake hazard. Earthquakes were the least of his concerns.

Suppose we could provide early warning for Mexico City; how long a lead time would we need? Collecting kids and grandmothers and running out on the staircase landing of your apartment and down nine or ten floors into the street takes around 4 minutes. Present alert systems provide at most one minute. If an evacuation of the entire city is desired, we should probably need between one day and one week. Also, a high degree of credibility plus shelter and living facilities for nearly 20 million people would be required.

The case of Haicheng, China is well known. Haicheng was a small town in southern Manchuria. The official early warning was given at 10 a.m. on February 4, 1975 and the earthquake occurred at 7:36 p.m. of the same day. The warning was highly credible since more than 500 foreshocks were felt by the population since the previous evening. In fact the foreshock activity was the main reason for issuing the early warning. The case of Haicheng is frequently cited in support of the feasibility of earthquake prediction. Yet 1328 people were killed, a significant proportion of the population.

Would an earlier warning – say, one or two days earlier – have made a difference? Probably the opposite. Even nine hours was too long, since many people disregarded the warning and went home at nightfall. On the other hand, a one-year warning might have encouraged local authorities to check and strengthen the more hazardous homes in town; and ten years' warning should have been sufficient to make the entire town earthquake-proof. The point is that early warning is not necessarily more effective than medium-term or long-term warning.

Mexico City enjoys the first official early-warning system in the world. It provides a one-minute lead time between the epicentral detection of an earthquake on the Pacific coast and the arrival of the seismic waves in Mexico City. Yet even if such a system were 100% reliable there would be major questions of policy involved. The most highly endangered part of the population, which lives above the 7th floor in downtown high-rise buildings, is least capable of any intelligent response. For them, the early warning is not early enough. Another major segment of the population – the elderly, the sick and the infirm – could be more endangered by an early warning than by the earthquake itself. Since the warning signal is transmitted over the mass media, and particularly over radio and TV, such people cannot be shielded from the warning system unless they decide to cut themselves off from the media. But since the system is far from 100% effective this dilemma is particularly unfair to them.

Do citizens have a right to be warned, or to ignore warnings when they have reason to be-

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lieve the system to be ineffective? Such moral quandaries appear to be largely unexplored. Unfortunately, I believe that they may be false dilemmas, since they assume – wrongly, I think – that earthquake risk is necessarily inherent in any building.

4 Earthquake Hazard Assessment

Zero-risk design and construction may seem prohibitive in terms of cost. But this is only because the risks associated with ordinary engineering structures are today higher than is commonly assumed. The recent examples of Mexico, Loma Prieta, Northridge and Kobe are too recent to require a reminder. In each case the engineers were taken aback at the extent and the severity of the damage.

The crushed rock known as *masado*, which was used in the construction of Port Island and Rokko Island in Kobe, had been tested and certified to be resistant to liquefaction. The road and rail structures which collapsed in Northridge, Kobe, and Oakland had been designed against realistic horizontal accelerations. The steel-frame structures which failed in Northridge may have had some serious design problems – recognizable with the help of hindsight. But they did not infringe the Building Code.

What about critical facilities and major lifelines? Modern hospitals collapsed in Mexico City, including some sections of the showcase Medical Center, causing many victims among the patients. A maternity ward collapsed. A steel-frame overpass of the Shinkansen "bullet train" line collapsed in Kobe. How about Interstate Highway 880 in Oakland, or the Ministry of Communications and the Telephone Building in Mexico City? Mexico was cut off from the rest of the world for over three days.

Such failures seem to me to reveal two fundamental weaknesses: (a) present techniques of earthquake hazard assessment lead to a serious underestimation of the true hazard, (b) present criteria of design on soft ground fail to take into account the true character of the ground motion.

4.1 Underestimation of the Hazard

Techniques of earthquake hazard assessment have not changed appreciably since about 1968. They are based on the obsolete idea that the earthquake process is uncorrelated and memoryless. Thus individual earthquakes are assumed to be independent events in a renewal process. The prototype of such renewal processes is the Poisson process.

It turns out that the assumption of statistical independence is unconservative for long return times. This is embarrassing because large earthquakes have long return times, and those are precisely the events of practical interest in terms of hazard assessment.

Consider two models, a renewal model and a so-called Hurst model. The Hurst model refers to self-organized hierarchical systems such as river basins, trees, or systems of geological faults. Let $R(T)$ be the maximum of some critical variable r, such as seismic energy or seismic slip in earthquakes, for a return period of T years (Lomnitz, 1994). Similarly, let $S(T)$ be the standard deviation of r for a period of T years. Hurst found that the ratio R/S, called the *rescaled range*, increased as T^H, where the exponent H is around 0.72 for geological processes. On the other hand, in uncorrelated processes the same exponent is $H=0.5$.

The difference $0.72-0.5=0.22$ measures the extent to which the assumption of independence differs from the Hurst assumption. For $T>27$ years, the two assumptions yield the same estimate of hazard. For $T>27$ years the assumption of independence becomes increasingly unconservative. For large recurrence periods, such as 10 000 years, the estimated values of R may differ by a factor of up to 3.7. Introducing the accepted scaling laws, it is found that a design acceleration of, say, 0.25 g obtained by the traditional method would have to be increased to 0.66 g for the Hurst model. This is a substantial model – dependent uncertainty.

4.2 True Ground Motion on Soft Ground

The character of strong ground motion is quite different on soft ground and on hard ground. Though the peak horizontal accel-erations were about the same on hard and soft ground, the Interstate 880 Freeway in Oakland collapsed only where it crossed an area on soft Bay mud. Su et al. (1992) concluded that the amplitudes of coda waves, and not the peak body-wave amplitudes, correlated best with the amount of damage.

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But what are coda waves? A coda is a train of finite length of large-amplitude surface waves which is practically undispersed. It is especially prominent and long-lasting on soft ground.

Such a wave train is generated at the interface between a layer of soft soil and a harder soil, as in Mexico City or in the San Francisco Bay area. When certain conditions are fulfilled there is coupling between the horizontally propagating P-wave in the soft layer and the Rayleigh wave at the interface. A coupled wave of this type was first described by Press and Ewing (1951). It has some interesting and peculiar properties:

- It is monochromatic and undispersed.
- It has a finite time duration which increases with radial distance.
- It propagates as an Airy phase, i.e. it corresponds to a group velocity minimum.

The latter property explains why the coda dominates locally over ordinary dispersed surface waves. In a manner of speaking, the coupled mode (which we call the PR mode) compares to random incoherent seismic waves as laser light to ordinary scattered light.

Figure 1 shows a PR wave in the Valley of Mexico. This mode is generated by Lg waves from a distant earthquake. The PR mode propagates at 1500 m/s, the velocity of sound in the top mud layer. It propagates only where the mud layer exists, i.e. within the area which was formerly covered by a large shallow lake. It has a near-constant period of 2.5 seconds and it is reflected at the edges of the mud layer; these reflections cause the observed beating pattern. The whole phenomenon can last around 5 minutes.

What are coupled PR waves? These interesting physical entities are hybrids of sound and Rayleigh waves; they exist at the interface between a soft saturated soil and an underlying harder soil. The coupling condition requires that the P-velocity in the top layer be larger than the S-velocity in the next layer. If in addition Poisson's ratio in the top layer is close to 0.5 we have the makings of disaster. The PR mode propagates at a single frequency, with a finite duration, and it travels as an Airy phase.

Thus I believe that damage on soft ground is due to the fact that engineers expect one type of wave while nature confronts them with another. Preventive technology against PR waves is likely to depend mainly on damping and base-insulation techniques. But why was none of this recognized a long time ago?

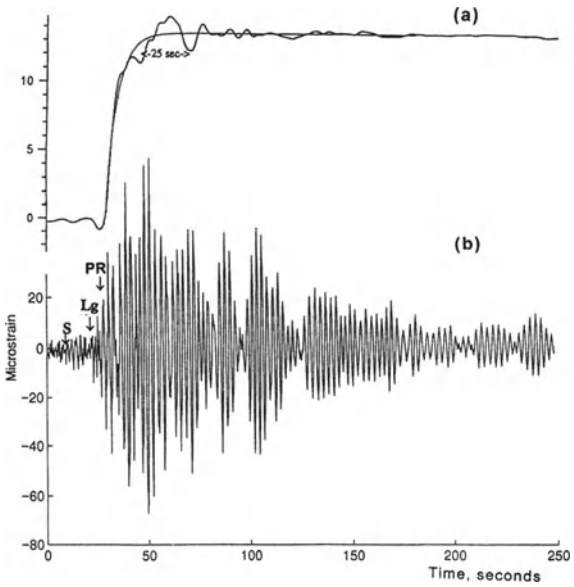


Fig. 1. (a) Low-pass filtered output with least-square fit, and (b) high-pass filtered output for the radial strain component as recorded on the Texcoco Seismic Array by a Bilham strainmeter. The event shown is the Michoacan earthquake of 11 January 1997 (M7.1). Both (a) and (b) are part of the PR mode. Dominant period is 2.5 seconds. Note the long duration and beating pattern. After Lomnitz et al., 1998

Since about 1955 the losses and casualties from earthquakes have been mounting steadily, both in Mexico and worldwide. The writing was on the wall: primitive stone masonry was in retreat worldwide. It had ceased to be the main cause of earthquake damage. Instead, an increasing proportion of losses occurred in engineered structures on soft ground. These structures were usually tall. They had a high center of mass. They were seriously underdamped: they featured around 5% of critical damping, as compared to 23% for a common automobile.

Yet engineers continued to design against random incoherent earthquake signals of short duration.

5 Can we Learn Anything From Mexico?

Thus our present ideas about earthquake disaster prevention are in a state of flux. An increasingly influential current of opinion regards the official policies of disaster management with distrust.

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It would seem that ideas coming from a non-Western nation such as Mexico should find an attentive audience, at least among the critics of official disaster policies. In my experience, the opposite is true. No one really wants to listen.

Here is my message, for what it may be worth. First, our disasters are not the same as those in the West, but the lessons to be learned may be relevant to all. After the 1985 earthquake in Mexico few foreign experts recognized the implicit threat to the San Francisco Bay area, to Kobe and to other urban areas on soft ground, especially to those areas located on bays and estuaries with a history of land reclamation involving the extensive use of artificial fill. Instead, the experts decided, in the words of a well-known American engineer, that the Mexican disaster was a "very special case which would not be duplicated elsewhere". They were fooled by the *differentness* of our disasters.

The U.S. Congress held a special session of inquiry after the Mexican earthquake, at which NSF presented an excellent brief by N.P. Suh suggesting that the disaster was attributable to a *knowledge gap.* Thus U.S. cities on soft ground were seriously threatened. This was sensible advice but no one listened, not even NSF. A special fund of $4 million was earmarked for research on the Mexico earthquake: the money was gobbled up by U.S. researchers who used it on whatever they were doing anyway. It took more than ten years for the Mexicans to reach the conclusion N.P. Suh had reached in 1985. The solution had stared us in the face all the time!

Why didn't building codes evolve with the changing risk panorama? Well, according to a recent study, the building code requirements in most countries are adjusted upwards after every disaster, but only apparently so. Actually they remain pegged at a design acceleration of around 10% of gravity, because every increase in design acceleration is offset by an equivalent raise in the ductility allowance. This self-defeating policy has gone on for decades.

The question is, should the public continue to trust engineers to keep pace with the advances in scientific research? Compare with what has been happening in automotive engineering. Today's cars are relatively cheap, popular, well-engineered solutions to the problem of urban transportation. When you buy a car you get a guaranteed, standardized, exhaustively-tested product. But unlike automobiles, housing is not road-tested. The safety level is unknown – buildings are not guaranteed nor certified under extreme loading conditions. The consumer is supposed to settle for an untested home, untested rail bridges, untested highway structures and so on.

Today we are gathered in Potsdam to look at our options in early-warning systems, and I agree that it is an important question. But are there any known evasive actions to be taken? When the alarm sounds, should people seek cover? Run downstairs? Use escape routes? Pull the sheets over their heads?

As long as no standard safety features become incorporated into the seismic design of buildings no one, certainly not the structural engineer, knows how a given structure will behave in an earthquake, or whether there will be a chance for the occupants to escape. There is only one option: the structure *must* be made totally safe against earthquakes. Early warning is available today, in the form provided by Gerhard Berz – a level-headed assessment of the hazard. This is as early a warning as people can reasonably use in daily life. Otherwise it is a sham, a placebo.

Since 1993 Mexico City has had an early warning system against earthquakes. It was implemented by politicians, not in addition but instead of more positive safety measures. In the best of cases, it can provide a one-minute warning before the seismic waves hit Mexico City. What if you live in a 9th floor apartment? What about small children, aged people, the ailing, the infirm? The government has no words of advice for them.

I submit that such an earthquake strategy is morally bankrupt. Even if the early warning system works, that does not relieve the authorities from the obligation of holding public hearings into the cause of collapse of 371 high-rise buildings in 1985. It does not exempt them from the obligation to enforce appropriate zoning laws in the downtown area, or to prevent the illegal occupation of endangered structures, or to discourage the use of unsafe welding practices in new steel-frame buildings as discovered in the 1994 Northridge earthquake, and so on.

Damage in the 1985 Mexico earthquake was not random: it was highly systematic. Yet so-

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ciety insists on blaming seismologists for the unavailability of earthquake prediction. As if we do not know what will happen in the next large earthquake in Mexico City. Ask Gerhard Berz.

Earthquake hazard is highly technology-specific. It is aimed against certain types of housing technology. Earthquakes do not kill: structures do.

We now know what causes the damage on soft ground. We know we can predict these earthquakes in a meaningful way – in a way which makes sense to engineers and to society in terms of decision-making. We know which solutions will work and which won't. We have learned not to trust people who claim that earthquakes cannot be predicted, or that relief is a pretext for rich nations to sell surplus technology to the natives. We have learned to think our local hazard situation through to the bitter end.

In principle and in the future, the safest place to be during an earthquake should be inside a building – any building. We cannot afford to set our aims any lower. When tons of reinforced concrete come crashing down around your ears it is too late. Early warning was nice to have, but safety should have come first.

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Towards an Earthquake Early Warning System for the Megacity of Istanbul

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Abstract

Due to the immediate vicinity of the North Anatolian Fault Zone, overpopulation and concentration of industries and infrastructure, Istanbul has developed to a megacity with extremely high vulnerability against earthquakes. Earthquakes with a destructive potential for Istanbul may happen along an about 250 km long zone extending from Adapazari-Izmit some 150 km east of Istanbul via the Marmara Sea area immediately south to some 100 to 150 km southwest of Istanbul.

An earthquake Early Warning System for Istanbul will have to face the fact that the warning time for most of the relevant earthquakes will be extremely short. The system introduced here, therefore, regards "Early Warning" in a wider sense comprising a rapid post earthquake information component in addition to the timely Early Warning capability. Altogether, the concept presented has four components:

- a long-term component (stocktaking, preparation phase)
- a medium-term component (years to days before an earthquake)
- a short-term component (earthquake happened, but the destructive seismic waves have not yet reached the urban area)
- an instantaneous component (earthquake hit urban area and rapid earthquake information is necessary).

The Early Warning System outlined in the paper may, thus, contribute to reducing economic losses and saving lives by improving the information base for earthquake disaster prevention, automatically protecting against important secondary earthquake hazards and providing rapid earthquake information relevant to disaster management.

1 Introduction

The problem of earthquake prediction in a deterministic sense has not been solved so far. However, there is a certain time interval after the occurrence of an earthquake and before the arrival of the dangerous seismic shear waves/surface waves at a threatened urban area which can be used for Early Warning. This time interval increases with the distance of the urban area to the earthquake (Fig. 1) and will, in general, not be more than some tens of seconds, only in extreme cases more than one minute (see Espinosa-Aranda et al., 2000 for Mexico City, this volume). In such an earthquake Early Warning System, a monitoring seismic network locates the epicenter of an earthquake and will issue an alarm if the magnitude of the earthquake or the local ground motion, respectively, exceeds a certain threshold. The wireless transmission of the alarm to the urban area is much faster than the 3–4 km/s velocity at which the seismic shear- and surface waves propagate. Thus, important seconds may be gained in which automatic shut down systems may be activated thus protecting sensitive industries, life lines and transportation infrastructure and public warnings issued for schools, hospitals, emergency services and disaster management, among others (Fig. 2).

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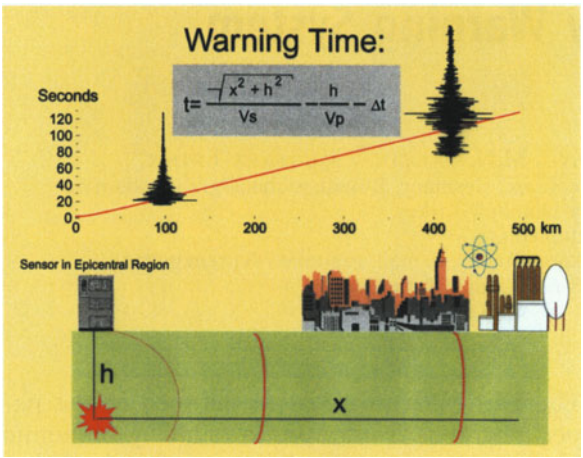


Fig. 1. Principle of an earthquake Early Warning System. The Warning time depends on the propagation velocity v_s of the destructive seismic wave (shear wave/ surface wave), the propagation velocity v_p of the fastest seismic wave (p-wave), the distance x and the depth h of the earthquake, and the time Δt lost with computer calculations and with activating the alarm system

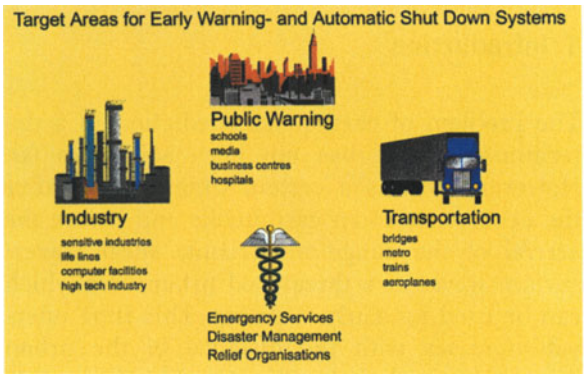


Fig. 2. Target areas for Early Warning and Automatic Shut Down Systems

Recent advances in seismic sensor technology, data acquisition, digital communication, computer hard- and software have made the realisation of such kind of Early Warning Systems feasible. There are now two operating systems in Japan which issue earthquake warnings for the railway operations (Nakamura 1996a, b). The only system that communicates an emergency message to the public is the one in Mexico City (Espinosa-Aranda et al. 1995, 1996). Two research-oriented systems have been implemented in Taiwan as a co-operative project between the Central Weather Bureau, the U.S. Geological Survey and the Southern Californian Earthquake Center (Lee 1995, Lee et al. 1996, Shin et al. 1996, Teng et al. 1997, Wu et al. 1997). In several systems Early Warning is regarded in a wider sense as "rapid earthquake information" whose main purpose is to provide rapid notification for emergency and recovery management immediately after a damaging earthquake. The TriNet project in Southern California advanced by Caltech, USGS and the Californian Division of Mines and Geology has the purposes of Early Warning as well as of providing ground shaking data within minutes after a damaging earthquake so that the effectiveness of emergency response can be enhanced (Heaton et al. 1996, Mori et al. 1998).

In this paper the proposed Early Warning System for the megacity of Istanbul will be regarded in the wider sense: It will include an Early Warning – as well as a rapid earthquake information component. The specific situation for Istanbul with respect to such a warning system will be introduced, the proposed system will be outlined and the present state of development described.

2 The Specific Situation for Istanbul

With more than 10 million people living in the immediate vicinity of the North Anatolian Fault Zone, Istanbul is a megacity with extremely high earthquake risk. Destructive earthquakes in the past 2000 years have hit Istanbul about once every century. The drastic increase of population from 1 to 10 million people between 1950 and 1990 (Fig. 3) runs parallel with an even more drastic increase of its vulnerability. In addition to overcrowding, faulty land use planning and construction, inadequate infrastructure and service as well as environmental degradation, especially loss of vegetation, and a high percentage of informal settlements are some major reasons for this. An extension of the North Anatolian Fault passes just 25 km south of the city. This region to the immediate south has been identified as a seismic gap where the probability of a large earthquake to occur in the near future is high (Toksöz et al. 1979). A large earthquake in this area would meet with a third to a half of the whole Turkish industry activity that is concentrated in the Marmara provinces near to Istanbul (Fig. 4).

An earthquake Early Warning System in the area of Istanbul does not encounter easy seismological conditions. The tectonics in the area

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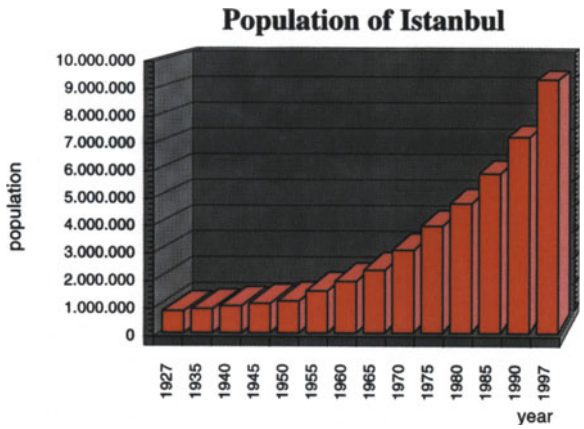


Fig. 3. Population growth of Istanbul

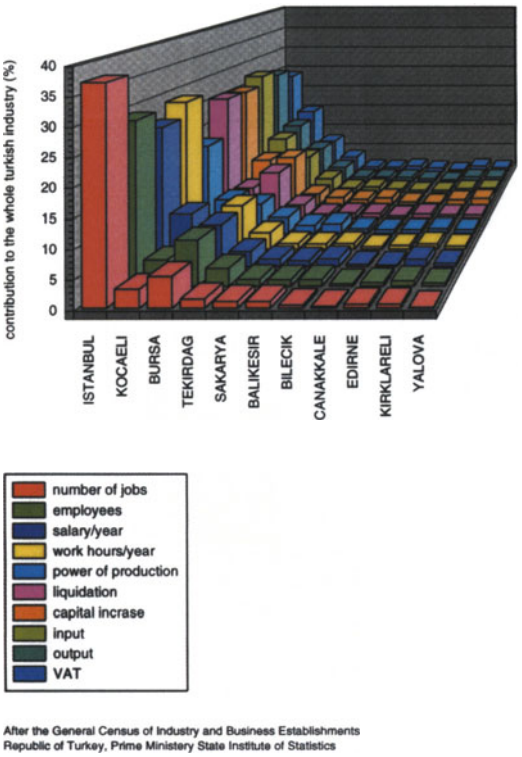


Fig. 4. Contribution of the Marmara Provinces to the whole Turkish industry activity of 1995

show a transition of the North Anatolian Fault Zone from strike slip east of the Marmara region to extension and different kind of fault mechanisms in the Marmara region itself (Fig. 5). Earthquakes with a destructive potential for Istanbul may happen along an about 250 km long section extending from Adapazari-Izmit some 150 km east of Istanbul via the Marmara Sea area immediately south to some 100 to 150 km southwest of Istanbul. Figure 6 gives a rough estimation of the warning times that may be possible for two configurations of a seismic network in this region, one with seismometers only on land (a) and another including seismometers at the bottom of the Marmara Sea (b). It is expected that configuration (a) will be completed by 1998. However, there are no specific plans yet for including ocean bottom seismometers in the system. It is obvious from Figure 6 that warning times for Istanbul may range up to 70s. However, for earthquakes immediately south of Istanbul, in the region of the seismic gap, time may not be sufficient for warning and only rapid post earthquake information may be possible. The situation is slightly better for configuration (b) where ocean bottom seismometry is included.

3 Outline of the System

The activities towards a Regional Early Warning System (REEWS) for Istanbul discussed here, are a co-operation between the Kandilli Observatory (Istanbul), TÜBITAK (MRC, Gebze), the Earthquake Research Institute (Ankara) in Turkey and the GeoForschungsZentrum Potsdam in Germany. The concept followed by these partners aims at an Early Warning System in the wider sense, i.e. a system that involves Early Warning – as well as post earthquake rapid information components. Altogether, the system under consideration consists of four components (Fig. 7):

- a long-term component (preparation component)
- a medium-term component (pre-seismic component)
- a short-term component (co-seismic component)
- an instantaneous component (post seismic component)

The *long-term component* is intended to collect and provide all relevant data to cope with a potential destructive earthquake in the area of Istanbul. It includes the stocktaking of the area, assessment of the crustal structure, neotectonics and regional seismicity as well as earthquake hazard assessment and microzonation.

It will be strongly related to the Earthquake Action Plan for Istanbul as drawn up by the Kandilli Observatory and the Earthquake Re-

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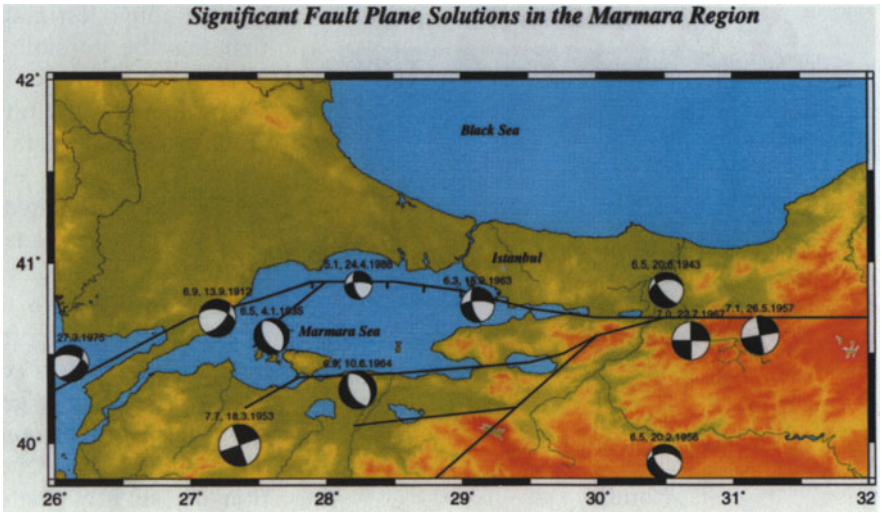


Fig. 5. Recent large earthquakes in the Marmara Sea Area and their focal mechanisms

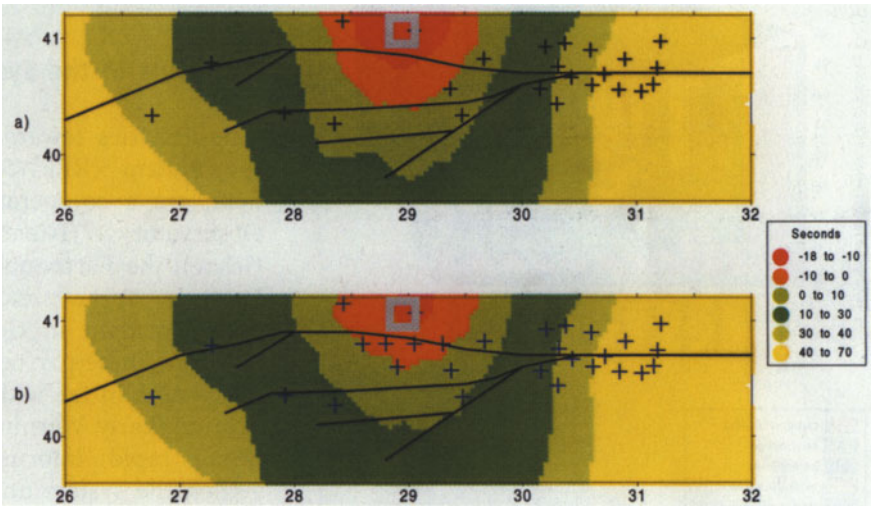


Fig. 6. Estimated earthquake warning time for Istanbul based on configurations of seismometer sites (crosses) without a) and with b) ocean bottom seismometers in the Marmara Sea. Fault lines are given in black

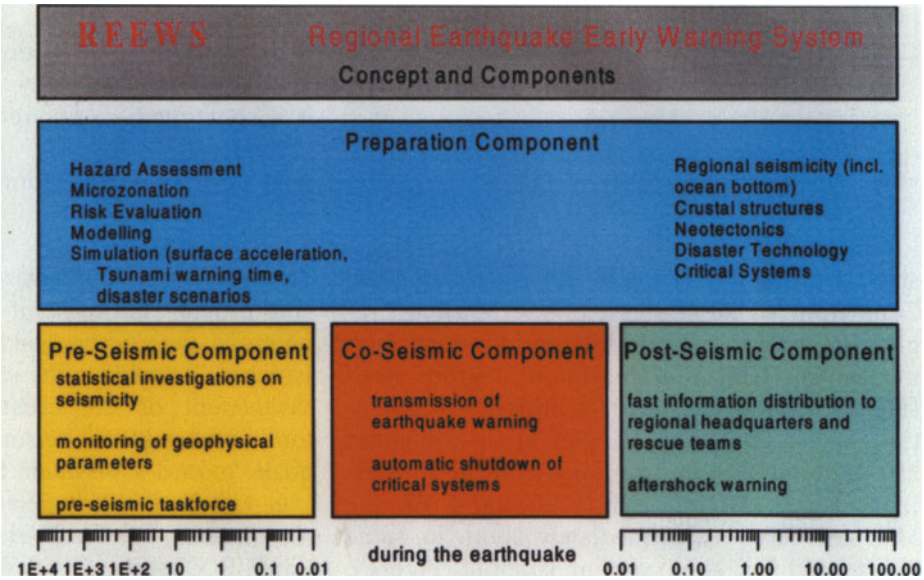


Fig. 7. Concept and components of the Regional Earthquake Early Warning System (REEWS) for Istanbul

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search Institute of Bogaziçi University in association with the Earthquake Research Division of the General Directorate for Disaster Operations in Turkey, and summarised in Erdik (1995). One important element will be simulations of earthquake scenarios for ground motion and their organisation in a GIS data base for enabling rapid access to peak ground acceleration in case of a damaging earthquake. Such simulations will extend those by Erdik (1993) of synthetic iso-seismic maps to be expected in case of magnitude 7 and 7.5 earthquakes occurring along the Marmara Graben System (Fig. 8). They will also refine the estimations of Erdik (1993) on the expected intensity increase due to geological condition (Fig. 9).

The *medium-term component* will be based upon seismological as well as multiparameter monitoring systems that have been established

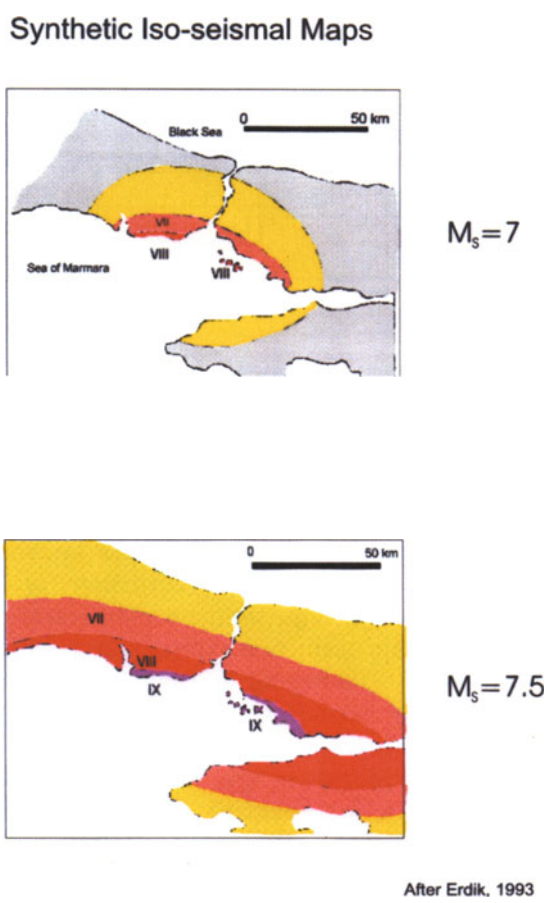


Fig. 8. Synthetic iso-seismic maps (intensities) to be expected in case of magnitude 7 and 7.5 earthquakes occurring along the Marmara Graben System (after Erdik, 1993)

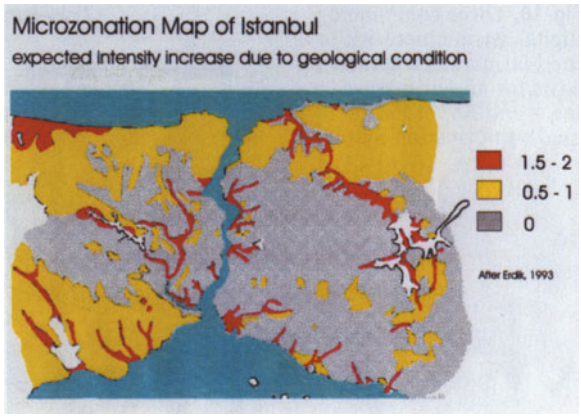


Fig. 9. Expected earthquake intensity increase in Istanbul due to geological condition (after Erdik, 1993)

in that region for earthquake prediction research purposes within the framework of co-operations between Japan and Turkey as well as Germany and Turkey within the last 15 years. The SABOnet, for instance, is a permanent digital seismic network which was installed in 1996 within the framework of the Turkish-German co-operation and consists of 14 three component seismometers, 4 transmitter relais stations and a processing center. The network covers roughly the area between 30.0 E to 31.5 E and 40.4 N to 41.0 N (Fig. 10). It is planned to combine it with a number of seismic broad band seismometers to be installed further west around the Marmara Sea and to have a second processing center in Istanbul (see also Fig. 10). The areas of multiparameter monitoring within the framework of Turkish-Japanese and Turkish-German co-operation are located south-east of Istanbul (Fig. 11). Here, groundwater level and – temperature, surface tilt and – deformation, water discharge, magnetic and magnetotelluric fields as well as hydrogeological parameters are monitored. Additionally, Turkish groups have started with installing a permanent GPS network around the Marmara Sea (Fig. 11). The combined control and analysis of seismicity and surface deformation will be the core of the medium-term warning component.

Whereas the long-term and medium-term components work ahead of the earthquake, the *short-term warning component* is activated only with the earthquake. It aims at automatically and rapidly determining the earthquake's hypocenter and magnitude as well as issuing an alarm in case of the earthquake being damag-

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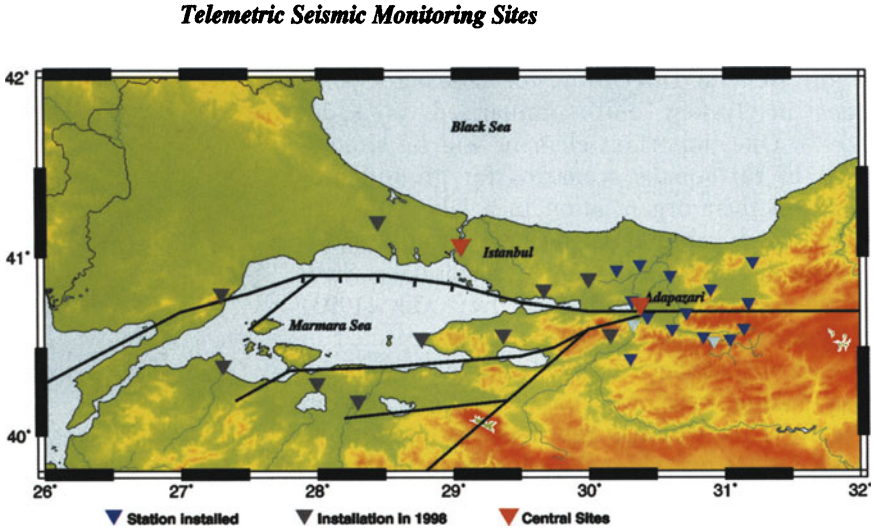


Fig. 10. Three component digital seismic network in the Marmara Sea area as a basis for an Early Warning – and Rapid Earthquake Information System

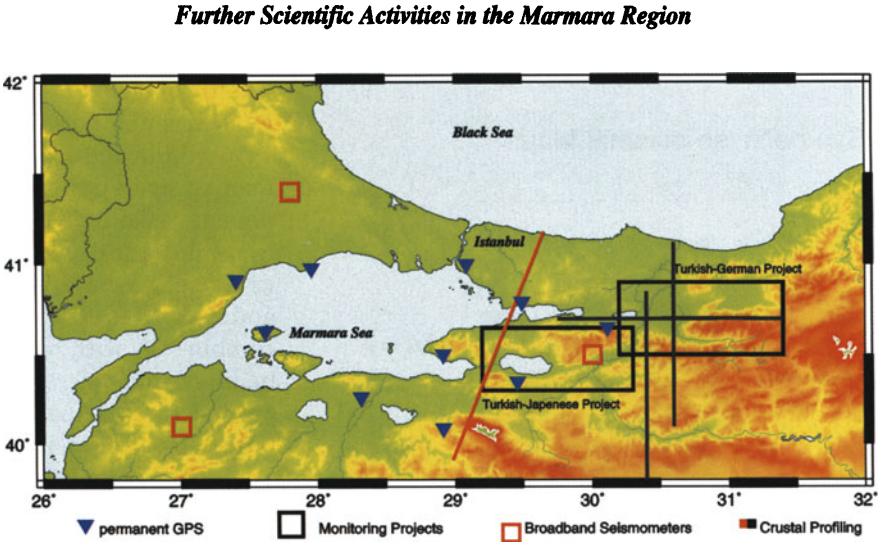


Fig. 11. Ongoing scientific activities to be integrated into the Earthquake Early Warning System for Istanbul

ing. At present, only part of the seismological network (SABOnet) is capable of a first estimation of these parameters within less than ten seconds. The automatic epicenter (hypocenter) determination may, however, have large errors, especially when the detected earthquakes occur outside the network (Fig. 12). Likewise, the automatically determined magnitudes are still underestimated, especially in case of earthquakes outside the network (Fig. 13). Both the automatic hypocenter and magnitude determinations need further improvement, and the rapid determination capability for these quantities has still to be extended to a larger area by combining the seismic networks existing in the region.

The *instantaneous component* of the system is the rapid post earthquake information system (see Fig. 14). It requires the rapid determination of the hypocenter, magnitude and focal parameters of a damaging earthquake, selects the appropriate scenario for ground motion, combines it with GIS based vulnerability information on the infrastructure of Istanbul, and thus provides a first damage estimation and feeds the results into a rapid information dissemination system in order to support disaster management and emergency actions. This component of the earthquake Early Warning System for the megacity of Istanbul is still in a very early stage of its planning and development.

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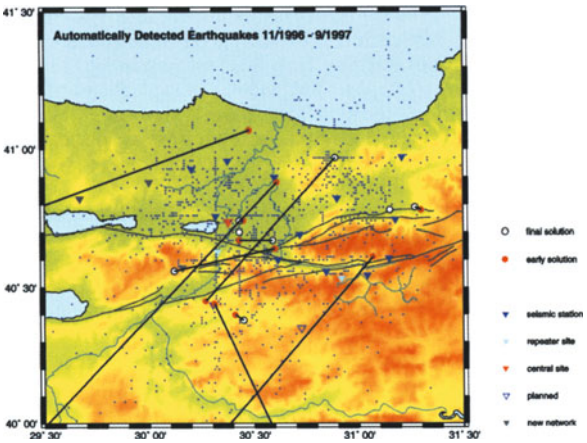


Fig. 12. Automatic detection of earthquakes with the SABOnet. Errors are large for earthquakes outside the seismic network

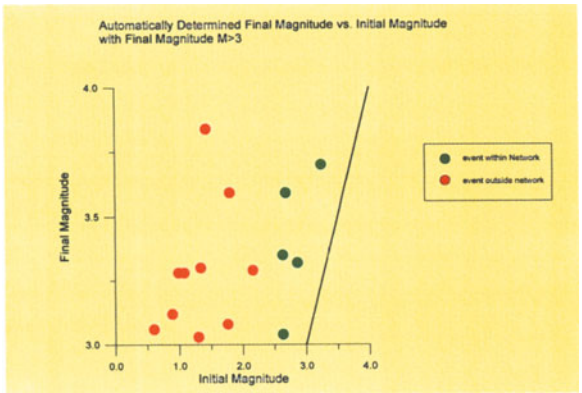


Fig. 13. Automatically determined magnitude (within the first 10s) versus the final magnitude. The initial magnitudes are underestimated, especially for earthquakes outside the seismic network

4 Conclusions

The concept of an earthquake Early Warning System for Istanbul as introduced above may contribute to reducing economic losses and saving lives in three ways:

- Improving the information base for earthquake disaster prevention by using the GIS based ground motion- and damage scenarios for supporting protection, preparedness and recovery measures as part of a disaster master plan.
- Automatically activating shut down functions for immediate protection against important secondary earthquake hazards such as fire, gas explosions, collaps of bridges and others.

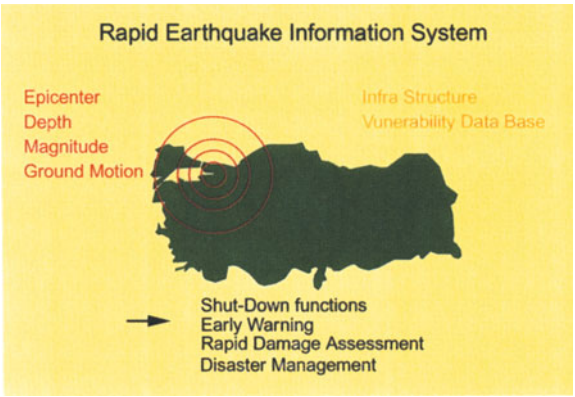


Fig. 14. Principle of a Rapid Earthquake Information System. Besides taking Early Warning functions, it combines appropriate scenarios of ground motion with GIS based data on infrastructure and its vulnerability in order to obtain a rapid first damage estimation and to support emergency actions in case of a damaging earthquake

- Providing rapid earthquake information and damage estimation as support for effective emergency actions and disaster management.

It is, however, unlikely, although not excluded, that the system may be used for direct warning of the public. The warning time will not be much more than 15s for most of the earthquake scenarios relevant for Istanbul usually not enough to escape from a house, but enough for the automatic activating of life saving shut down functions.

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CHAPTER 5.5

The Seismic Alert System in Mexico City and the School Prevention Program

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Abstract

The Seismic Alert System (SAS) is a public service developed with the sponsorship of the City Government Authorities, with the aim to mitigate seismic disasters. Since August, 1991, after 84 months of continuous operation, the SAS has been able to detect 681 seismic events in the Guerrero Coast; 12 of them so strong as to trigger general alerts in Mexico City, 33 restricted, and one false general alert. The warning ranges strong or restricted correspond to seismic magnitude forecasted great than 6, or great than 5. During the "Copala" M7.3 earthquake, on September 14, 1995 the SAS was activated and issued a general warning signal in Mexico City, 72 seconds prior to the first arrival of "S" ground motion. This earthquake warning reached an estimated population of more than 4 million citizens. The response of children in schools was massive due to the application of an earthquake hazard reduction program. The Copala earthquake helped us to identify strengths and weaknesses of societal response to the earthquake early warning signal. The long-term plan of hazard mitigation of the National Ministry of Public Education, Secretaria de Educacion Publica (SEP), has created an earthquake awareness in the children of various school levels. Even though the children did not suffered the disastrous consequences of the 1985 earthquake, they are today more aware than the average person who lived through that disastrous event and who is still not trained.

1 Introduction

The idea of using the difference in velocities of earthquakes and electrical waves for an earthquake early warning system was proposed in 1868 by Cooper (Cooper 1868). In Mexico, seismological research shows a high probability that a strong earthquake similar in size to the one in 1985, could occur in the Guerrero Gap, between the cities of Acapulco and Zihuatanejo (Singh et al. 1981, 1982, Anderson et al. 1994). The consequences of this earthquake for Mexico City are of high risk for the population because of the soil conditions (Ordaz at al. 1995) and the structural characteristics of buildings.

In January 1986, after the big earthquakes that struck Mexico City in 1985, the Mexican National Council of Science and Technology (CONACyT) together with the National Research Council (NRC) of USA, issued research recommendations to learn about the damages suffered in this seismic event (CONACyT 1986). The societal and technical study was a main issue to promote the development of an earthquake early warning system in response to seismologists' concern in the early 80's about the seismic growing hazard in the "Guerrero Gap".

The development and implementation of the Mexican SAS has being sponsored by the Mexico City Government Authorities since 1989.

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This project started operating in August 1991 for evaluation with a few users, and by the end of 1992 as an experimental project broadcasting the early warning to some public elementary schools, applying it in 25 buildings where the earthquake warning signal sounds when the SAS magnitude forecast is greater than 5. Planning for the dissemination and education program of the early warning signal was conducted taking into account the opinions of public and private organizations for emergency response, government officials, lifeline administrators, disaster researchers, and the general population. Six public deliberations were carried out in 1992, (Fundacion Javier Barros Sierra 1992) providing conclusions that were used to design experimental evaluation programs for the education of SAS users.

However, after the successful seismic detection that generated early warning signals, between 65 to 73 sec. in advance, during two Guerrero earthquakes, M5.8 and M6, on May 14, 1993, (Espinosa-Aranda et al. 1995), as well as after two years of initial operation with near to 100 seismic events detected, the Mexico City Government Authorities announced the start of SAS as a public service on August 1st, 1993. Since this date the early warning signal has been issued with the support of many of the local AM/FM commercial radio stations in Mexico City area, but in accordance with the Government recommendations, to protect the population still not trained in prevention drills, the SAS general warning signal is issued only if the magnitude forecast is grater than 6.

The fact that most major earthquakes which are likely to cause damage in Mexico City will come from the Guerrero coast 280 km away, and the low requirements of SAS development, maintenance and operation, give this project a high benefit return and social value for the Mexico City population. From January 1990 until December 1997, the system cost $ 3 million dollars for development, installation and operation. The 1998 maintenance budget is $ 600 000 which includes the cost of some spare parts and technological enhancement.

The 1993 administrative decision to start the SAS as a public service opened the challenge of how to educate and prepare a population of 20 million people to use the early warning signal. The effectiveness of a public earthquake early warning system focuses on the ability to provide alert as well as to achieve an adequate population response.

The issuing of the seismic alert is only one element in the process where the preparedness of city residents is fundamental. Drills and education can determine the population's proper response using the SAS alert signals. The M8.1 Michoacan earthquake of September 19, 1985, at 7:19, killed about 10 000 people and injured 30 000 in Mexico City. The high cost in lives was due in part to the soil conditions and structural characteristics of buildings, but also due to the lack of any early warning signal, and a lacking for rapid response in case of big earthquakes (Esteva 1988).

2 Societal Response to the Earthquake Early Warning Signal

After the September 14, 1995, M7.3 "Copala" earthquake (Anderson et al. 1995), where the SAS issued an alert signal to the public with a 72 second advantage, it was estimated that 4389,000 people were warned during this particular earthquake (Espinosa et al. 1996). The response of the population to the early warning signal is summarized in Table 1, where two groups of people can be easily identified: those that received training as a result of a long term plan and those who had no previous training.

The frequency of emergency drills, Table 1, shows that children attending public schools in Mexico City received intensive training in a systematic manner, with evacuation drills at least once a month. Other groups, such as the

Table 1. People in Mexico City reached by the "Copala" Sep. 14, 1995, SAS earthquake early warning signal

Users	Type of user	%	People warned	Drills per year
Children at public schools	trained	44	1 970 000	10
Listeners of radio stations	not trained	46	2 000 000	?
Users at public places with alert METRO	not trained	9	400 000	0
Users in El Rosario complex	trained	1	10 000	2
Total	–	100	4 389 000	–

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residents of the El Rosario neighborhood received training with at least two evacuation drills per year.

2.1 Disaster Mitigation School Program

The rapid response program for public and private schools in Mexico City started after the September 1985 earthquakes. Since 1986, the National Ministry of Public Education, Secretaría de Educación Pública (SEP), has successfully developed and applied an earthquake hazard reduction plan for all basic education schools in the nation's capital[1]. This plan known as School Emergency and Security Program, Programa de Seguridad y Emergencia Escolar is aimed at improving the response of teachers and students to a variety of disasters, including earthquake disasters.

According to education officials, as a result of this program the ensuing evacuations to the "Copala" earthquake were performed in an orderly and well-coordinated manner. A comparative research about children's response to the early warning signal was further conducted on two private schools in Mexico City with similar results (Arjonilla 1998).

The major achievements of the Mexican Ministry of Education (SEP) hazard reduction plan are:

1. Development of an emergency and security program for schools: Programa de Seguridad y Emergencia Escolar.
2. Establishment of **security committees** in all basic education schools in Mexico City.
3. Disaster impact evaluation plans.

The activities promoted under the School Emergency and Security Program include development and distribution of instructional materials such as: booklets, posters, guides and videos. In addition, the School Emergency Office (Dirección de Emeregencia Escolar) which is the area in charge of this program in the Ministry of Education, has allocated an important budget to carry on different projects, such as: teacher training, publications, etc. It has also implemented mechanisms to evaluate school population performance in emergency situations. In addition, this Office has established joint projects with different authorities and NGO's to enhance all activities related to civil protection.

2.1.1 School Disaster Action Plan

Refers to a series of activities including the enforcement of evacuation techniques, school building and population supervision, communications capabilities, rescue actions, after disaster organization, first aid actions, etc. Since 1992, this plan started to use the early warning technology of SAS in 25 schools (National Ministry of Public Education, 1995). In those schools with no SAS receivers, in accordance with the SEP official recommendations, school principals are encouraged to keep a radio on during work hours, to listen to AM-FM stations that activate local sirens when on SAS general warning is issued.

2.1.2 School Security Committees

Are formed by teachers, parents, and students, which all together are integrated in four working teams: security/prevention, communications, first aid, search and rescue. Team members cooperate and share responsibilities as group leaders, assistants, and volunteers. Committees are responsible for a vast number of activities, including establishment of safety zones, training, and preventive actions. Today emergency drills are carried out at least once a month in almost 6223 schools in Mexico City.

2.1.3 Disaster Impact Evaluation Activities

Are performed after an earthquake has occurred. The main activity is the performance of scenario evaluation and impact in every school. Including damage evaluation of all school buildings that could have been affected by a strong earthquake; the quantity and distribution of children, and the type of evacuation that they carried out.

Table 2 shows the results obtained from the application of this program, between 1990 and 1996. Until 1996, 6332 schools participated in

[1] Basic education refers to the following school levels: preschool, elementary, and secondary education (also known as junior high).

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Table 2. Results of the Emergency and Personal Security School Program

School term	Total schools	School Committees Security		Disaster impact		Disaster action plan	
		TOTAL	%	TOTAL	%	TOTAL	%
1989–1990	5585	5505	98.6	831	14.9	659	11.8
1990–1991	5730	5618	98.0	4215	73.6	4224	73.7
1991–1992	5641	5475	97.1	4622	81.9	4481	79.4
1992–1993	5596	5407	96.6	5079	90.8	4919	87.9
1993–1994	5876	5775	98.3	5330	90.7	5330	90.7
1994–1995	6207	6058	97.6	5839	94.1	4724	76.1

the School Emergency and Security Program. This is 99% of all basic education schools in Mexico City. The average periodicity of emergency drills in schools was between 0.8 to 1.5 per month. Evacuation timing varied according to school building characteristics. For example, it took 60 seconds for preschool children to evacuate school buildings with just one floor. Whereas primary school children average 80 seconds and secondary schools timed from 45 to 90 seconds.

The restricted warning signals are sent to the 25 original selected schools when the SAS seismic magnitude forecast is greater than 5. This happens on average once every two months, and the general warning, when SAS seismic magnitude forecast is greater than 6; on average once every 9 months.

2.2 Other Trained Groups

Community-based organizations at the big housing complex El Rosario and the local city government carry out disaster prevention activities such as practice of earthquake response simulations. Since 1995, El Rosario has a public audio warning system with some high power loud-speakers installed in towers, controlled by the SAS. Also, with the same system, between 1995 and 1997, others universities like the Tecnologico de Monterrey and the Universidad Autonoma Metropolitana, started using the SAS warning signals in their campus.

2.3 Groups With no Training

The average Mexico City adult residents who listen to the alert signals on the commercial radio stations have no training in evacuation or earthquake mitigation, although the government of Mexico City in 1995 disseminated a brochure to 2 million households, and for some time a spot was transmitted repeatedly all day long on the radio stations to promote the earthquake education and rapid response. These procedures have been recommended for communicating risk (Mileti 1990). However, earthquake drills for the average city resident have not been carried out frequently.

Another important user group is the people traveling on the Mexico City METRO who do not hear the SAS warning signal, because the signal is issued to operators to travel and stop the trains at the next station, where they open the doors and wait for the seismic effects or receipt of further instructions.

3 SAS Performance

Since August, 1991, after 84 months of continuous operation, the SAS has been able to detect 681 seismic events in the Guerrero Coast; 12 of them so strong as to trigger general alerts in Mexico City, 33 restricted ones, and one false general alert. The performance and reliability of SAS is continuously monitored (Jimenez et al. 1993). There are two scenarios in the issue of the early warning signal; one for earthquakes striking at night and the other for earthquakes striking at day during working hours.

One of the factors for the success of SAS during the "Copala" earthquake was probably because it occurred at 8:04 in the morning, the day time scenario, with the majority of people awake and the children at schools, with an estimated scope of 4 389 000 people covered by the warning signal. In a night scenario this situation could be less favorable. By now only the people at El Rosario housing complex or the

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people who live near the schools or universities with loudspeakers installed could be reached by the earthquake early warning sound.

The SAS does not get the same results for day or night and during those months when the children are on vacations, but we are starting the installation of commercial telecontrolled warning receivers, able to be turned on and warn when the SAS issues its alert signals.

4 Conclusion

The SAS lesson in Mexico City during the "Copala" earthquake help us to identify strengths and weaknesses of societal response to the earthquake early warning signal. The main goal of the SAS is life safety. The long term plan of the SEP for hazard mitigation has created earthquake awareness in the children of various school levels. Even though they did not suffer the disastrous consequences of the 1985 earthquake, they are more aware of earthquake warning than the average person who lived through that event and who is still not trained. The SEP program ensures that all students, teachers, parents and school officials will have the training and support they need to carry out an adequate drill response.

There is a need to identify how the not trained general public responds to the early warning signal. The ability of the general public who listens to the radio to respond to early warning signals should be improved. Improvised response and decisions of untrained people should be avoided. More involvement is needed from federal and local government decision makers to carry out a general program to improve awareness in the average people and promote mechanisms that could be used when an earthquake strikes at night. There is a need to generate more awareness of the seismic risk in Mexico City.

Fortunately the "Guerrero Gap" big earthquake has not occurred and we can propose and discuss new ideas and programs to prepare the untrained people.

Acknowledgements

We thank Daniel Ruiz who was head of the Public Works Department of Mexico City, Secretaría General de Obras del Gobierno del Distrito Federal, and sponsored the development and implementation of the Seismic Alert System, from the beginning of the project in 1990, to November of 1997. Also to Cesar Buenrostro the new head of the Public Works Department, who accepted the challenge to continue promoting and sponsoring the SAS use. The invaluable collaboration of the National Ministry of Public Education Secretaria de Educacion Publica, who started the experimental use of the SAS radio receivers in many schools of Mexico City since 1992.

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CHAPTER 5.6

Earthquake Early Warning System in Japan

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1 Introduction

Japan is situated in one of the most active areas in the world, where the Pacific and Philippine Sea Plates are subducting the Eurasian Plate and where stress and strain of the crust are accumulated (Fig. 1). This results in a lot of earthquakes, tsunamis and volcanic eruptions. As many as 50 000 earthquakes are located in a year, among which 1000–2000 earthquakes are actually felt (Fig. 2). Some strike towns and cities causing destructive disasters. The Southern Hyogo Prefecture Earthquake (the Great Hanshin-Awaji Earthquake Disaster) was the worst earthquake disaster in the past 50 years with more than 6000 casualties. Therefore, efforts for prevention and mitigation of disasters caused by such phenomena have been continued as one of the most important national programs in Japan.

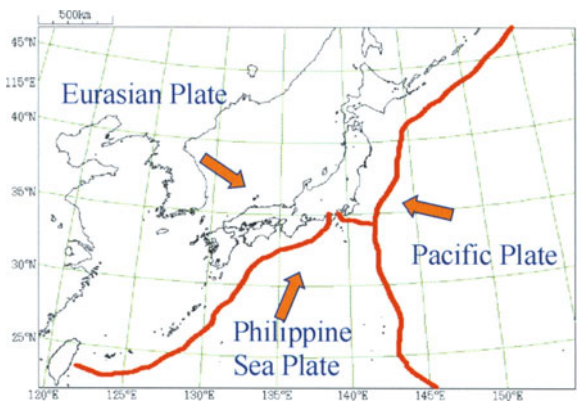


Fig. 1. Tectonics around Japan

The Japan Meteorological Agency (JMA) is the unique agency within the Government of Japan which is responsible for tsunami forecasts (warnings/advisories), the short-term prediction of a large-scale earthquake, and the information services on earthquakes, tsunamis and volcanic activities. Such information as well as tsunami forecasts are issued immediately after the occurrence of earthquakes or volcanic eruptions, and are used to trigger the emergency response to be taken by related organisations of the national government, polices, fire departments, and municipalities. They are also disseminated to residents through municipalities and the mass-media. To accomplish the above-mentioned responsibility of JMA, maintenance and operation of nationwide seismological and volcanological observation networks as well as cooperation with related national and international organs and universities has been continued.

2 Concept of Earthquake Warning

For emergency responses to be taken by related organisations in the cases of an earthquake, it is most important and indispensable for them to know the potential degree of the disaster. Development of a seismic observation network enables us to estimate a location and a magnitude of an earthquake and to pass this information on to the people. However, knowledge on

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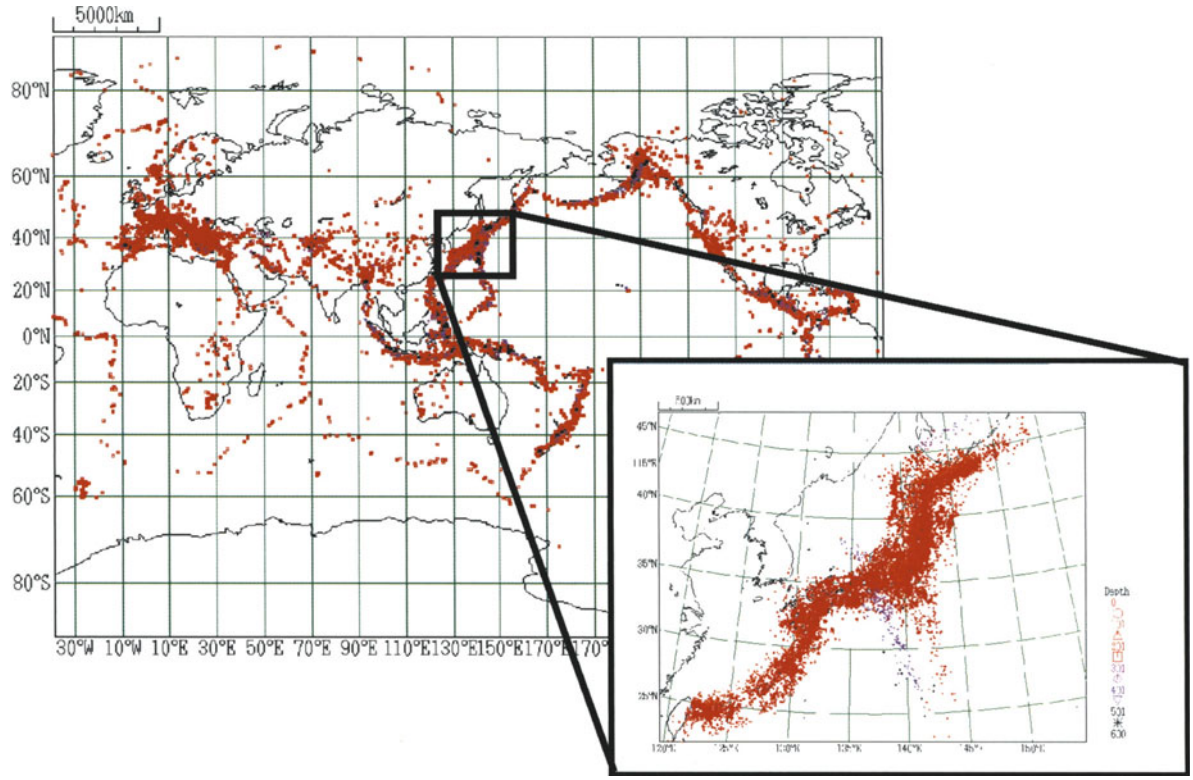


Fig. 2. Seismicity of the world and Japan, using bulletins of JMA and International Seismological Center (ISC)

the location and magnitude is less important for persons responsible for emergency management than information on the ground motion which in turn may implies the potential degree of disaster. If seismic intensities are derived from ground motions on a near real-time base, the necessary measures can be measured on immediately and properly.

3 Development of Seismic Intensities in Japan

The Japanese seismic intensity scale has been developed uniquely. The Japanese people always anticipate the occurrence of a tsunami when a tremor of an earthquake is felt. The seismic intensity is used not only to obtain information on the degree of a disaster caused by an earthquake, but also to trigger action which may reduce a tsunami disaster such as tsunami forecasts or self-evacuations. The JMA had established the tsunami forecast procedure using seismic waveform readings and seismic intensities which were determined by the meteorological observatories and weather stations and were gathered to Regional Tsunami Warning Centers through JMA's meteorological communication circuits to determine a location and a magnitude of an earthquake. A hypocenter, a magnitude, and seismic intensities as a result of the procedure were to be announced immediately to people through the municipalities and mass-media as earthquake information. It enabled them to judge themselves if evacuation would be needed or not before a tsunami forecast, for which 15–30 minutes were necessary. The earthquake information, which comprise seismic intensities at the meteorological observatories and weather stations where a tremor was felt, was also used for decision making by responsible organisations for disaster management and emergency response such as local governments, polices, fire departments and so on. Seismic intensities entail the most important information just after an occurrence of an earthquake as only very little fact data indicating the degree of the disaster are available.

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4 Present Situation

4.1 Observation Network

The sooner Seismic Intensity Information is issued, the easier it is to take measures and actions to reduce earthquake disasters. Objective measurement of seismic intensity and the prompt compilation of results are needed for the immediate provision of seismic intensity information to related organisations and the public. In order to meet with this need, the JMA developed a Seismic Intensity Meter, which is capable of measuring a seismic intensity objectively and automatically using seismic wave data which is then automatically sent to the respective Regional Centers. This was done for the first time in the world in 1991. It enables us to obtain seismic intensity distribution data automatically and immediately after an earthquake occurrence. Measurement of seismic intensity has been conducted fully automatically since 1996 by means of Seismic Intensity Meters after about 600 sets of Seismic Intensity Meters had been installed by the JMA at 20 km intervals all over Japan (Fig. 3).

Moreover, each of the 47 prefectural governments has also installed the equipment in cities, towns, and villages on its own initiative. A total number of seismic intensity meters in Japan reaches a sum of nearly 4000. JMA collects all of seismic intensity data from the local government's Seismic Intensity Meters and together with the information from JMA's own seismic intensitiy meters compiles the earthquake information.

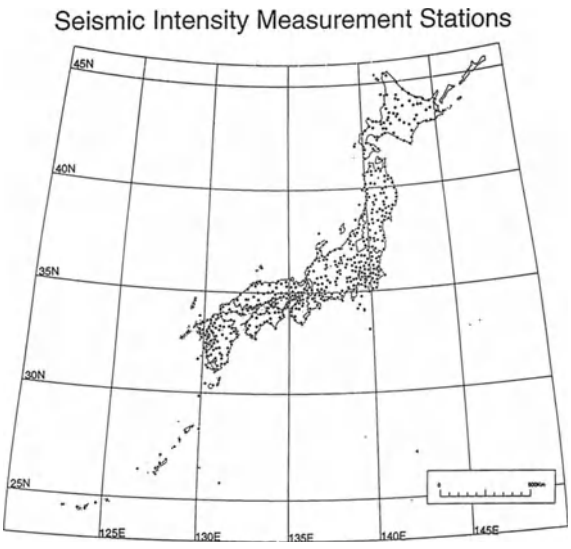


Fig. 3. Distribution of Seismic Intensity Measurement Stations maintained by JMA

JMA also prepared the "Explanation Table of JMA Seismic Intensity Scale." This table provides the up-to-date situation and damage caused by earthquake based on instrumental seismic intensity. The intensity scale provides useful information to estimate the damage. This will aid officials to take effective measures in emergency situations.

4.2 Earthquake Information Issuance Procedure

When an earthquake takes place with the Seismic Intensity being 3 or more, a quick report including the maximum Seismic Intensity and the area names are disseminated in about two minutes after the earthquake takes place (Fig. 4). After determination of the hypocenter and the magnitude of the earthquake, tsunami warning/advisory will be issued if necessary, and then earthquake information will be issued. The earthquake information contains the area names with the seismic intensity 3 or more, the hypocenter and the magnitude. The "area" used in a quick report and seismic information is of 182 blocks into which the Japanese islands are divided. JMA will also issue the seismic intensity observed at every measurement station as earthquake information. If an earthquake with a maximum intensity of 2 or 1 occurs, seismic information including only a hypocenter, a magnitude, and the seismic intensity of each observation station will be issued.

4.3 Dissemination of Earthquake Information

The information on earthquakes should be disseminated urgently and without fail to the authorities and the public. In this regard, JMA has been developing and improving its systems to disseminate the information to the authorities concerned by facsimile via dedicated lines. Some of the authorities have already introduced or are planning to introduce computer systems, directly connecting to the JMA's system to receive and process the information from JMA through dedicated lines on a real-time basis. JMA has also been providing the ur-

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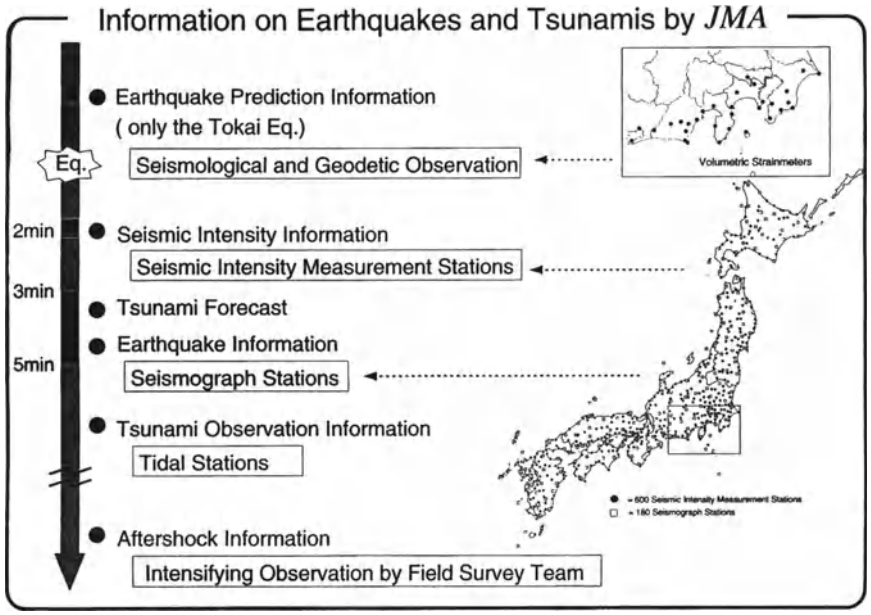


Fig. 4. Time Chart of Earthquake Information Provision

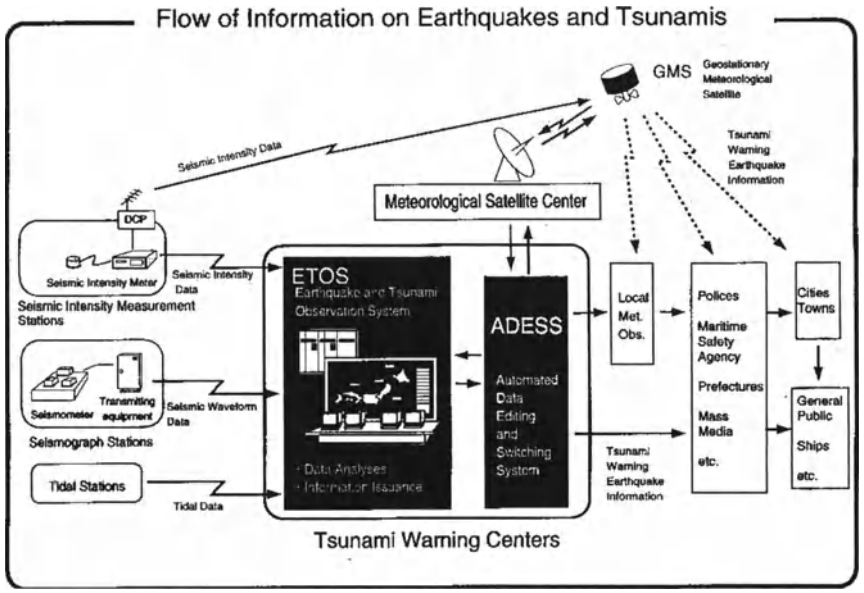


Fig. 5. Dissemination of Earthquake Information

gent information to the authorities and other users since 1993 through the "Satellite-based Information Dissemination Systems" using the Geostationary Meteorological Satellite (GMS). In addition, the information is broadcast to the public under cooperation with radio and television services, by interrupting programs and/or superimposing on television screens to notify of the occurrence of an earthquake (Fig. 5).

4.4 Example of use of Seismic Intensity Value

Delegations from related ministries/agencies will be called to meet at the Cabinet Information Center in the case of a Seismic Intensity of 6 or more in the whole country, or of 5 or more in the Metropolitan area (Fig. 6).

The National Land Agency has been developing and operating a "Disaster Information System" which quantitatively estimates the amount of casualties within 30 minutes after an earthquake. Seismic intensity data provided by JMA

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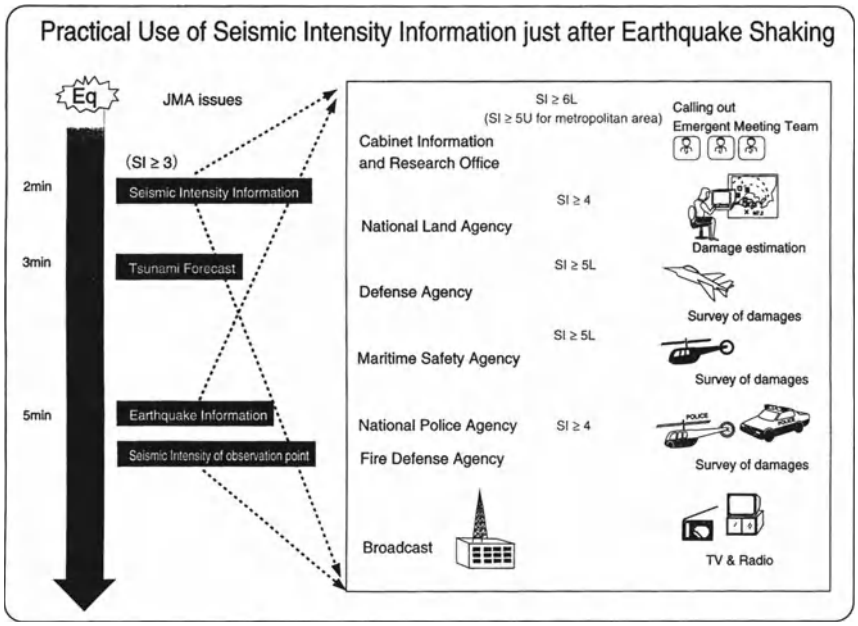


Fig. 6. Example of Practical Use of Seismic Intensity Information

is put into the system as the initial values of its estimation.

The Self Defense Force and Maritime Safety Agency will carry out an aerial survey in the case of a Seismic Intensity of 5 or more.

5 Strategies for the Future

5.1 Estimated Seismic Intensity Distribution

Seismic Intensity varies from place to place based on differences in soil and geological conditions. It is necessary for authorities to have a detail distribution of seismic intensity to take appropriate emergency responses and measures. JMA in cooperation with the National Land Agency has been developing a technique of seismic intensity estimation at places where Seismic Intensity Meters are not installed (Fig. 7).

With this technique Seismic Intensity with a grid size of 1 km is calculated using instrumental seismic intensity values taking geological factors into account. The result is used for damage or loss estimation, a method which has been developed by the National Land Agency.

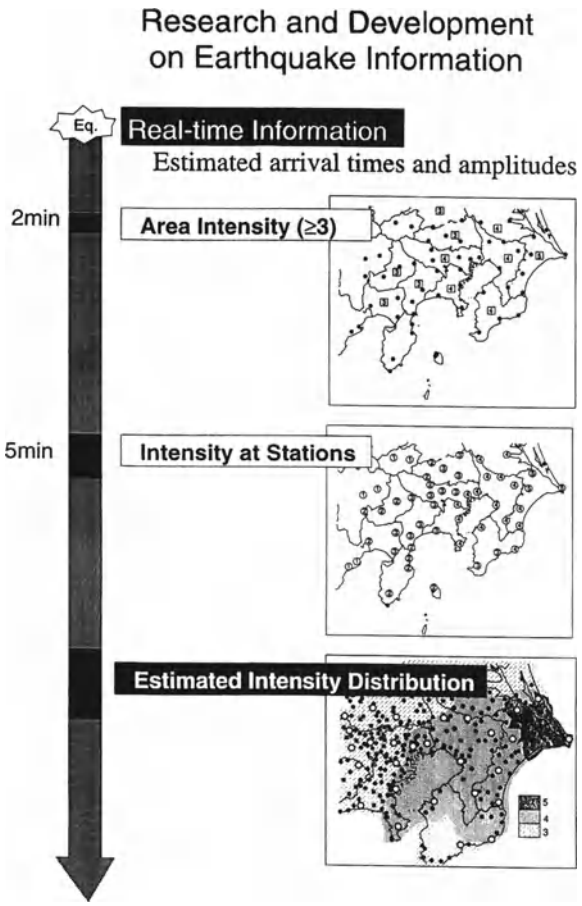


Fig. 7. Example of Estimated Seismic Intensity Distribution

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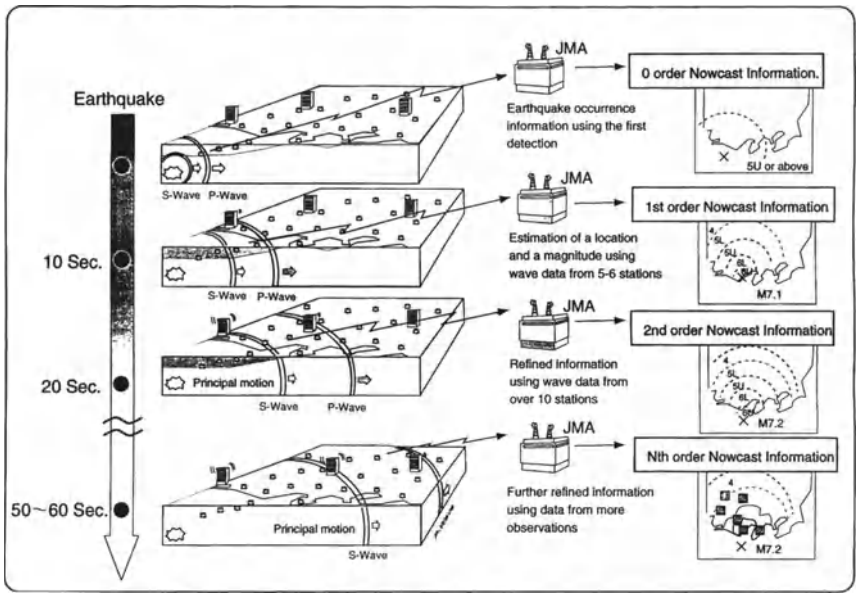


Fig. 8. Conceptual Image of Seismic Wave Propagation and Nowcast Information

5.2 Standardisation of Instrumental Seismic Intensity Measurement

There are various kinds of seismic intensity scales in the world. This is mainly because social conditions and infrastructures such as houses/buildings construction, surface topology, land uses, and populations, vary from country to country. We have to be very careful in applying the seismic intensities of other countries.

It is desirable to establish a world standard of seismic intensity scales. For this purpose, a Seismic Intensity Meter developed by the JMA is very suitable and convenient because it is capable of measuring seismic intensity objectively at any place in the world. We only have to modify the explanation table to adopt to the situation in the respective country/region.

5.3 Nowcast Earthquake Information

JMA is planning to develop an earthquake warning system to disseminate information on the estimated arrival times and amplitudes of the seismic wave before its arrival (Fig. 8). This information is based on the occurrence of an earthquake and the forecast of the arrival times of a principal motion, which may cause damage to buildings. However, we do not call it a Forecast but Nowcast Earthquake Information because it is extremely short-notice warning with only several tens of seconds available to respond. This kind of information is effective in the mitigation of an earthquake disaster if users can control their system properly; for example, the control of ground transportation such as trains and cars, or plants of industrial factories.

It should be noted that the earlier this kind of information can be issued, the less accurate it would be. JMA has been studying technical feasibility concerning a Nowcast earthquake information system and availability of the information as time goes by after the occurrence of the earthquake.

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UrEDAS: The Early Warning System for Mitigation of Disasters Caused by Earthquakes and Tsunamis

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Appendix 1 460

Abstract

An earthquake is a devastating natural disaster which can cause huge amount of casualties and extensive damage within a period of a few minutes. UrEDAS (Urgent Earthquake Detection and Alarm System) is an intelligent and unique alarm system. This system comprises of a single station including three component seismometers and does not need any extra organisation for networking. Immediately after the arrival of a P-wave, it provides information on magnitude, location and the depth of the earthquake. The damage potential is then estimated by relating the magnitude, epicentral distance and depth within three seconds after P-wave detection.

With this approach, similarly, by relating the hypocentral depth, magnitude and the distance between offshore point and coastal line, estimation of the damage potential of Tsunami is also possible. By quickly estimating the earthquake parameters within a few seconds, an alarm can be issued in advance for areas that are vulnerable to earthquakes and tsunamis. To be able to effectively use this approach, together with the early alarm measures it is also necessary to educate and prepare people for disaster during big and destructive earthquakes.

1 Introduction

An early warning system is necessary mainly for the purpose of issuing an early alarm, so as to allow sufficient time to escape or stop important running facilities, and not for the determination of exact earthquake parameters. It is considered that the following functions are necessary to realize an early warning system:

- to quickly detect an earthquake
- to install seismometers at a considerable distance from the urban area, and thus to allow for enough time to escape. The time is calculated by the difference in the velocity between telecommunication (300 000 km/sec) and earthquake motion (8 km/sec)
- to provide automatic management
- automatic management is required for all procedure in issuing an alarm. Otherwise misjudgments might occur
- to inform of the existence of an early warning system
- to educate people on the meaning of the information or alarm. Furthermore, training is

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important, as to teach people how to behave in the case of alarm
- to be able to recognise a possible false alarm and error information
- since there is always a possibility of getting a false alarm, organisations who use the alarm system should have their own risk guidelines.

The main concept of an early warning system was first introduced by J.D. Cooper, M.D. on San Francisco Daily Evening Bulletin of 3rd November 1868 (See Appendix). This report explained the concept as follows:

> A very simple mechanical contrivance can be arranged at various points from 10 to 100 miles from San Francisco, by which a wave of the earth high enough to do damage, will start an electric current over the wires now radiating from this city, and almost instantaneously ring an alarm bell, ... This bell should be very large, of peculiar sound, and known to everybody as the earthquake bell. Of course nothing but the distant undulation of the surface of the earth should ring it. This machinery would be self-acting, and not dependent on the telegraph operators, ...

At that time, no system could actually realise this idea. After a century, based on this concept the Coastline Detection System for the Tohoku Shinkansen Line of JNR (Japanese National Railways, after JR (Japan Railways)) was constructed as a first such system. Following that, a system called UrEDAS (Urgent Earthquake Detection and Alarm System) was developed based on this idea. This system is the only system able to detect earthquake with P-wave motion. The Coastline Detection System for the Tohoku Shinkansen line will be soon upgraded to detect P-wave as UrEDAS.

2 Development of UrEDAS

The UrEDAS mentioned above is the result of JNR's continuous study of the earthquake-safe operation of Shinkansen trains. UrEDAS and previous studies performed before UrEDAS can be summarised as follows:

2.1 Ordinary Alarm Seismometer

An ordinary alarm seismometer issues an alarm if the ground motion vibration exceeds the preset level. In case of JNR (or JR), 40 Gal (=cm/sec^2) is a preset level. To deal with high frequency vibration, some seismometers have a low pass filter of 5 Hz.

In April 1965, the year when the Tokaido Shinkansen (bullet train) went into operation, a M6.1 earthquake occurred at Shizuoka Prefecture. After that, JNR (Japanese National Railways) decided to construct a new earthquake warning system with ordinary alarm seismometers and wave recording seismometers. These seismometers were installed every 20 to 25 km along the Shinkansen Line. They issue an alarm if the acceleration of horizontal ground motion exceeds 40 Gal (=cm/sec^2). This preset level of 40 Gal was determined as the level where earthquakes are suspected to be destructive, thus, the system will not issue alarms against small earthquakes and will not be confused with passing trains or other environmental noise.

2.2 Coastline Detection System for Tohoku Shinkansen Line

After construction of the system mentioned above, JNR started to study a new early warning system for the Shinkansen lines which can be summarized as follows:
1. based on the P-wave, the system can detect earthquakes and estimate their effect on the railroad,
2. the stations for this system are installed near an epicentral area far from the railroad, providing time for an early warning.

When this study was started, there were many problems to be solved on P-wave detection. However it was possible to install seismometers near the epicentral area. Coastal line seismometers were installed based on this idea. This system was designed to shift the P-wave detection system.

The Tohoku Shinkansen Line runs approximately 70 km inland from the coastline and almost all the earthquakes occur off the sea bed at the Tohoku area. Ordinary alarm seismometers were installed along the coastline at the Tohoku area in 1984 to complete the early warning system and this system can control the train operation before the main shock attacks the railroad.

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2.3 UrEDAS

As previously mentioned, at the time of development of the Coastline Detection System for the Tohoku Shinkansen Line, it was impossible to issue an alarm with P-wave detection. In these terms, UrEDAS is a unique early warning system because it can determine earthquake parameters with P-wave data from only one station, and it can issue the exact alarm based on damages caused by the previous earthquakes.

Figure 1 shows the time required to issue an alarm for both P-wave and S-wave alarm on a modelled waveform. Conventional alarm seismometers cannot detect the P-wave but can observe the ground motion. When the ground motion is an earthquake, the S-wave is detected, but at a later stage. On the other hand, an alarm can be issued earlier by detecting the P wave. However, in this case the trigger level is very important since the system also issues an alarm merely when the earthquake motion exceeds a certain pre-set trigger level. If the trigger level is lowered, detection can be performed earlier, but false alarms often occur.

In order to check the new alarm method, railway damage for the past earthquakes are plotted in Fig. 2. In this figure, M-Δ diagram, the horizontal and vertical axis shows magnitude and epicentral distance, respectively. It clearly shows that damage occurs for $M > 5.5$ earthquake and damaged areas are confined within a certain distance range around the epicenter. For example, earthquakes with M6, M7 and M8 result in damage within epicentral distances of 12 km, 60 km and 300 km respectively. If the magnitude and epicenter location with depth can be estimated rapidly, the area to be alarmed can be clearly determined. Reasonable alarm can be issued immediately after the earthquake. This new alarm is referred as M-diagram.

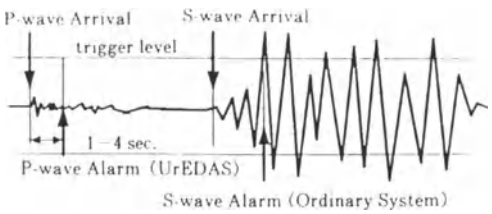


Fig. 1. Alarm timing of UrEDAS and ordinary alarm seismometers

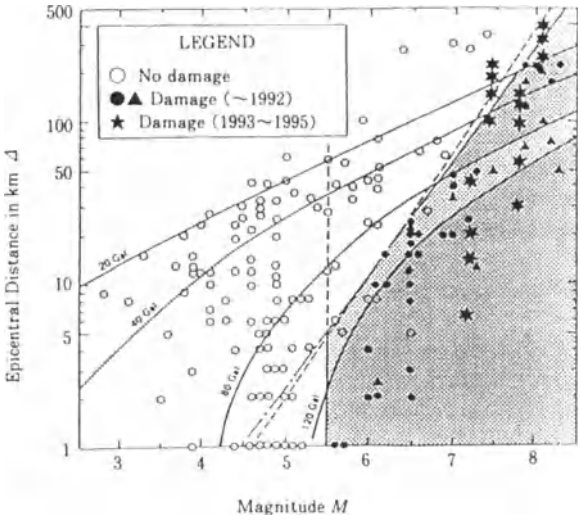


Fig. 2. M-Δ diagram

2.4 Compact UrEDAS

In 1996, the P-wave detection function of UrEDAS was combined with the ordinary alarm seismometer. This new alarm seismometer is called "Compact UrEDAS". Compact UrEDAS can issue both a P-wave alarm and an ordinary alarm. This P-wave alarm is based on an intensity index named the PI value (Nakamura, 1998). The PI value is defined as the maximum value of DI for t seconds after P-wave detection. DI is defined as a power of earthquake motion, DI = log(a*v), where a is acceleration (in Gal = cm/sec^2) and v is velocity (in mkine = 1/1000 cm/sec). Both the PI value and DI are similar to instrumental seismic intensity which is related to the damage condition.

3 Method for Determining Earthquake Parameters with P-wave

3.1 Magnitude

Duration time and the predominant period of the vibration is proportional to the earthquake magnitude. Therefore, the magnitude of an earthquake can be predicted from the predominant period of the initial motion. The predominant period of the initial motion can be estimated by the zero-crossing method, in general. A quick method of estimating predominant frequency, for each time step in real time was proposed by Nakamura (1985).

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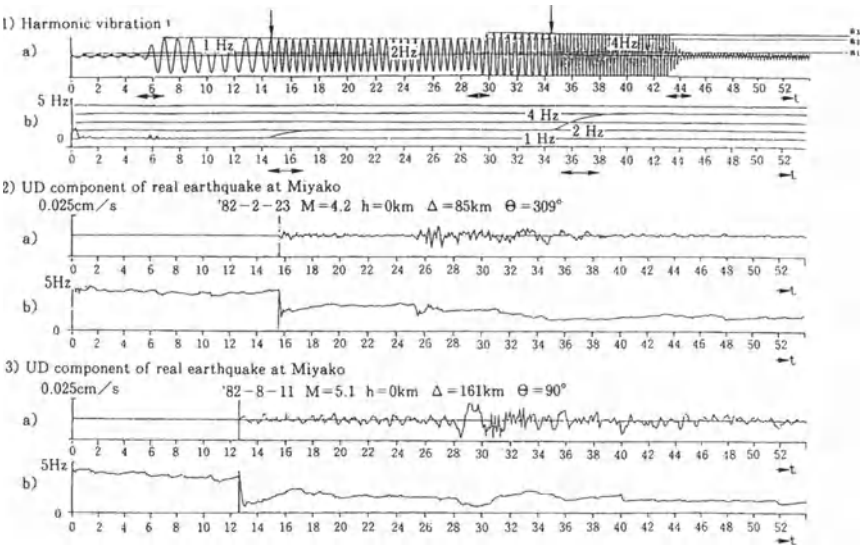


Fig. 3. Estimation of predominant frequency in real-time

Frequency F(i) is defined as a gravity center of power spectra of the velocity and frequency axis as follows:

$$F(i) = (Ai/Vi)^{0.5}/(2\pi)$$

$$= \left(\int wV(w)dw / \int V(w)dw\right)^{0.5}/(2\pi)$$

where A(w) and V(w) are power spectra of acceleration and velocity.

There may be considerable variation. Using this method, the predominant frequency can be estimated continuously in real-time as shown in Figure 3. The fluctuation of the magnitude estimated by UrEDAS are almost within ±0.5 relative to the magnitude estimated by JMA.

3.2 Epicentral Azimuth

The direction of seismic motion and wave propagation coincides at the observation point. Therefore, the epicentral azimuth can be estimated from the direction of the initial motion, projected on the horizontal plane. The azimuth estimations derived simply from the amplitude ratio of the EW component to the NS component show large dispersions and are not accurate. Therefore the following method was proposed by Nakamura and Saito (1983) to obtain better results.

1. Estimation of the cross-correlation at time lag t=0, Rnsud and Rewud, which represent correlation coefficient for NS-UD component and EW-UD component, respectable, between vertical motion Xud and horizontal motions, Xns and Xew, as follows,

$$\text{Rnsud}(i) = \alpha * \text{Rnsud}(i-1) + \text{Xns}(i)\text{Xud}(i)$$
$$\text{Rewud}(i) = \alpha * \text{Rewud}(i-1) + \text{Xew}(i)\text{Xud}(i)$$

2. Derivation of an epicentral azimuth (i) from the ratio Rnsud/Rewud for each time step i, i.e.,

$$\tan\theta(i) = \text{Rnsud}(i)\text{Rewud}(i)$$

3. Then the epicentral azimuth θ of the detected earthquake is defined as the average of the steady part of $\theta(i)$ after the P-wave arrival

Here Xns(i), Xew(i) and Xud(i) are amplitudes of UD, NS and EW, α is smoothing coefficient parameter; $0 \leq \alpha < 1$, shows time step. Table 1 gives the relationship between the signs of Rnsud(i) and Rewud(i) and the quadrant of $\theta(i)$. Figure 4 compares the epicentral azimuth estimated by the local network of Tohoku University or the national network of Japan Meteorological Agency (JMA) and that by the method proposed above using the data of a single UrEDAS observation point. They coincide within ±20 degrees.

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Table 1. Sign of R_{nsud} and R_{ewud} and Quadrant of θ

Case no.	Sign an R_{nsud}	Sign of R_{ewud}	Quadrant of θ	Reference
1	–	–	I	N / II I / III IV / S
2	+	–	II	
3	+	+	III	
4	–	+	IV	

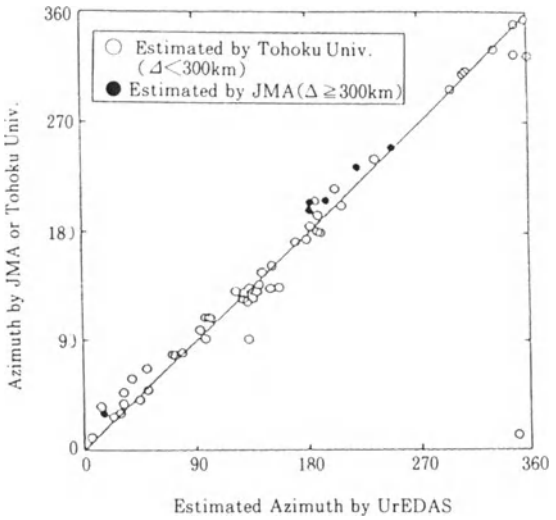


Fig. 4. Comparison of Azimuth of UrEDAS, Tohoku Univ., and JMA

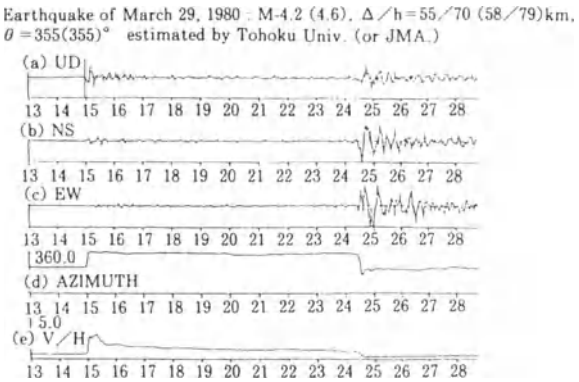


Fig. 5. Relationship between Azimuth and V/H

3.3 Identification of P-wave and S-wave

This process is based on the condition that the detected seismic motion is a P-wave, and identification of whether it is P-wave or S-wave is possible by utilizing the characteristics of the seismic wave motion incident from below, at approximately right angles to the ground surface. Namely, in principle, if the ratio V/H is greater than one, it can be considered as the P-wave, and if the ratio V/H is less than one, it can be considered as the S-wave (see Fig. 5).

3.4 Hypocentral Distance

In general, the magnitude of an earthquake is predicted from the amplitude of the initial motion and the distance from the hypocenter. As the amplitude of an initial motion can be automatically measured and the magnitude of the earthquake can be estimated from the period of the initial motion, the hypocentral distance can be estimated from this information on the initial motion. Although the accuracy of estimating the hypocentral distance in this way (a half to twice) is not high, a more accurate estimation of the hypocentral distance by using the duration of preliminary tremors is possible after the arrival of the principal motion.

3.5 Epicentral Distance and Depth

Based on the hypocentral distance R by using the ratio of the vertical to horizontal initial motion, the epicentral distance Δ and depth h can be estimated. Figures 6 and 7 show the relations of V/H to Δ/R, and to h/R respectively. By means of Figures 6 and 7, Δ and h can be estimated from V/H and R.

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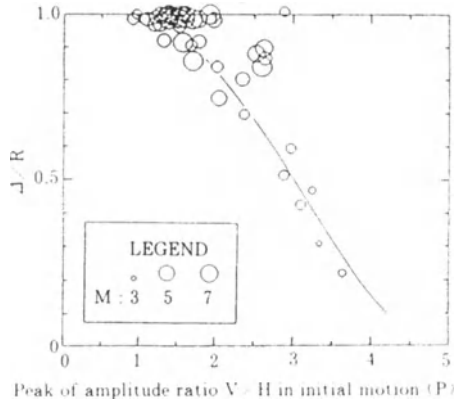


Fig. 6. Relationship between V/H and Δ/R

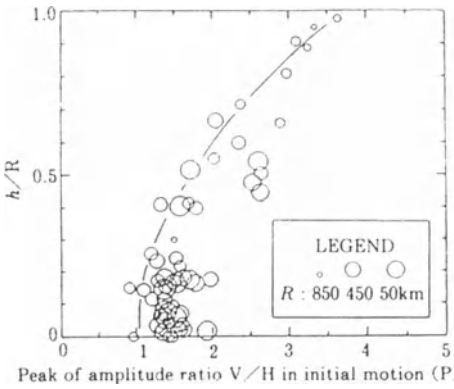


Fig. 7. Relationship between V/H and H/R

4 Existing UrEDAS

4.1 The Tokaido and San-yo Shinkansen Line UrEDAS

There are 19 UrEDAS stations covering about 1000 km along the Shinkansen line from Tokyo to Hakata. Operation started in 1992 for Tokaido (eastern) part and in 1996 for San-yo (western) part which are shown in Figure 8. In the case of an earthquake, each station estimates the potential damage area individually within 3 seconds after detecting the P-wave, and issues an alarm to cut off the power supply for the Shinkansen trains if necessary. This alarm is based on the M-Δ diagram.

On the other side, 48 ordinary alarm seismometers are installed along the Shinkansen line. Even if these seismometers issue the alarm for an earthquake having a maximum acceleration of more than 40 Gal, UrEDAS can determine if the train should return to operation with its own judgment. Table 2 shows a number of issued alarms both from UrEDAS and ordinary alarm seismometers. It shows that the UrEDAS is effective in preventing false alarms.



Fig. 8. Distribution of UrEDAS Networks in Japan

4.2 Tohoku, Joetsu and Hokuriku Shinkansen Lines UrEDAS

There are 43 Compact UrEDAS stations along the Tohoku, Joetsu and Hokuriku Shinkansen lines, 8 stations along the coastline toward the Pacific Ocean and 5 stations along the coastline toward the Japanese Sea.

4.3 Teito Rapid Transit Authority (Tokyo Metropolitan Subway) UrEDAS

There are 6 Compact UrEDAS stations around the Tokyo Metropolitan Area. Compact UrEDAS for both the Shinkansen and the subway is now operating with ordinary alarm function only. However it will soon be able to issue a P-wave alarm based on the PI value.

4.4 Other UrEDAS in Study

Furthermore some UrEDAS stations are currently being studied. The Miyako UrEDAS station is a prototype to establish theory on P-wave detection. The Tokyo metropolitan UrE-

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Table 2. Operation results of Tokaido bullet train based on UrEDAS and orginary alarms

Period	Number of issued UrEDAS alarm		Number of ordinary alarm issued		Total number
	Total num.	M-Δ: M > 4.5 in '92, M > 5.5 in other years	PGA > 40 Gal with 5 Hz LPF	Total num.	
March–December '92	10	◎●●○○○○○○○	□	1	11
January–December '93	4	◎◎○○	□□□	3	7
January–December '94	1	◎	□□□	4	4
January–December '95	2	◎◎	□□□□□	6	7
January–December '96	0		□□□	3	3
January–December '97	1	◎	□□□□	4	5
January–August '98	0		□	1	1

○ : UrEDAS alarm M > 4.5 or 5.5
◎ : UrEDAS false alarm caused by coda wave after the distant large earthquake
● : UrEDAS false alarm cause by lightening elecromagnetic noise
□ : Ordinary alarm
◎ : Ordinary alarm and UrEDAS alarm M > 5.5

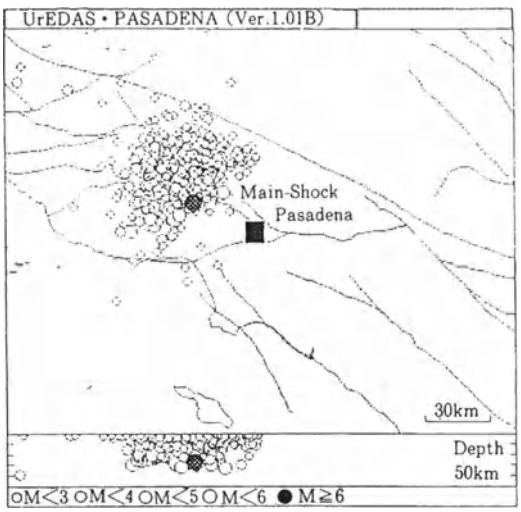


Fig. 9. Main shock and aftershocks of Northridge Earthquake detected by Pasadena UrEDAS

DAS network has 5 stations around the Tokyo metropolitan area. For an examination of data distribution, centralised earthquake parameters were distributed by more than 50 users by facsimile within 4–5 minutes.

The California UrEDAS located at the Pasadena observatory of Caltech (California Institute of Technology) had observed earthquake motion with only one station up to the 1994 Northridge Earthquake. Figure 9 shows the result of observation on the Northridge Earthquake and its aftershocks.

5 Application for Tsunamis

For a tsunami warning system, it is possible to simulate the tsunami arrival time and its maximum wave height around the UrEDAS station based on the estimated earthquake parameters. The arrival time can be calculated from the inverse propagation diagram of the coastline UrEDAS station with estimated magnitude, epicentral distance and epicentral azimuth. Maximum wave height is known from the Abe's formula (1981) with estimated magnitude and epicentral distance. Abe's formula is

$$Mt = \log H + \log D + 5.80,$$

where Mt is tsunami magnitude (= moment magnitude Mw), H is maximum wave height (m), D is the shortest distance from the epicenter to the station detecting the earthquakes (km). However, if the epicenter location can be estimated, it is possible to make a recommendation on refuge action, considering the past tsunami damage. Almost all the tsunami earthquakes occur far from the coastline, and UrEDAS can predict both earthquake and tsunami damage simultaneously before the S-wave arrival.

On December 28, 1994, a M7.5 earthquake attacked the northern part of Japan. This earthquake is named the "1994 Sanriku-Haruka-Oki Earthquake" by JMA. As this name means "an earthquake far off the Sanriku area", the begin-

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ning of destruction was about 200 km off the coastline. This earthquake caused a Tsunami. For example, the 40 cm high first wave of the tsunami was observed 31 minutes after the earthquake occurrence at Hachinohe about 150 km from the epicenter. The Coastline Detection System station was installed at Hachinohe, and at the time, the P-S time was more than 20 seconds. In this case, UrEDAS can issue alarms for both for earthquake and tsunami about 15 seconds before the S-wave arrival.

6 Conclusion

In terms of early warning systems, the development of UrEDAS and other seismic alarm systems for the Shinkansen train control were explained. In this paper, UrEDAS is a unique early warning system which can detect P-waves and can determine the earthquake parameters with only one station on the spot. The method of detection and determination of P-wave were also explained. This system is capable of automatically estimating the accurate seismic factors within a few seconds after detecting a P-wave arrival. As a seismic disaster prevention system, UrEDAS is applicable in many fields such as nuclear power plants, petrochemical plants, elevators in high rise buildings and large scale industrial facilities.

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Appendix 1

San Francisco Daily Evening Bulletin of 3rd November 1868

Earthquake Indicator

EDITOR BULLETIN – Since the Japanese magnet indicator has proved a failure, we are now obliged to look for some other means of prognosticating these fearful convulsion, and I wish to suggest the following mode by which we may make electricity the means, perhaps, of saving thousands of lives in case of the occurrence of more severe shocks than we have yet experienced. It is well known that these shocks are produced by a wave-motion of the surface of the earth, the waves radiating from a center just as they do in water when a stone is thrown in. If this center happens to be far enough from this city, we may be easily notified of the coming wave in time for all to escape from dangerous buildings before it reaches us. The rate of velocity, as observed and recorded in Dr. J. B. Trask's work on Earthquakes in California from 1800 to 1864, is 61.5 (six and one fifth) miles per minute, or a little less per hour (40 miles) than the tidal wave is reported to have traveled across the ocean to this port from the Sandwich Islands or Japan.

A very simple mechanical contrivance can be arranged at various points from 10 to 100 miles from San Francisco, by which a wave of the earth high enough to do damage, will start an electric current over the wires now radiating from this city, and almost instantaneously ring an alarm bell, which should be hung in a high tower near the center of the city. This bell should be very large, of peculiar sound, and known to everybody as the earthquake bell. Of course nothing but the distant undulation of the surface of the earth should ring it. This machinery would be self-acting, and not dependent on the telegraph operators, who might not always retain presence of mind enough to telegraph at the moment, or might sound the alarm too often. As some shocks appear to come from the west, a cable might be laid to the Farallone Islands, 25 miles distant, and warnings thus given of any danger from that direction.

Of course there might be shocks the central force of which was too near this city to be thus protected, but that is not likely to occur once in a hundred times.

By J. D. COOPER, M.D.

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On the Establishment of an Automatic Earthquake Information Broadcast System in Taiwan

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Abstract

An efficient earthquake auto-location algorithm has been developed by the Central Weather Bureau (CWB), Taiwan. The CWB can now routinely obtain earthquake information in one minute after the occurrence of an earthquake using this new algorithm. In order to take full advantage of this capability, four automatic information broadcast media, namely, e-mail, World Wide Web, FTP server and pager system, have been configured to receive and transmit automatically the earthquake information from the CWB seismic monitoring system. This new automatic earthquake information broadcast system will enable the CWB to disseminate information about felt earthquakes even more quickly and widely than its current practice through the fax and paper reports.

1 Introduction

Interest in rapid access to earthquake information had grown enormously in the past few years. In addition to satisfying the public and media needs, the rapid notification programs provide valuable information for rapid earthquake disaster response, thereby mitigating the loss. Recognizing the importance of rapid earthquake information for seismic hazard mitigation, efforts to design and implement systems to provide rapid earthquake information have expanded over the last 10 years. Recently, a real-time strong-motion network was installed in the Taiwan area by the Central Weather Bureau (CWB) for monitoring purposes. In order to maximize the use of data from this network, a rapid earthquake information and early warning system is under active development. A rapid response information release system for large earthquakes in Taiwan has been implemented CWB through a Taiwan Rapid Earthquake Information Release System (TREIRS). In this paper, we shall describe the instrumentation and system performance of the TREIRS.

2 Instrumentation

The CWB of Taiwan has deployed a modern digital accelerograph network. The network headquarters receives a continuous digital data stream input from 58 strong-motion stations (Fig. 1) on a real-time basis. At a digitization rate of 50 samples/sec, three channels of strong-motion data take up the 4800-baud band of the CWB leased telephone lines, whereas an additional 4800-baud band is used for transmitting short-period velocity data. A group of PC respectively operates under MS-DOS, Windows/95, and Windows/NT system for data acquisition, processing, and communication (Fig. 2).

A block diagram of two major data processing systems used for the TREIRS is shown in Figure 3. One system is for the continuous recording, and the other for triggered recording. For rapid earthquake information release sys-

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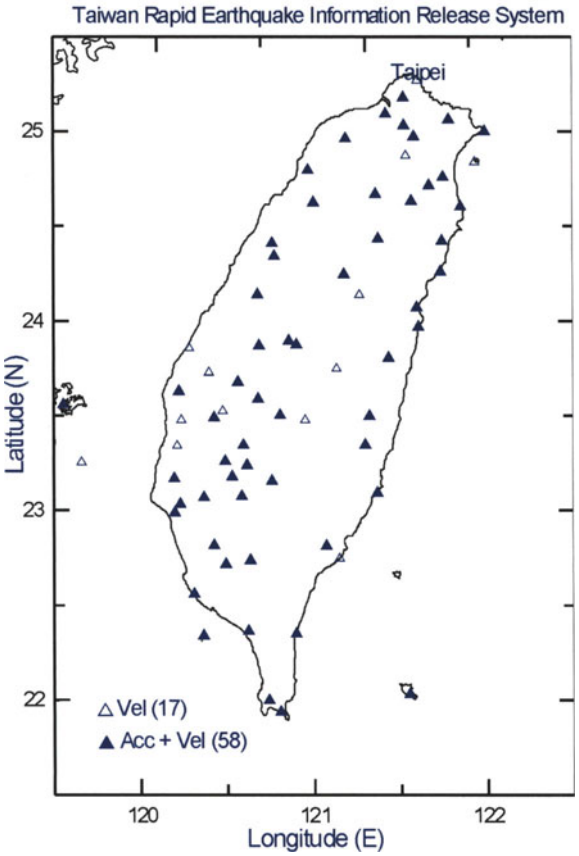


Fig. 1. Map showing station locations of telemetered digital accelerographs and short-period seismographs (solid squares), and telemetered digital short-period seismographs (open squares) in Taiwan

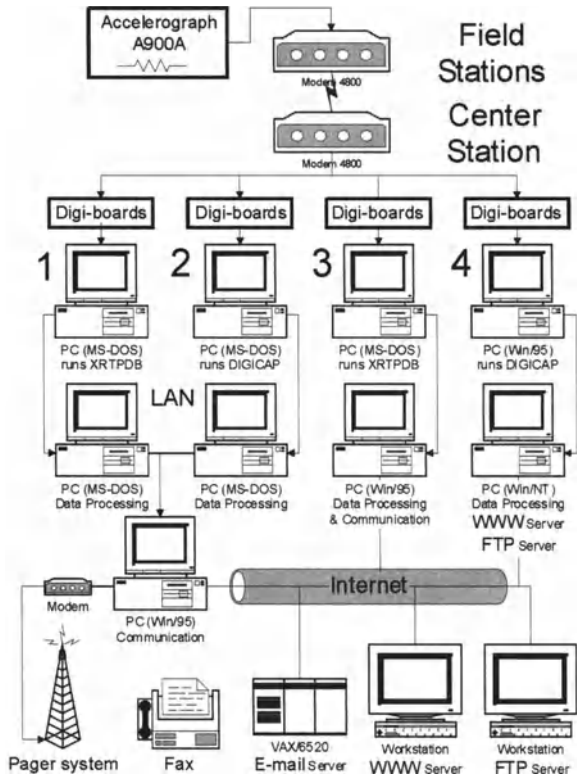


Fig. 2. A block diagram showing the hardware of the Taiwan Rapid Earthquake Information Release System (TREIRS)

tem, the incoming data is processed by a software XRTPDB written by Tottingham and Mayle (1994). Whenever a set of pre-specified trigger criteria are met, digital waveforms are saved and analyzed by a program for automatic phase picking, and for automatic earthquake location. Results are disseminated in four different ways, namely, through E-mail, World Wide Web, FTP sever, and pager system (Wu et al. 1997a).

The incoming data is also processed by another PC system. The data is continuously recorded at 1-minute intervals per file by a software DIGICAP written by Mayle (1995). Each one-minute file is then subjected to automatic triggering, phase picking, earthquake location, and PGA calculation. The results are included in the earthquake report for official announcement in routinely manner.

3 System Performance

Taiwan Rapid Earthquake Information Release System (TREIRS) had been operational since March 3, 1996. While most M_L>4.0 earthquakes were recorded by TREIRS, only the events having P (or S) arrivals from six stations have been processed. Up to December 14, 1997, seventy-nine events were identified and automatic reported (Fig. 4).

3.1 Location Difference Between Automatic and Manual Picking

As a comparison, the epicenters of seventy-nine earthquakes as determined by the TREIRS automatic location versus off-line manual location from March 5, 1996 to December 14, 1997 are shown in Figure 4. The average difference in epicenter location is about 7.2 km, and with a standard deviation of 9.7 km. In general, the earthquakes which occurred inside the TREIRS network had smaller location difference compared to the ones outside the network.

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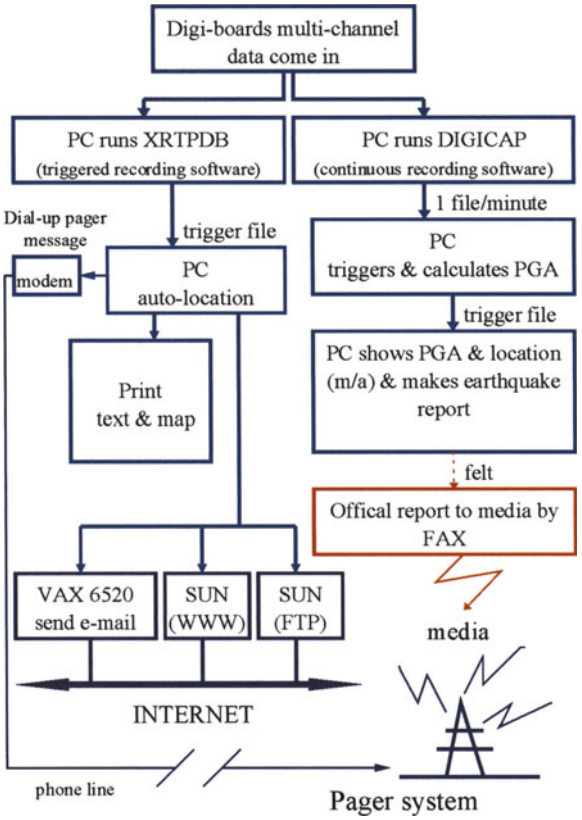


Fig. 3. A flow chart showing the data processing of the TREIRS

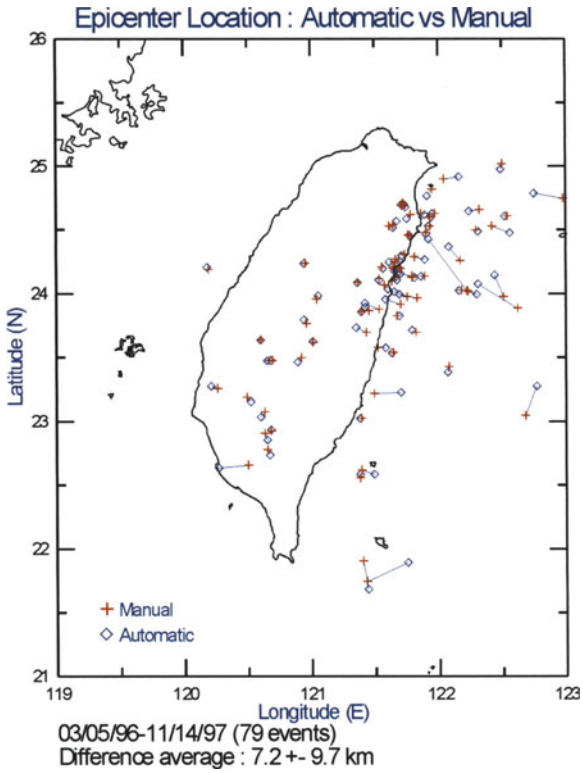


Fig. 4. Location difference of 79 earthquakes determined by automatic and manual picking

3.2 Magnitude Difference Between Automatic and Manual Picking

Figure 5 shows the TREIRS magnitude difference of the seventy-nine events obtained by automatic and manual location. The automatic determined magnitude is generally underestimated by 0.05 and with a standard deviation of 0.16.

3.3 Effective Response Time

In this study, the effective response time is defined as the time interval between system received the *P*-wave arrival of the nearest station and source parameters reporting time. Based on the fifty-one reports that provide the reporting time, we found the average effective response time is 52.5 sec and with a standard deviation of 7.6 sec (Fig. 6).

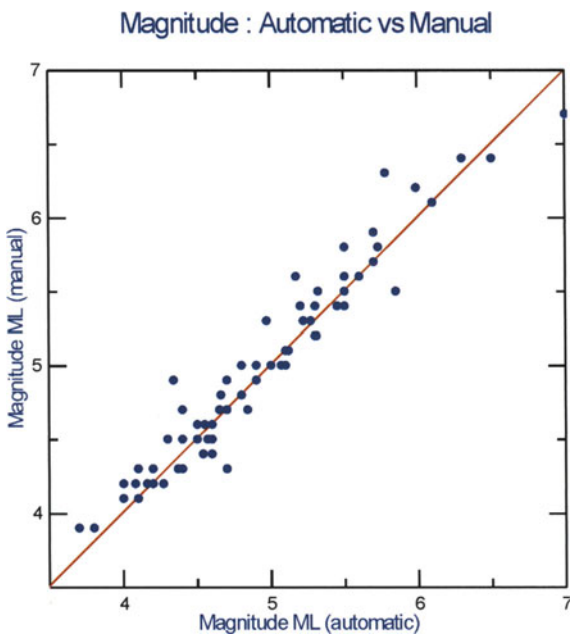


Fig. 5. Magnitude relationship (A) and difference (B) of 79 earthquakes determined by automatic and manual picking

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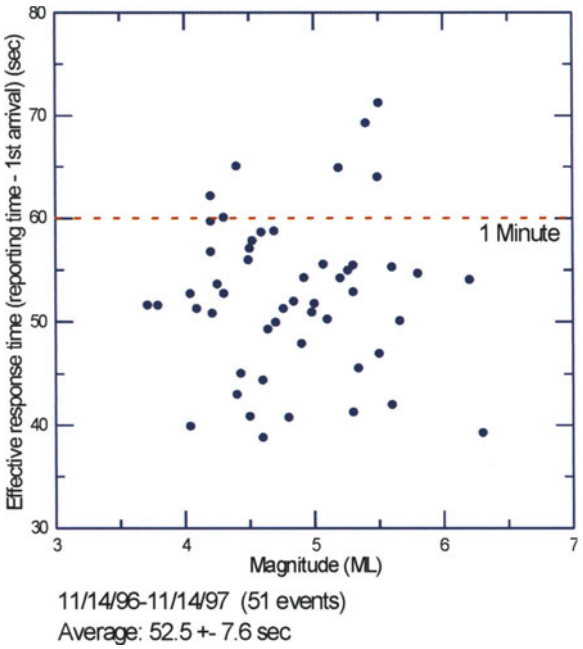


Fig. 6. Earthquake effective response time versus magnitude

4 Summary

We have deployed an inexpensive, real-time telemetered accelerograph network in Taiwan, which is capable of the on-scale recording and rapid reporting of large earthquakes. Our results show that we have achieved earthquake location and magnitude determination in about one minute after the occurrence of the felt earthquake. We are confident that a 30-second earthquake reporting time can be achieved in the future. This paper and other papers of this series published before (Teng et al. 1997; Wu et al. 1997a, 1997b, 1998a, 1998b) essentially pave the way for an earthquake early warning system to be put in operation in Taiwan.

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European Warning System

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1 The Council of Europe EUR-OPA Major Hazards Agreement

The Committee of Ministers of the Council of Europe adopted Resolution (87) 2 in March 1987 establishing an intergovernmental Open Partial Agreement. It is named "Open" because any non-member State of the Council of Europe may apply to accede to it.

This Open Partial Agreement has to date 23 member States: *Albania, Algeria, Armenia, Azerbaijan, Belgium, Bulgaria, France, Georgia, Greece, Italy, Lebanon, Luxembourg, Malta, Republic of Moldova, Monaco, Morocco, The Former Yugoslav Republic of Macedonia, Portugal, Russia, San Marino, Spain, Turkey, Ukraine.* Japan has the status of observer.

The European Commission, UNESCO, WHO and the Office for co-ordination of Humanitarian Affairs (OCHA) of the United Nations participate in the Agreement. The International Federation of Red Cross and Red Crescent Societies are also associated in its work.

2 Main Objectives

The main objectives of the EUR-OPA Major Hazards Agreement are:

- on the one hand, to reinforce and promote co-operation between member States in a multi-disciplinary context to ensure better prevention, protection and organisation of relief in the event of major natural or technological disasters by calling upon present day resources and knowledge to ensure an efficient and interdependent management of major disasters;
- on the other hand, to use the Agreement as a suitable platform for cooperation between Eastern Europe, the South of the Mediterranean and Western Europe in the field of major natural and technological disasters.

One of the main points of this Agreement is to have seeked to ensure a direct interest and participation of the member States by fostering the creation of European Centres. These structures facilitate a concrete contribution from the different partners, with common objectives, through the implementation of European information, training and research programmes (see appendix 1 list of the European Centres).

3 Activities

The activities carried out within the Agreement are situated at three levels:

1. *the political level* with the periodical meetings of the Ministers of the Agreement and of the Committee of Permanent Correspondents;
2. *the scientific and technical level with:*
   the "European Warning System",
   the "European Network of Specialised Centres",
   the "European Advisory Evaluation Committee for Earthquake Prediction".

The "European Advisory Evaluation Committee for Earthquake Prediction" held its meeting in Potsdam on 4–5 September 1998 at the invita-

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tion of the GeoForschungsZentrum for which I would like to thank here on behalf of the Council of Europe.

The "European Advisory Evaluation Committee for Earthquake Prediction" is responsible for giving enlightened advice on the earthquake predictions put forward by scientists. It was established within the context of the Council of Europe EUR-OPA Major Hazards Agreement in the light of the problems raised by earthquake predictions made by groups of scientists, announced directly or through the press, involving considerable potential damage and loss of life.

Seismologists, aware of this kind of problem, had themselves adopted a European Code of Ethics on information relating to earthquake prediction during the International Conference organised by the Council of Europe in Strasbourg from 15–18 October 1991.

The Committee was set up by the Committee of Ministers of the Council of Europe. It has been operational since 10 June 1994. It is in a position to reply to requests forwarded by the governments of member States of the EUR-OPA Major Hazards Agreement.

3.1 Specific Programmes

1. Use of space technology to assist risk management: the STRIM Programme.
2. The European programme on training in the field of risk sciences: the FORM-OSE programme.
3. The "Communication and Information" Programme EDRIM: Electronic discussion group for Risk Management.

4 European Warning System (SAE) Objectives

The objective of the European Warning System (SAE) is to foster information and concertation between member States of the Agreement in the assistance provided to a State hit by a disaster. In fact, it provides member States in almost real time with technical data concerning the occurence of an earthquake. The European Warning System is also used for other types of major disasters.

In the event of an earthquake whose magnitude is more than or equal to 6 on the Richter scale and of an earthquake whose magnitude is less than that, but whose destructive effects are important, the Euro-Mediterranean Seismological Centre in Paris (EMSC) informs in real time, the 24-hour stand-by team responsible for the warning system at the Council of Europe of the location of the earthquake's epicentre and its magnitude.

Seismic surveillance is carried out by 33 networks of seismometres. Prompt determination of epicentres allowing the location of the epicentre within the hour following the seismic event is achieved by processing the data of the 33 networks by EMSC. The networks are situated in: Germany, Israel, Turkey, United Kingdom, Norway, Switzerland, Greece, Slovenia, Belgium, USA, Canada, Djibouti, Polynesia, Russia, Italy, Spain, France, Netherlands, Lebanon, Rumania, Portugal, the Ivory Coast, Nepal, Mongolia.

As soon as the person responsible for the European Warning System is informed of the occurrence of an earthquake, he triggers the system addressing two types of messages:

A first message is addressed to the country affected, requesting for additional information on the situation in the country as well as its decision on a request for aid from the other member States and the institutions participating in the EUR-OPA Major Hazards Agreement. On the basis of the response of the affected country, the person responsible for the European Warning System (SAE) immediately sends the information to the member States (operational structures and Permanent Correspondents) and to the institutions participating in the Agreement.

Parallel to the first message, a second message giving technical data on the earthquake is addressed to the member States and to the institutions participating in the Agreement: European Union, Office for the co-ordination of Humanitarian Affairs (OCHA), WHO, UNESCO of the United Nations.

The tables below show the statistics of the triggering of the European Warning System from 1 January 1997 to 1 July 1998.

The intervention of the European Warning System (SAE) is limited to the dissemination of technical data on an earthquake (time, location, magnitude) as well as to a first evaluation of damages among member States and international organisations participating in the Agreement.

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Table 1. European Warning System: January–December 1997

Date	Type of Disaster	Place	Magnitude	Alert
13. 1. 97	EQ	Cyprus	5.3	
22. 1. 97	EQ	Turkey	5.5	
21. 2. 97	EQ	Kuril Islands	6.5	
28. 2. 97	EQ	Turkey	4.7	
18. 3. 97	EQ	Crete	5.0	
25. 4. 97	EQ	Kuril Islands	5.6	
16. 5. 97	EQ	Albania	4.7	
15. 6. 97	EQ	Hokkaido, Japan	5.5	
27. 6. 97	EQ	Azores Islands	5.8	
7. 7. 97	Forest fires	Greece		
July 97	Flooding	Central Europe		Action Programme STRIM
14. 7. 97	EQ	Kuril Islands	5.9	
27. 7. 97	EQ	Central Mediterranean Sea	5.5	
5. 9. 97	EQ	Kuril Islands	5.8	
26. 9. 97	EQ	Central Italy	5.5	26. 9. 97 for info
3. 10. 97	EQ	Central Italy	5.1	
5. 10. 97	EQ	Kuril Islands	5.7	
8. 10. 97	EQ	Hokkaido, Japan	5.6	
13. 10. 97	EQ	Southern Greece	6.1	
14. 10. 97	EQ	Central Italy	5.2	
22. 10. 97	EQ	Kuril Islands	5.8	
5. 11. 97	EQ	Crete/Greece	5.0	
5. 11. 97	EQ	Greece (Corinth)	5.6	
6. 11. 97	Flooding	Extremadoura, Spain		
12. 11. 97	EQ	Greece/Albania	5.2	
14. 11. 97	EQ	Aegean Sea	5.3	
15. 11. 97	EQ	Hokkaido, Japan	6.3	
18. 11. 97	EQ	Southern Greece	5.2	
18. 11. 97	EQ	Ionian Sea	5.9	
28. 11. 97	EQ	NW Kuril Islands	5.9	
5. 12. 97	EQ	E.Cst Kamchatka	7.8	5. 12. 98 for info
7. 12. 97	EQ	E.Cst Kamchatka	5.7	
17. 12. 97	Crash Ukrainian aircraft	Greek territory (Morna)		Action Programme STRIM

Humanitarian aid is then ensured by the Commission of the European Union (through DG XI and ECHO) and by OCHA of the United Nations.

This sharing of duties was taken during a tripartite meeting in Geneva in December 1994 within the framework of the follow up to Resolution 4 adopted at the Ministerial meeting on the reinforcement of the links between international institutions in the field of risk management adopted during the 6th Ministerial meeting on 6 October 1994 in Brussels.

Futhermore, we are setting up a permanent network of telecommunications between civil protections of member States based on a network of electronic discussion group, the EDRIM network.

EDRIM is a programme using new information and communication technologies whose objective is to foster international co-operation for assistance in decision-making in risk management.

Based on the use of the I'net system, it facilitates communication between national bodies responsible for risk management at several levels:

- Traditional communication: audio and video conferences allowing virtual meetings with the support of appended tools: presentation of text, images, shared work on a common document for all participants;
- Access to the shared knowledge sources provided access authorisation and previous agreement on exchange formats and/or storing formats: notion of "distributed universal library";
- Access to treatment codes developed and made common;
- General codes of treatment of basic data in particular from geographical information systems (SIG);
- Specialised codes in particular for modelling;

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Table 2. European Warning System: January–July 1998

Date	Type of Disaster	Place	Magnitude	Alert
17. 1. 98	EQ	Kuril Islands	6.0	
13. 2. 98	EQ	Dodecanese Islands, Greece	4.6	
25./26. 2. 98	Landslide	Moldova		Post-crisis analysis
9. 3. 98	EQ	Eastern Med. Sea	5.2	
13. 3. 98	EQ	Black Sea	5.1	
16. 3. 98	EQ	Kuril Islands	6.1	
25./27. 3. 98	Severe weather	Greece		
26. 3. 98	EQ	Central Italy	5.6	26. 3. 98 for info
3. 4. 98	EQ	Central Italy	4.9	
4. 4. 98	EQ	Turkey	5.1	
5. 4. 98	EQ	Central Italy	5.2	
12. 4. 98	EQ	Austria	5.8	
15. 4. 98	EQ	Kamchatka	5.8	
22. 4. 98	EQ	Kuril Islands	5.5	
29. 4. 98	EQ	Southern Greece	5.2	
6. 5. 98	Flooding/mud slides	Italy (Campanie)		Post crisis analysis
12. 5. 98	EQ	E. Kuril Islands	5.8	
14. 5. 98	EQ	Honshu, Japan	6.1	
18. 5. 98	EQ	Southern Italy	6.1	18. 5. 98 for info
27. 5. 98	EQ	E. Kamchatka Pen	5.8	
28. 5. 98	EQ	E. Kamchatka Pen	5.6	
June 98	Severe flooding	Russian Federation		
1. 6. 98	EQ	E. Kamchatka Pen	6.6	
27. 6. 98	EQ	Turkey	5.7	27. 6. 98 for info
3. 7. 98	EQ	Hokkaido, Japan	5.3	
9. 7. 98	EQ	Azores Islands	5.8	9. 7. 98 for info 13. 7. 98 request for assistance
16. 7. 98	EQ	Greece	5.3	

- Concept of distributed resources accessible to any authorised person opening the way to any type of distance learning;
- Setting up at all levels of authorisation system (passwords, etc.) and/or security locks offering protection and security in the information exchange in a restricted network.

In conclusion, we are studying technical modalities of connection between the European Warning System (SAE) and the EDRIM network. Indeed, the SAE represents an important contribution to foster cooperation and decision making for emergency situation management linked to seismic events. Connecting it to the EDRIM network will foster receipt in real time of information and interactivity between the structures having the responsibility of risk management and the responsible person of the European Warning System of the EUR-OPA Major Hazards Agreement.

Appendix

European Network of Specialised Centres of the Agreement

European Centres

1. CEMEC – European Centre for Disaster Medecine (San-Marino)
2. CUEBC – European University Centre for the Cultural Heritage (Ravello, Italy)
3. AFEM – European Natural Disasters Training Centre (Ankara, Turkey)
4. ECPFE – European Centre on Prevention and Forecasting of Earthquakes (Athens, Greece)
5. EMSC – European Mediterranean Seismological Centre (Bruyères-le-Châtel, France)
6. CESG – European Centre for Seismic and Geomorphological Hazards (Strasbourg, France)
7. ECGS – European Centre for Geodynamics and Seismology (Walferdange, Luxemburg)
8. ICoD – Euro-Mediterranean Centre on Insular Coastal Dynamics (Valletta, Malta)

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9. OOE – Monaco Scientific Centre, European Oceanological Observatory (Monaco)
10. ECNTRM – European Centre of New Technologies for the Management of Natural and Technological Major Hazards (Moscow, Russian Federation)
11. ISPU – Higher Institute of Emergency Planning (Florival, Belgium)
12. CEISE – European Centre for Research into Techniques for Informing the Population in Emergency Situations (Madrid, Spain)

Associate European Centres or Associate Euro-Mediterranean Centres

1. CERU – Associate European Centre for Urban Risks (Lisbon, Portugal)
2. ECTR – Associate European Interregional Educational Centre for Training Rescuers (Yerevan, Armenia)
3. GHHD – Associate European Centre on Geodynamical Risks of High Dams (Tbilisi, Georgia)
4. Associate European Centre on Training and Information of Local and Regional Authorities and Population in the Field of Natural and Technological Disasters (Baku, Azerbaijan)
5. CEPRIS – Associate Euro-Mediterranean Centre for Evaluation and Prevention of Seismic Risk (Rabat, Morocco)
6. CSLT – Associate European Centre for School Level Training on Risk Prevention (Sofia, Bulgaria)
7. CRSTRA – Associate Euro-Mediterranean Centre for Arid Zones (Ksar Chellala, Algeria)
8. TESEC – Associate European Centre of Technological Safety (Kiev, Ukraine)
9. ECILS – Associate European Centre for the Vulnerability of Industrial Installations and Infrastructures (Skopje, Former Yugoslav Republic of Macedonia)

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25 Seconds for Bucharest

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Abstract

The Romanian capital Bucharest faces a significant earthquake hazard with a 50% chance for an event greater than 7.6 moment magnitude within 50 years. The last devastating earthquake hit in 1977 when 35 high-rise buildings were destroyed and 1500 fatalities were counted. An Early Warning System (EWS) based on the traveltime differences between the primary P-wave and the destructive S-wave allows a warning time of about 25 s. Peculiarities of the Romanian intermediate depth seismicity such as the stationary epicenters and the stability of radiation patterns, and a line-of-sight connection between the epicentral area and the capital allow to design a simple and robust EWS. Simplicity and robustness of the system are sought in order to reduce the risk of false alarms, which is crucial for making the system cost-beneficial.

1 Introduction

The value of EWS for hazards with long warning times such as tsunamis, volcanic activities, tornadoes is undisputed. In the case of earthquakes, warning times are fairly small, ranging from seconds to a maximum of about one minute for Mexico City. However, even a small time window can provide opportunities to automatically trigger measures such as the shutdown of computers; rerouting of electrical power; shutdown of disk drives; shutdown of high precision facilities; shutdown of airport operations; shutdown of manufacturing facilities; stopping of trains; shutdown of high energy facilities; shutdown of gas distribution; alerting of hospital operating rooms; opening of fire station doors; starting of emergency generators; stopping of elevators in a safe position; shutoff of oil pipelines; issue audio alarms; shutdown refineries; shutdown nuclear power plans; shutoff water pipelines; maintaining a safe-state in nuclear facilities (Harben, 1991). Only few of these options can actually be carried out once the warning time is down to a few seconds.

Every EWS consists of four components (1) a monitoring system composed of various sensors, (2) a real-time communication link that transmits data from the sensors to a computer, (3) a processing facility that converts data to information, and (4) a system that issues and communicates the warning. The output of the third component, the information the specific user requests, will depend on the need of the user. In case of an earthquake it can be an estimate of magnitude and location of the event but equally well a projection of the expected acceleration or intensity at specific sites.

A group of civil engineers and seismologists from the National Institute of Earth Physics (NIEP) in Romania and Karlsruhe University in

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Germany propose an Early Warning System (EWS) for the capital city of Bucharest. EWSs can be grouped in those that require the determination of hypocenter and magnitude because site and strength of the earthquake cannot be anticipated. The systems developed in California (Heaton et al. 1996; Harben 1991), Taiwan (Teng et al. 1997), and UrEDAS (Noda & Meguro, 1995) in Japan belong to this category. The other group relies on the direct reaction of the system on one or several strong motion records. The first EWS for the Shinkhansen (Nakamura 1989; Nakamura 1996), the Mexican EWS (Espinosa-Aranda et al. 1995) and the system proposed here share this property.

We discuss the seismological boundary conditions of an EWS for the Romanian capital of Bucharest. The earthquakes threatening the capital are intermediate deep events with magnitudes close to $M_w = 8.0$ at an almost fixed epicentral distance of about 150 km. The travel-time difference between the destructive S-wave arriving in Bucharest and the epicentral P-wave is always greater than 25 s, which represents the maximum possible warning time. Moreover source mechanisms are extremely stable for larger and smaller events so that a projection of the level of ground motion to be expected in Bucharest can be based on the amplitude of the epicentral P-wave rather than on cumbersome determination of magnitude and depth. This feature allows the design of a simple, robust and fast EWS. With 25 s, a system with the largest warning time after the Seismic Alarm System for Mexico City could be established.

In the following we characterise the Romanian seismicity and its implication for an EWS. The stability of the warning time and scaling relations required to predict the expected level of ground motion in Bucharest are evaluated. From this discussion the key design components of an EWS are proposed. A paragraph giving guide-lines to assess the cost-benefit relation of the system concludes the paper.

2 Seismological Boundary Conditions for a Romanian EWS

2.1 Seismicity

Figure 1 shows the historic and instrumentally observed seismicity of Romania for the last 1000 years (Oncescu et al. 1998). The open circles represent shallow events with depths smaller than 60 km, the dots indicate earthquakes with depths exceeding 60 km. The crustal seismicity is variously spread over most of the territory with usually small magnitudes ($M \leq 5.5$), whereas the epicenters of the deep seismicity

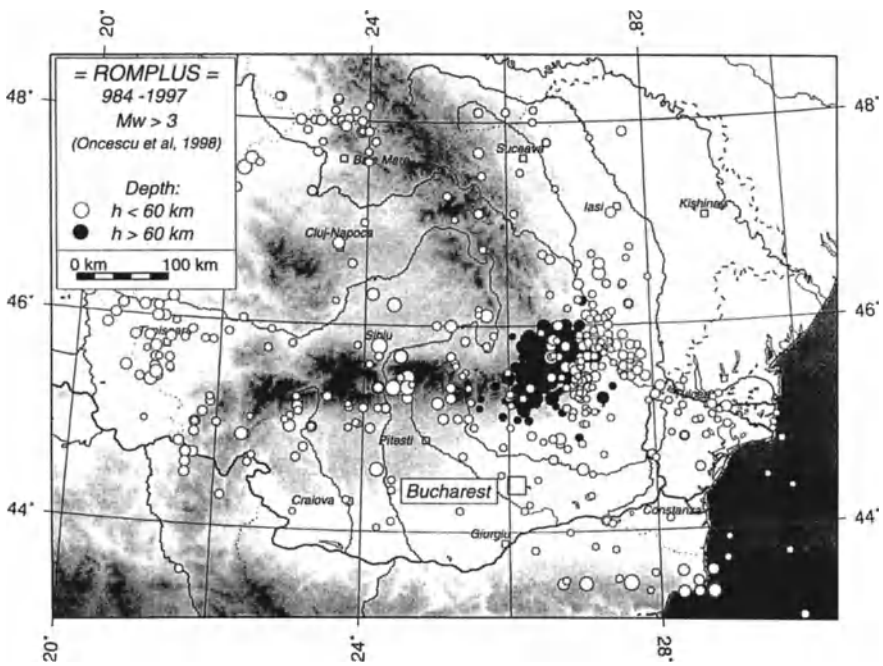


Fig. 1. Seismicity of the Carpathian Arc and surrounding regions during the last millenium. Note that the main sources of earthquake activity are clustered in a small area in intermediate depth

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are confined to a small area, called the Vrancea region. The instrumentally well-located intermediate depth seismicity is even more localised than indicated in Figure 1. The epicenters are confined to a region of 30×70 km, with an average epicentral distance to Bucharest of about 130 km. The depths of these events range between 70 and 200 km. Their magnitudes can be as large as 8.0 as hypothesized for the 1802 earthquake. Although crustal earthquakes of larger magnitudes are known (1916, 1902) it remains in fact that the earthquake hazard for the capital of Romania (Bucharest) is almost exclusively controlled by the intermediate depth Vrancea earthquakes. With Radu's (1994) catalogue of this century for events with $M_w > 6.3$, a Gutenberg-Richter relation for the cumulative number of events/year can be established (Wenzel et al. 1998):

$$\log_{10} N(\geq M_w) = 4.1 - 0.78\, M_w \qquad (1)$$

This is equivalent to average recurrence times of 10 years for an event with $M_w \geq 6.5$, 25 years for $M_w \geq 7.0$, and 50 years for $M_w \geq 7.4$. Alternatively, the historic catalogue of the last 600 years provides the similar estimate of 3 events/century with $M_w \geq 7.25$ or 6 events/century with $M_w \geq 6.8$.

Within the last 60 years Romania experienced 4 strong Vrancea earthquakes: Nov. 10, 1940 ($M_w = 7.7$, 160 km deep); March 4, 1977 ($M_w = 7.5$, 100 km deep); Aug. 30, 1986 ($M_w = 7.2$, 140 km deep); May 30, 1990 ($M_w = 6.9$, 80 km deep). The 1977 event was catastrophic chawith 35 high-rise buildings collapsing and 1500 causalities, the majority of them in Bucharest.

2.2 Traveltimes

Observed arrival times at the epicentral station MLR and at the Bucharest station BUC1 were used to display the time differences as a function of hypocenter depth. These data come from the telemetered network which has been operating in that area since 1981. Figure 2 shows the measured traveltime differences between the S-arrival in Bucharest and the epicentral P-arrival. Apart from one example (24 s) it always exceeds ≥25 s for all source depths, with a trend to increased warning times

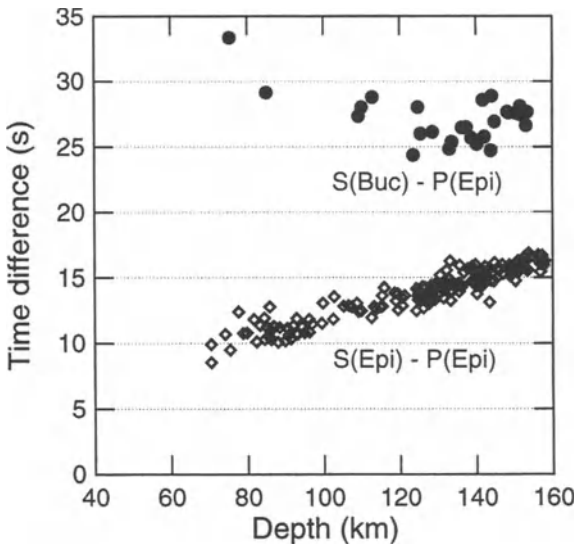


Fig. 2. Observed traveltime differences between the S-wave arriving in Bucharest and the P-wave arriving in the epicenter (S_{BUC}–P_{EPI}) and between the epicentral S-wave and P-wave (S_{EPI}–P_{EPI}). The first time difference specifies the warning time and generally exceed 25 s. The second time difference can be used for control purposes, shows a stronger depth dependence and ranges between 10 and 17 s

(≈30 s) for the more dangerous shallow events. It also shows the time delay between the S- and P-wave both arriving in epicenter. This delay time is about 8 s shorter than the maximum available one.

These experimental findings are consistent with traveltimes calculated with a standard velocity model (Oncescu et al. 1998). If Bucharest is located at an offset of 130 km from the epicenters the time delay between the S-arrival in Bucharest and the P-arrival in the epicenter is about 26 s for sources at 100 and 150 km depth. The sensitivity of the delay time (t_{SP}) between S (Bucharest) and P (epicenter) with respect to epicentral offset d and source depth h is

$$\Delta t_{SP} = 0.008 \frac{\text{sec}}{\text{km}} \cdot \Delta h + 0.172 \frac{\text{sec}}{\text{km}} \Delta d \qquad (2)$$

Moving the source by 50 km up or down changes the delay time by less than 0.4 s, whereas a shift in epicentral distance by 10 km contributes 1.7 s. The variations of this parameter, however, are expected to remain within this range so that a value of 25 s early warning time represents a stable estimate for Bucharest.

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2.3 Source Mechanisms

Fault plane solutions of the strong earthquakes of the last 60 years display a consistent pattern of wave radiation. Figure 3 shows the fault plane solutions for the strong earthquakes of 1940, 1977, 1986 and 1990 (Oncescu and Bonjer 1997). All events are of thrust type with the rupture plane oriented SW-NE. The fault plane of the second shock of the 1990 earthquake, that occurred 14 h after the main shock is rotated by 90° from SW-NE to SE-NW. Nevertheless, all solutions show a vertical T-axis. As P-wave radiation has a maximum along the T-axis, stations located in the epicentral area should always record a strong P-wave signal specifically on the vertical component. In order to also assess the radiation pattern of smaller magnitudes, Plenefisch (1996) analysed 74 focal mechanisms of subcrustal Vrancea events that occurred between 1977 and 1990, with moment magnitudes covering a range from 3.9 to 7.5. With few exceptions, all events are of thrust type with the T-axis pointing almost vertically. It appears thus a valid assumption that a strong Vrancea earthquake would produce a strong P-wave signal at an epicentral station and that the radiation pattern for events with $M_w > 6.5$ is relatively stable.

The amplitude of this arrival has the potential to serve as indicator for a strong event without determination of magnitude and depth. This fact forms the key paradigm for the design of an EWS.

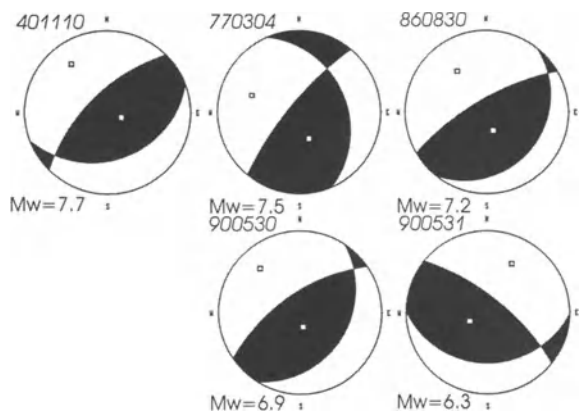


Fig. 3. Fault plane solutions of the strongest Vrancea earthquakes in this century (after Oncescu & Bonjer 1997). Note that in all cases the T-axis points vertically, so that a strong P-wave vertical component can be consistently expected

2.4 Ground motion

Lungu and Coman (1994) derived an attenuation law for Vrancea seismicity in the azimuthal direction of Bucharest. With moment magnitudes (M_w) instead of Richter magnitudes, the relation reads:

$$\ln PGA = 3.86 + 1.06 \cdot M_w - 1.15 \ln R$$
$$-0.0066h + 0.35P \qquad (3)$$

with peak ground acceleration (PGA) in cm/s^2, depth (h) in km, hypocentral distance ($R = \sqrt{h^2 + d^2}$) in km, average value of PGA for P = 0 and average value plus one standard deviation for P = 1. Table 1 shows values for horizontal PGA (related to S-wave motion) for 3 source depths and 4 magnitudes indicating that an increase of 50 km source depth can be balanced by an increase in magnitude by 0.5 units.

Thus the prediction of ground motion in Bucharest from source parameters requires a fairly precise determination of both magnitudes and focal depth which in turn requires operation of an extended seismic network, communication between stations and central processing facility, and data being adequately processed. With regard to an EWS it becomes complex, vulnerable and a lot of time would be lost before a warning could be issued.

If, on the other hand, only the P-wave amplitude of an epicentral station suffices as indicator for a strong earthquake, the system design becomes very simple and thus reliable and precious time can be saved. The prediction of the level of ground motion the capital will experience must then be established on the basis of scaling relations between P-amplitudes in the epicenter and S-amplitudes in Bucharest.

Table 1. Horizontal peak ground acceleration (in cm/s^2) of Vrancea earthquake predicted in Bucharest with the attenuation relation of Lungu and Coman (1994) for variable source depth (h) and moment magnitude (M_w)

Mw	h (km)		
	100	150	200
7.0	116	67	39
7.5	197	114	66
8.0	335	194	113
8.5	570	329	191

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2.5 Amplitude Scaling Relationships

We took an empirical approach to study the dependency of S-wave filtered horizontal peak acceleration in Bucharest at stations BUC1 and INC on the P-wave filtered vertical peak acceleration in the epicentral zone at station MLR (Fig. 4). We had four data sets to use:

- for small earthquakes, data from the stations of the telemetered network, with 1 s S13 seismometers, which we deconvolved for the instrument response and differentiate in the frequency domain,
- for small-to-moderate earthquakes, data from PCM5000 data loggers equipped with 2 s S13 seismometers and 5 s SH1 seismometers vertical and horizontal components respectively, which we also deconvolved for the instrument response and differentiate in the frequency domain,
- for three events with magnitudes around 5, data from K2 data loggers equipped with FBA23 accelerometers, which we only filtered,
- for two large events with magnitudes around 7, digitised data from SMA-1 film recorders, which we only filtered.

We chose to filter the data between 1–2 s, because the site effects in Bucharest show an amplification in this spectral range (Bonjer et al. 1998). Moreover, these periods are dangerous for the large number of medium and high-rise structures built in Bucharest before 1977. By doing this filtering in real-time in the final EWS system, we also try to avoid large peaks of acceleration at the epicentral station coming from small, but near events. The filtered PGAs are displayed in Figure 4 and show a clear positive correlation. A relatively large scatter in the lower magnitude range is due to the poor signal-to-noise ratios and to less accurate calibrations. Above magnitude 5, there is a good correlation between the P-wave filtered peak acceleration in the epicenter (P_{EPI}) and the S-wave filtered peak acceleration in Bucharest (S_{BUC}). The PGAs scale is according to

$$S_{BUC} \approx 10 \cdot P_{EPI} \tag{4}$$

A similar good correlation holds between the maximum horizontal acceleration caused by the S-wave in the epicenter (S_{EPI}) and the maximum vertical acceleration caused by the P-wave in the epicenter (P_{EPI}). The scaling relationship in this case is

$$S_{EPI} \approx 10 \cdot P_{EPI} \tag{5}$$

Equations (4) and (5) indicate that the PGA as measured here is more or less equal in the epicenter and in Bucharest. Secondly a record of the maximum vertical acceleration caused by the P-wave in the epicenter (P_{EPI}) allows to accurately predict S_{BUC} and S_{EPI}. The prediction of the S_{BUC} allows a warning to be issued a warning once its value is large enough; the prediction of the S_{EPI} allows to confirmation or cancellation of the warning.

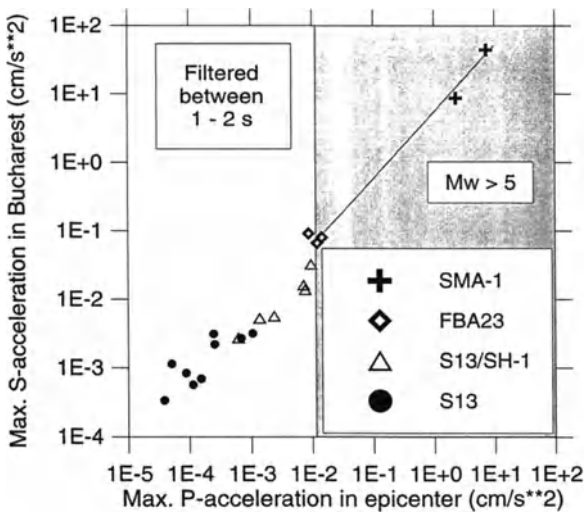


Fig. 4. Observed P and S accelerations filtered between 1–2 s: S amplitudes in the target area (S_{BUC}) are 10 times larger than P amplitudes in the epicentral area (P_{EPI})

3 System Design

A design that exploits the seismological facts discussed in the previous section consists of a minimum configuration of 3 accelerometers operated in the epicentral area and located at close distances to each other that allow direct cable connection with the processing unit. Essentially only one instrument is required. For back-up purposes and to avoid accidental triggering, several instruments should record continuously and the processing unit should react to coincidental high amplitudes measured by a subset of the instruments (say two out of three). A frequency band limited between 1 and

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2 s is probably appropriate, but eventually subject to additional tests. The tasks of the processing unit are:

- to bandpass incoming signals,
- to compare vertical P-wave amplitudes with a specified threshold value,
  - if this value is exceeded by one instrument, to check whether another accelerometer also exceeds this threshold within a small time window,
  - if this is the case, to predict horizontal PGA for the S-wave arriving in Bucharest (SBUC) according to equation (4) and issue a warning with this information,
- to estimate the maximum amplitude of the horizontal acceleration arriving 10 to 15 s later (S_{EPI}) with equation (5),
- to compare the observed value of S_{EPI} with the anticipated one and decide whether the alarm has to be cancelled or confirmed.

Operations (5) and (6) introduce more redundancy into the system without a significant increase in complexity. All instruments and the processing unit form one facility at an epicentral location. Thus access and maintenance can be handled easily and no communication between remote stations and computers is required in the decision process.

It is possible to use direct UHF radio communication for the alerting message because antennas could be installed between the mountainous epicenter and Bucharest along a 'line-of-sight', so that no additional repeater stations are necessary. The communication with users of the warning message could occur with pagers or by other means.

4 Cost-Benefit Analysis

A cost-benefit analysis attempts to answer the question of whether the costs of installation and operation of a system (EWS in this case) are smaller than the expected benefits. As there may be different users such an analysis may come up with quite different results for individual users. It is also clear that one part of the costs are false alarms. We do not want to perform an in-depth analysis here but rather indicate trends that may help to guide the discussion about the installation of an EWS for Bucharest. For cost-benefit evaluation we apply the procedure outlined in Holden et al. (1989). We assume installation costs of US $ 200.000,– (accelerometers: 20000,– $; computers: 40000,– $; radio communication equipment: 12000,– $; labor: 100000,– $; other costs: 28000,– $) and an amortising period of 10 years so that the amortised annual capital costs of the system (C_s) amounts to US $ 20000,–. Annual operating costs (C_o) are expected as US $ 20000,– (labor: 10000,– $; communication costs: 2000,– $; others: 8000,– $). The net benefit (NB) of the system can be expressed as:

$$NB = P(eq) \cdot B_w - [C_s + C_o + P(f_a) \cdot C_{fa}] \ldots \quad (7)$$

with the annual probability of a damaging earthquake P(eq), the estimated savings if a warning is issued B_w, the annual probability of a false alarm $P(f_a)$, and the costs of a false alarm, C_{fa}. Equation (7) contains potentially annual benefit and subtracts all costs. Obviously, if $NB < 0$ the system is not beneficial, if $NB > 0$ a net benefit can be expected. Assuming a damaging earthquake every 50 years and a false alarm every 5 years, the break-even point ($NB = 0$) is specified as

$$B_w = 2\,\text{Million} + 10 \cdot C_{fa} \quad (8)$$

Thus the savings earned by a warning must exceed ten times the costs of a false alarm plus 2 million US $. If no false alarm occur the savings must exceed only 2 million US $. As the damages caused in Bucharest by an $M_w > 7$ Vrancea earthquake can easily exceed that value, it means that an EWS as proposed in this paper could be cost-efficient.

5 Conclusions

The Romanian intermediate depth seismicity exhibits two peculiar properties: (1) The epicenters are almost invariable, so that the distance to Bucharest always remains constant; (2) the fault plane solutions of large and small events remain amazingly similar with the T-axis pointing upward. The combination of both properties is the key to predict S-wave ground motion in Bucharest from P-wave ground motion in the epicentral area.

These properties allow to design an EWS which is simple, robust, and cheap. It provides

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a stable warning time of 25 s, exceeded only by the Mexico City EWS. The purpose of this paper was to highlight the seismological boundary conditions so that technical issues and cost analysis have been addressed only briefly. In particular, user specific needs and problems related to the reception of such a system by potential users need to be considered before a planning stage can be entered.

It is expected however that after an initial phase of testing, governmental institutions and the commercial sector will supply warning receiver systems once the EWS is fully operational. These systems could include either pager messages, that display an alert message or at an advanced stage pager-driven switches to stop technical operations automatically. The value of the EWS for the latter option can only be judged on the basis of an application specific costs-benefit analysis, but simple considerations suggest that it will be cost-efficient.

Acknowledgements

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Early Warning Success for the 1976 Tangshan Earthquake: A Best Practice Integrating Public Administration and Science [1]

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Public administrators of the Qinglong County were able to combine scientific information, public education, extensive preparation, and speedy county-wide communications to prevent human tragedy during the Great Tangshan Earthquake (GTE) of 1976. About 470000 residents of the Qinglong County evacuated their homes just before the 1976 M 7.8 Tangshan earthquake (United Nations 1995, Wang 1991, Qian 1989, Qian 1986). No one in this county died from the destruction caused by GTE. In the counties surrounding Qinglong, however, nearly a quarter of a million people were crushed to death (Qian 1989, Chen et al. 1988, Qian 1986).

More than twenty years ago, on July 28, 1976, a magnitude 7.8 earthquake destroyed the Chinese city of Tangshan, killing 240000 people. Exactly two weeks prior to this large earthquake, Chunqing Wang, the official in charge of disaster management for the Qinglong County (located 115 km from the cityof Tangshan) attended a conference organized by the State Seismological Bureau (SSB) for the Tangshan region.

The five-day conference began on July 14, 1976. The Qinglong official listened carefully to the speakers at the seminars, panel discussions, and exhibitions. He took detailed notes on techniques of forecasting by the lay public and precautionary work for large earthquakes. On the evening of July 16, 1976, scientist Chengmin Wang of the SSB's Analysis and Prediction Department, spoke at a meeting session of sixty attendees. He explained that professional earthquake monitoring groups and lay detection centres had reported abnormal signals for the Beijing - Tianjin - Tangshan - Bohai - Zhangjiakou region relating to a possible earthquake. The analysis of scientific data acquired by seven major techniques, including stress and electrical measurements, indicated that there was a good possibility for this region to be struck by a significant earthquake between July 22 and August 5, 1976. Use of detection techniques by the lay public were suggested, along with examination of buildings in critical condition, public education, and other preparation measures.

On July 21, 1976, Qinglong official Chunqing Wang returned to his county. He reported on the Tangshan conference, and especially on the talk given by scientist Chengmin Wang of the SSB. The county committee took the report very seriously. More than 800 officials of Qinglong county's administrative system listened to Chunqing Wang's report. A flood was also predicted at the time. It was decided that an Associate Secretary of each community, with another official, should return to their communities immediately, without first seeing their families, to teach the people about earthquake and flood prediction and preparation. In a county-wide telephone conference on July 25, 1976, County Secretary Guangqi Ran discussed earthquake and flood preparations. During the days of July 25-26, 1976, each community in the Qinglong County held an emergency meeting to prepare and instruct villagers in disaster reduction. Examination of buildings in critical condition were made. Special attention was given to prepare reservoirs. Most villages had

[1] An earlier version of this paper and the accompanying posters were presented at the United Nations General Assembly 50th Resumed Session on Public Administration and Development, April 1996, and at the United Nations Conference on the Integration of Public Administration and the Science of Disasters, January, 1997.

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overnight watch guards on duty. County and village broadcasts instructed people not to close their doors and windows at night so that they could leave their houses immediately at the beginning of an earthquake. They were also told to avoid being close to tall buildings and power lines. On July 27, 1976, a leading county official gave a major talk at the county's agricultural meeting on the earthquake situation and on the mitigation measures for the area. At 3:04 am on July 28, 1976, the Great Tangshan Earthquake (GTE) struck.

More than 180000 buildings in the county were destroyed by the GTE; over 7000 of these totally collapsed. However, only one person died, and he died of a heart attack. Meanwhile, in the city of Tangshan and in all of its other surrounding counties, at least 240000 people were crushed to death and 600000 were seriously injured. Five hours after the earthquake, Qinglong County dispatched the first medical team to the disaster zone, and within a very short time organized and sent relief teams to Tangshan to help with rescue work and the transport of the wounded.

Dr. Wu Dong of Qinglong's Dazhangzi Hospital happened to be travelling to the city of Tangshan on the day of July 27, 1976. That night, he stayed over at his relatives' house. He told them about the possibility of an earthquake, and kept his clothes by his bedside. When the GTE struck, he left the building after arousing his relatives' family of four. Except for one minor injury from a falling object, the whole family escaped unhurt.

There was indeed a big difference between preparedness and unpreparedness in the Great Tangshan Earthquake! The official early warning document alerting Qinglong County residents of a possible large earthquake was issued by the county's top administrators four days before the Great Tangshan Earthquake. This early warning document came to light during a UN research mission to Qinglong County to verify the facts surrounding the county's historic actions. The United Nations has subsequently compiled, based on numerous documentation obtained during its research effort, a detailed reconstruction of the Qinglong County experience during the 1976 Tangshan earthquake (United Nations 1995). This account clearly details a best practice in public administration.

This case study and others illustrate three key areas of successful collaboration leading to identification of natural disaster risk and effective mitigation. These three areas are (1) public administrators who not only have policy but follow the guidelines; (2) citizens who are not only knowledgeable but also empowered; and (3) scientists who work together multi-disciplinarily. When public administrators, scientists and citizens all work together, they have the possibility of arranging a high degree of survival in a disastrous earthquake or other large and destructive natural event.

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Predictions and Social Response Capacities in Face of the 1995 Menglian Earthquake (M=7.3): An Overview

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Abstract

Yunnan Province is one of the seismically most active provinces in China. Within a period of 7 months, three large events occurred in Yunnan and its border: July 12, 1995, at Menglian (the Sino-Burmese border; M=7.3); Oct. 24, 1995, at Wuding (M=6.5); Feb. 3, 1996, at Lijian (M=7.0). This paper gives an account of the predictions and social response capacities in face of the 1995 Menglian event.

The Menglian earthquake, a foreshock-mainshock-aftershock sequence, occurred at 21°59'N; 99°04'E at 05:46'41.2"on July 12, 1995. Since Nov. 1994, predictions of the intermediate-term (>1 year), short-term (3 months) and immediate-term (1 day before the mainshock) were made by analyzing in detail the observed seismic and precursory anomalies. Correspondingly, three events of M>5.0, one of M>6.0 and the mainshock took place. The predictions laid the base for decision making of the government at all levels in disaster prevention and mitigation. In addition, three large aftershocks (M=5.1, 5.0 and 5.0) were predicted.

As early as 1986, the earthquake emergency response strategy entitled "Technical Countermeasures and Social Response" was published by the Seismological Bureau of Yunnan Province. In 1993, the "Strategy for the Immediate Response to the Destructive Event" was issued by the Government of Yunnan Province. Together with the wide-spread, intensive education of the public, the social response capacities were up-graded prior to the 1995 Menglian event. In Menglian County, stricken with intensity VIII and VII, only 11 people were killed and 136 injured.

1 Introduction

Yunnan Province is located in the southwest corner of China, with an area of 394000 km^2 and a population of 40 million. Due to the direct effect caused by the collision of the Indian and Eurasian plates, Yunnan is one of the seismically most active provinces in China. The recorded events are numbered as high as 7000 and more each year. Since 1970, 7 devastating earthquakes with a magnitude greater than 6.5 took place in Yunnan and its borderland, resulting in heavy casualties and economic losses (Table 1).

The Menglian earthquake is a foreshock-mainshock-aftershock sequence. The mainshock occurred in the Sino-Burmese border (21°59'N; 99°04'E), at 05:46'41.2" on July 12, 1995, with a depth of 9 km and the maximum intensity VIII on the China side. Areas of intensity VIII, VII and VI covered 110 km^2, 1500 km^2 and 10400 km^2, respectively (Lide et al. 1997).

Three stages predictions of intermediate-, short-, and immediate-term had been made before the event took place. The outcome of the prediction effort was only really significant when the immediate-term prediction was made at site just one day ahead of time. As one of the emergency measures, schools were shut down and those who lived in dangerous houses were evacuated. In Menglian County (with a

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Table 1. List of casualties and economic losses caused by earthquakes (M≥6.5)

Time	Location	M	Casualties		Economic losses [100 million]	Prediction
			Died	Injured		
Jan. 5, 1970	Tonghai	7.7	15621	26783	12.01	None
1974	Daguan	7.1	1423	1600	Several	None
May 29, 1976	Longling	7.3 7.4	98	2442	7.64	Long-, medium-, short-, and imminent-term
Nov. 6, 1988	Laneanggengma	7.6 7.2	748	7752	20.5	Long-, medium-, and short-term
July 12, 1995	Menglian (Sino-Burmese border)	7.3	11	136	3.19	Long-, medium-, short- and imminent-term
Oct. 24, 1995	Wuding	6.5	52	13815	8.14	Long-term
Feb. 3, 1996	Lijiang	7.0	309	17057	40.31	Long-, medium-, and short-term
			18262	69585		

population of 105435), stricken with intensity VIII and VII, only 11 people were killed and 136 injured.

The Menglian earthquake is looked on as a success, because all possible means of emergency measures had been taken after the predictions were made. Other two successful predictions made by Chinese scientists in recent years have been the 1996 Ganzi, Sichuan, earthquake (M=5.5) and the 1997 Jiashi, Xingjiang, earthquakes (M=6.3 and 6.4) (Guomin & Ghuanzhen 1997).

2 Predictions and on What Bases the Predictions are Made

Predictions of three stages and the major bases supporting the predictions were demonstrated clearly by Lide et al. (1997). In general, the predictions were made step by step by analysing in detail the observed seismic and precursory anomalies. Table 2 lists the predictions and social response measures taken after the predictions were released, and later comparison with the events that actually happened. In short, the prediction at any of the stages was not based on any single observed anomaly. The intermediate-term prediction was generally made by studying carefully the regional seismicity pattern (seismic activity, quiescence, relative migration, etc.) and the correlation of sun spot variation versus large events in Yunnan, and precursory anomalies (Lide et al. 1997; Seismological Bureau of Yunnan Province 1995; Earthquake Bulletin 1995). One year before the event, results obtained from the spatial (field) scanning of seismological data in the whole province, revealed that the region near the epicenter showed anomalous variations in 8 items, namely: small event frequency, b value, modulation ratio, response ratio, recurrence period, τ_0 value, coda duration, and spatial distribution pattern of earthquakes (gaps and belts).

At present, there are 13 approaches for precursory observation at 55 fixed stations (151 station-items in all) in Yunnan. The distribution of precursory anomalies at the fixed stations before the Menglian event is shown in Figure 1. The time span for those observed anomalies can be seen in Table 3. In the short-term and impending stages, the area where precursory anomalies were concentratively revealed was closer to the epicenter. It suggests that, besides the direct foreshock activity occurring in the seismogenic gap or its vicinities, the abrupt large-amplitude variations of precursory anomalies which appeared within the area where the intermediate- and short-term anomalies had already shown up might probably be taken as one of the bases in immediate-term prediction. In the Menglian case those observation items concerning ground fluid dynamics, i.e. water level, Radon, Mercury, water tempera-

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Table 2. Prediction and social response capacities in face of the Menglian Earthquake (M = 7.3)

Time	Prediction	Response and Countermeasures	Event
Nov. 1994 to Jan. 1995	The intermediate-term prediction. A possible M6-7 event in Southwestern Yunnan (major risk areas in Gongshan, Lushui, Yongde, Lancang, Jinghong and Mengla) and the bor dering area with Burma in the coming 1–3 years. Concluded at the 1995 YSB ETC Meeting in Nov. 1994	• In Jan. 1995, Southwestern Yunnan was drawn up as one of the nine highest risk areas in China at the SSB ETC Meeting • On Jan. 17, directors at YSB discussed the matter and laid out countermeasures in case of emergency • On Jan. 26, at the information release meeting, held by YSB and attended by heads of 23 provincial departments, the probable earthquake risk was released, requiring that appropriate response strategy should be made ready by each department	
Jan. 26	The short-term prediction. A possible event about M5.3 in the area from Jinggu to Menghai and the bordering area with Burma by the end of Feb. Presented at the YSB ETC Meeting on Jan. 26	• The Seismological Offices in the predicted area were informed about the situation by phone call	A M5.2 event took place in Lancang County on Febraury 18 (without casualty)
March 3	The short-term prediction. A possible event about M5.5 in Western Yunnan and the bordering area with Burma in March and April. Released in the "Earthquake Information" (9502) by YSB	• The "Earthquake Information" (9502), issued by YSB on Mar. 3, was submitted to the Provincial Government • On Mar. 15, at the emergency ETC meeting, held in Dali Prefecture and attended by 10 prefectural seismological offices in Western and Southwestern Yunnan, measures for the intensified observation were laid out • By the end of March, a special emergency funding of 400 000 RMB was allocated by the Provincial Government • On Apr. 3, the "YSB 8 Items of Emergency Countermeasures" (#42, 1995) was reported to the Provincial Government, and then put into action	A M5.6 event took place in Jingping County on April 25 (without casualty)
June 8	The short-term prediction A possible event about M5.5 in the area of Tengchong, Lancang, Jinggu and Menghai and the bordering area with Burma in mid July, but more likely by the end of June. Released in the "Earthquake Information" (9505) by YSB	• On May 24 and 31 and June 7, three enlarged ETC meetings were held, analyzing in detail the observed precursory anomalies • On June 8, the " Earthquake Information" (9505), plus 4 items of emergency countermeasures, were submitted to the Provincial Government • Approved by the Government, those countermeasures were put into action by the Seismological Offices in Simao, Lincang, Baoshan and Dali Prefectures • On June 12, the "Earthquake Information"(9501), issued by Simao Prefecture, was delivered to Menglian County and its vicinities	An M5.5 event took place to the west of Menglian on June 30 (without casualty)

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Table 2 (continued)

Time	Prediction	Response and Countermeasures	Event
July 1	The short-term prediction. A possible moderate-strong event, if not a strong one, in the second half of the year. Released in the "Earthquake Information" (9506) by YSB	• On July 1, the "Earthquake Information"(9506), issued by YSB, was submitted to the Provincial Government	
July 7	The short-term prediction. The Menglian M5.5 event probably increased the risk of a strong event in Southwestern Yunnan and the bordering area with Burma. Released in the "Bulletin of the ETC Meeting in Southwestern Yunnan" (# 81, 1995) by YSB	• A workteam of 13 professionals, headed by He Xihu, deputy director of YSB, rushed to Menglian County • In light of the historical characteristics of the seismic belt, the workteam suggested Menglian and Menghai counties taking up emergency action • The "Bulletin of the ETC Meeting in Southwestern Yunnan" (#81, 1995) outlined the intensified observation over the impending event	On July 10, a M6.2 event took place in the area, where the M5.5 occurred. (without casualty)
July 11	The immediate-term prediction. At 0:10 am, on July 11, an emergency ETC meeting was held at site. The workteam stated that the M6.2 event was too small to be taken as the mainshock and the forthcoming maximum event should be over M7.0, within 3 days	• A second workteam of 18 professionals was sent ot Menglian County • Schools were shut down and those who lived in the dangerous houses were evacuated • Seismological Offices at the levels of Prefecture and County reacted according to their ready-made response plans	The Menglian mainshock (M=7.3) occurred in the bordering area in Burma on July 12 (11 killed and 136 injured)

YSB Yunnan Seismological Bureau, *SSB* State Seismological Bureau, *ETC* Earthquake Tendency Consultation

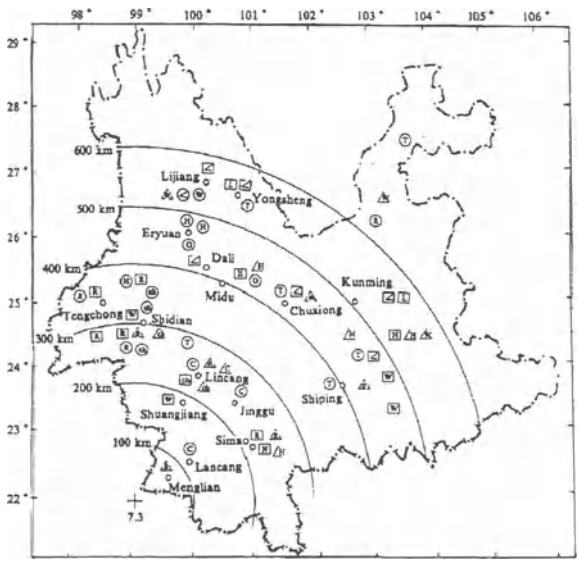


Fig. 1. Distribution of precursory anomalies at the fixed stations before the Menglian M7.3 earthquake (From Chen et al., 1997)

ture and water quality showed abrupt variations. It is clear that ground fluid is very sensitive in the process of an event, and at the impending stage in particular. This procedure suggests that the physical basis (Scholz et al. 1973) still holds and the statement (Anlu & Shihong 1998) is reasonable.

As for the immediate-term prediction, the four events listed in Table 2 from Feb. 18 to July 10, 1995, particularly the last two foreshocks, might be taken as the most distinct and most prominent bases to confine the location and to make an assessment of magnitude for the mainshock (Lide et al. 1997). In addition, three strong aftershocks (M=5.1, 5.0 and 5.0) were predicted.

3 Social Response Capacities

Research on earthquakes, and especially on the prediction of earthquakes, is one of the major scientific efforts in China. Yet, it is only a scien-

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Table 3. Time span of the observed precursory anomalies before the Menglian earthquake (M=7.3)

13 Approaches for the Precursory Observation at 55 Fixed Stations (151 stations-items in all) in Yunnan	7 Items at 18 Stations Appeared Intermediate-Term Anomalies (early than Jan. 1995)	8 Items at 20 Stations Appeared Short-Term Anomalies (Feb–May, 1995)	5 Items at 20 Stations Appeared Immediate-Term Anomalies (June 1 to one day before the event)
Short leveling across fault	●	●	●
Short base line	●		
Water level	●	●	●
Water radon	●	●	●
Water Mercury	●	●	●
Water temperature		●	●
Pendulum tiltmeter	●	●	
Water tube tiltmeter		●	
Extensometer			
Geomagnetism			
Resistivity			
Inductance stress			
Water quality (CO_2, pH value, F^-, SO_4^{2-}, HCO_3^-, Mg^{2+}, Ca^{2+}, conductivity, CH_4)	● F^-	● (HCO_3^-, CO_2, SO_4^{2-}, Ca^{2+})	●

tific approach. Once the prediction is released, a notable impact on society follows. Therefore, the social response capacities play a vital role in earthquake disaster reduction. From Table 2 it can be seen that the predictions laid the base for decision making of the government at all levels in disaster prevention and mitigation.

In China, earthquake prediction is released according to the rules written in the "Stipulations for Issuing Earthquake Prediction" (SIEP) which, issued by the State Seismological Bureau with the approval of the State Council, has come into force for implementation since 1988 (the temporary SIEP was issued in 1977). As early as 1986, the earthquake emergency response strategy entitled "Technical Countermeasures and Social Response" was published by the Seismological Bureau of Yunnan Province. It states steps that the whole society has to take in case of necessity, and the emergency response measures that the probably stricken area has to put in action after a short-term has been prediction made. In 1993, the "Strategy for the Immediate Response to the Destructive Earthquake" was issued by the Government of Yunnan Province, in which obligations, responsibilities and requirements for the departments concerned and their leading bodies at all levels are described clearly.

On the other hand, the wide-spread, intensive education of the public is stressed, because it is recognised that implementation of a hazard reduction program after the prediction has been made can only succeed through successful involvement of the whole society. By doing a good job of precautionary work, casualties could be greatly reduced (Table 1). As for the Menglian case, how to response and what countermeasures are to be taken after each stage of predictions are clearly listed in Table 2.

4 Discussion

1. China began performing an earthquake prediction program in 1966, when the March 8 Xingtai earthquake (M=6.8) took place. In the past three decades and more, Chinese scientists have learnt lessons through both success and failure. Though, theoretically, no breakthrough has been made so far, in practice we did predict, on a largely empirical basis, a few events of a certain type and with obvious characteristics, such as the 1995 Menglian event, 1996 Ganzi event, and 1997 Jiashi event, etc. Now, a program on seismogemic process and earthquake precursory mechanism in China is under way (Shiyu et al. 1998)

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2. Different approaches of statistics have been made on the level of earthquake prediction in China. According to (Xuanhu & Jinzi 1997), the evaluation was correct that China would probably experience a successivion of strong events with a magnitude of around 7.0 in 1995 and 1996. The 1995 Menglian (M=7.3), 1996 Lijiang (M=7.0), 1996 Atushi (M=6.9) and 1996 South Yellow Sea (M=6.1) all took place in the designated areas with intensified observations. The rate of annual prediction in 1995 and 1996 reached 40% by the R value evaluation. According to (Guomin & Ghuanzhen 1997) and (Yongtai & Jinzi 1997), the prediction capability for the intermediate-term prediction (1 year) reaches 20–30% (or 16% by other statistic data) in China. Reference (Shihong 1998) suggests that the medium-long-term prediction reaches an applicable level. The rate of the short- and immediate-term prediction by the prediction card applied since 1992, is around 3%. (Yet, this may not be taken to describe the prediction level on the whole, because the card is filled in by individuals, groups, research divisions or even by amateurs.
3. The belief in earthquake predictability comes out of the historic, philosophic, and social viewpoints rather than science alone. Those predicted events mentioned above all took place in the remote impoverished area or inland area of a province (Jianhua et al. 1998). It means that had a false prediction been made it would not have made great impact on the social and economic stability of the province or surrounding provinces.
4. The Menglian event shows clearly that in implementation of an earthquake hazard reduction program after prediction has been made, political engagement and commitment of the government are a fundamental prerequisite, and the public awareness the key factor. Now, the Law of Earthquake Preparedness and Disaster Reduction of the People's Republic of China began implementation on March 1, 1998. The Law consists of 7 chapters, i.e. the general regulations, monitoring and prediction of earthquake, earthquake disaster prevention, earthquake response, rescue work and rehabilitation after an event, legal responsibilities and appendix.
5. Besides publications in Chinese the endeavor in making earthquake prediction in China is also mentioned by Hui 1996; Wangshao 1998; Jingen 1998 and Silver & Wakita 1996, recently.

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Project of Creation of an Earthquake Early Warning System for Armenia

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Abstract

After the destructive Spitak earthquake of 1988 it became clear that the level of seismic resistance of buildings and constructions in Armenia is significantly lower than the level of seismic hazard. With these conditions the creation of an Early Warning System to warn the population of an earthquake with a magnitude $M \geq 5.0$ become an important element of the seismic risk mitigation in Armenia.

The developed project includes the creation of such a system around Yerevan where about 40% of the population of the Republic is concentrated.

Within the framework of this project the seismic hazard of Yerevan is analysed according to the data on statistics of the seismicity of the region and historical sources of destructive earthquakes around the capital of Armenia. Evaluation of seismic risk of destruction of buildings and constructions was also performed.

The possibility and efficiency of the creation of an EWS to warn the population of Yerevan 3 to 8 s before arrival of a destructive seismic wave are described in this article.

1 Introduction

At present investigations in the field of prediction of earthquakes show that there are no methods for the perfect forecasting of earthquakes in its classical meaning. However, the existing technology for seismic monitoring makes it possible to issue an EWS for an occurring earthquake.

Such a system can provide warning of an earthquake from several to dozens of seconds before the arrival of the ground motions caused by the strong earthquakes.

At present there are several such systems in operation world-wide from which the most well-known ones are successfully operated in Mexico and in Japan (Espinosa-Aranda 1996; Nakamura 1996). For example the EWS operating in Mexico from 1991 functioned during the earthquake of 1995 with magnitude $M = 7.3$.

The project on the creation of an EWS for the capital of Armenia – Yerevan is described in the presented article. In the first part of the article the data on the level of seismic hazards and risk for Yerevan are given and in the second part the possibility of creating an EWS is justified and analyses of optimal configurations of this system are also given.

2 Historical Sources of Earthquakes Near Yerevan

Yerevan is situated in the north-east of the Ararat valley of the central part of the Armenian upland. This territory is one of the most seismoactive regions of Armenia. Destructive earthquakes date back as far as the 6th Century BC. The first mention of a destructive earthquake is given in the chronicle of the famous armenian scientist-historian of the 5th Century

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Table 1. Parameters of destructive earthquakes causing the most damage in Yerevan

Earthquakes	Year	Longitude	Latitude	Magnitude
Garni	1679	44.80	40.10	7.0
Dvin	893	44.60	40.00	6.5
Tsakhadzor	1827	44.50	40.60	6.5
Ararat	1840	44.10	39.60	7.6
Talin-Arouch	972	43.90	40.30	6.5
Parakar	1937	44.43	40.13	4.7

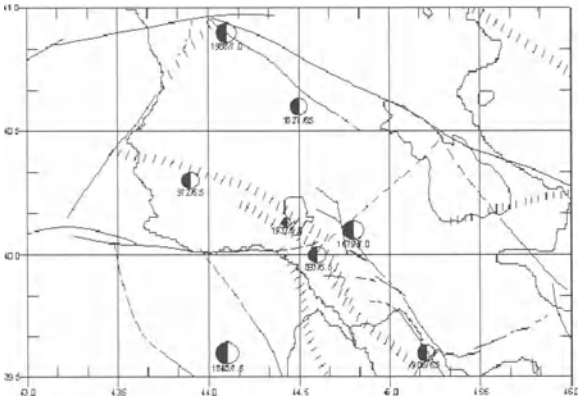


Fig. 1. Historical sources for destructive earthquakes around Yerevan

Movses Khorenatsi, according to which the large fall on the northern side of Big Ararat and which can be seen with the naked eye was formed during the mentioned earthquake. Further more according to the data of the Armenian historiography the following destructive earthquakes are known: Dwin (851–893), Talin-Arouch (972), Ararat (1319, 1840), Garni (1679), Tsakhadzor (1827) and others.

The greatest destruction in Yerevan was caused by the Garni earthquake of 1679 the magnitude of which was estimated to be M = 7.0. It was followed by severe thunder heard at a great distance from Garni to the Aragats mountain. The earthquake caused an extensive fault in the earth's surface and hillside failures. Many churches and monasteries were destroyed. The number of human victims has been estimated to be about 7 600.

The Parakar seismogeneous zone – the most active in the 20th century is situated directly near the western outskirts of Yerevan. Seven large earthquakes occurred here during that period. Among them the strongest earthquake occurred in 1937 (M = 4.7), and the last one on – March 1, 1997 (M = 3.7). This earthquake which caused a certain panic among the population of the capital, was registered by the net of seismic stations of NSSP RA (regional, telemetric and strong motions).

Above, the parameters of destructive earthquakes causing the most damage in Yerevan are listed in Table 1.

Places of location of historical destructive earthquake around Yerevan are shown in Figure 1.

3 The Evaluation of Seismic Hazard and Risk of the Building's Destruction of Yerevan

Before the Spitak earthquake the territory of Armenia was constructed with buildings and structures designed for a ground acceleration of 0.1–0.2 g corresponding to seismic effects with an intensity of 7–8 by the scale MSK-64, according to the seismic zonation map of that time. However, the Spitak destructive earthquake of 1988 with a magnitude M = 7.0 and with the intensity influence of 10 in the epicentral zone causing more than 25 thousand deaths and the destruction of most buildings and constructions in all Northern regions of Armenia, showed that seismic hazard of the territory of the Republic had sharply increased.

Taking this fact into account the new seismic zonation map of the territory of Armenia was developed in the NSSP RA in 1995 (Balassanian et. al. 1997). This map was designed by a detailed analysis of the statistics of the region's seismisity including prehistorical, historical and instrumental periods. It embraced the area with coordinates $\varphi = 38°10' \div 41°40'$, $\lambda = 43°00' \div 47°30'$.

Comparing seismicity of the region with geological, geochemical, geomorphological and seismogeodetical data and also with the data of the depth structure of Armenian territory and decoding of aerocosmic photos the new deterministic map for the territory of Armenia was designed. On the basis of selected zones with different seismic potentials, the seismic influences were estimated for the territory of Armenia by intensity and horizontal ground acceleration (Figs. 2, 3).

According to this map the level of seismic hazard has been found to be I = 9 with expected horizontal ground acceleration to 0.4 g in Yerevan.

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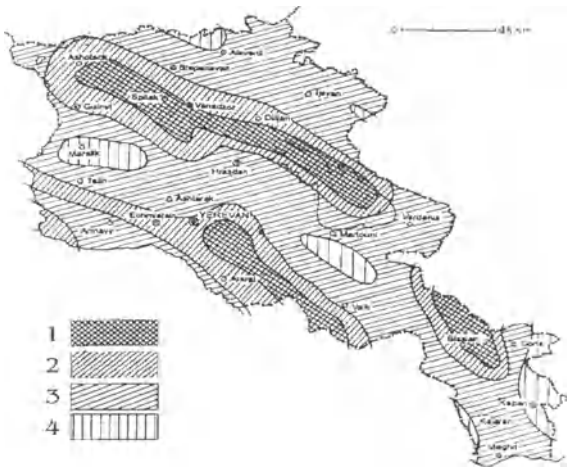


Fig. 2. The deterministic seismic zonation map for the territory of Armenia: seismic areas are identified according to values of maximum horizontal accelerations: (1) –0.5 g; (2) –0.4 g; (3) –0.3 g; (4) –0.2 g

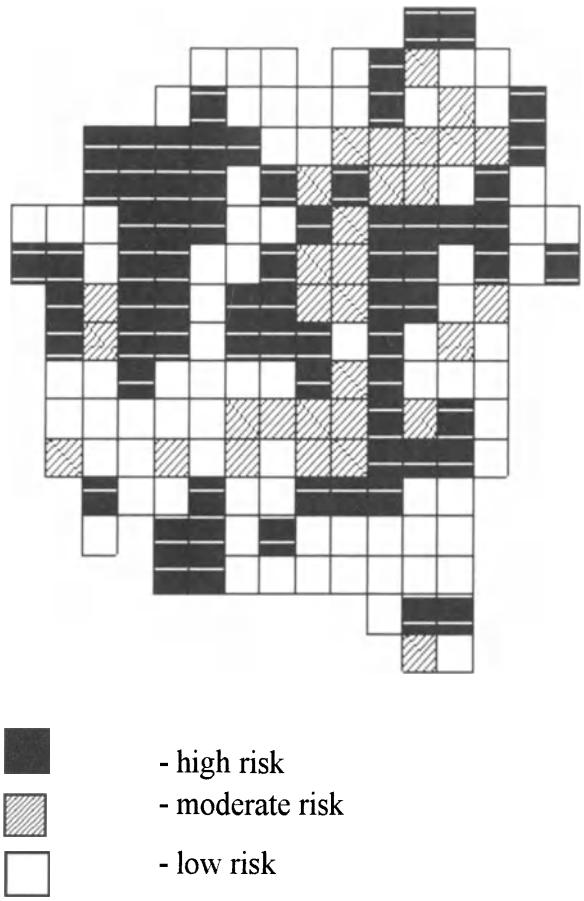


Fig. 3. Map of the level of seismic risk of Yerevan (each unit – 1 km^2)

It is obvious that these values significantly exceed the accelerations design values for which existing buildings and structures of the capital were constructed.

Taking into account the discrepancy between the seismic resistance of the existing buildings system in Yerevan and seismic hazard and also the fact, that about 40% of the whole population of the Republic is concentrated in the capital of Armenia, it is important to evaluate the seismic risk of Yerevan.

This problem was solved stage by stage (Balassanian, Manoukian):

1. Ground conditions of the city were studied using seismic microzonation data of the territory of Yerevan. On the whole it can be divided into 3 types:
   - The first type – rocky soils applying to the first category of ground according to current standards of earthquake engineering of RA. Maximum value of expected horizontal accelerations is evaluated in 0.32 g on these soils.
   - The second type – weathering rocky and coarse sandy soils, applying to the 2nd category of ground. Maximum value of expected horizontal accelerations is evaluated in 0.40 g.
   - The third type – loose sand applying to the third category of ground. Maximum value of expected horizontal accelerations is evaluated in 0.48 g.
2. Seismic resistance of each building of the city was estimated after being graded into one of 6 groups according to its structural properties.
   - I: Private masonry buildings (one-two-storeyed) being constructed without taking into account the codes of earthquake engineering;
   - II: Stone (including complex constructures) up to 6-storey buildings;
   - III: Masonry, large block 5-storeyed;
   - IV: Large-panel, framed-brace, 9-storeyed buildings;
   - V: Framed buildings with the storeys up to 16;
   - VI: Framed buildings, constructed by the methods of the lifting of the storeys.

All of them except private houses of first group were designed for seismic forces with the value of expected horizontal acceleration 0.1 g for

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category I grounds and 0.2 g in the cases of the II and III categories grounds. For designed seismic resistance of the 1st group buildings, it can be accepted to be equal to 0.1 g regardless of soil conditions.

Actual seismic resistance of all above mentioned types of buildings was determined by a similar method which was used in the work (Balassanian, Manoukian).

$$a_{bg} = a_{dgn.\,bg} + \Delta a_{bg} \quad (1)$$

where a_{bg} is the actual value of the ground acceleration which buildings can withstand during the earthquake; $a_{dgn.\,bg}$ is the design values of the acceleration of buildings; Δa_{bg} is an extra capacity of the building to the resistance of seismic loads which was evaluated taking into consideration the experience of the Spitak earthquake.

The Spitak earthquake has shown that the buildings of the fourth group are the most favourable from the point of view of seismic resistance.

And the buildings of the Ist, Vst and the VIth groups were the most unreliable.

The Δa_{bg} values for these groups of buildings can be as follows: for the buildings of the IVth group $\Delta a_{bg} = +0.05$ g; for the buildings of the second and the third groups $\Delta a_{bg} = 0$ and for the Ist, the Vth and the VIth group of buildings $\Delta a = -0.05$ g.

By putting layer by layer the data for the dwelling construction of the city into a computer marking the actual seismic resistance of each building and data on seismic microzonation of Yerevan the level of seismic risk was estimated for each unit of 180 km square of Yerevan which is illustrated in Figure. 3.

The analysis shows that the buildings having actual seismic resistance (in acceleration values) within 0.05–0.15 g and being situated at the zone of seismic hazard with expected maximum horizontal acceleration 0.4–0.48 g are in an adverse condition. This territory is estimated as the zone of high risk.

The buildings having an estimated bearing capacity (in acceleration values) 0.2 g and situated at the zone of seismic hazard 0.32–0.40 g and the buildings with bearing capacity 0.25 g and being situated at the zone of 0.40–0.48 g are estimated as moderate risk zones.

The zone of low risk is determined by the buildings having a bearing capacity of 0.25 g and being situated at the zone of seismic hazard –0.32 g.

The performed investigations allow us to conclude the following:

- about 60 km^2 of the territory of the city is in the zone of high seismic risk (about 33% of all the area of the city);
- there are 1516 buildings (about 22% of all capital buildings of Yerevan) in the mentioned territory, which were constructed without consideration of private houses, built without observing the Codes of Earthquake Engineering.

Let us examine a simple scenario of possible damages to buildings in Yerevan in the case of activation of the zone SSZ including Garni seismogeneous fault. Let us analyse the earthquake with the following parameters: M = 7.0 average distance from Yerevan – D = 15 km.

The estimation shows that the maximum expected horizontal acceleration of the ground surface in Yerevan will be on the III category grounds $300 \times 1.2 = 360$ cm/s^2. On the II and I categories grounds they will be equal to 300 cm/s^2 and 240 cm/s^2 respectively. The performed analysis in [4] shows that in this case about 1516 residential and public buildings will be damaged. Of them:

- 840 buildings are stone (including complex structure) with a number of storeys up to 6;
- 303 buildings are framed with a number of storeys up to 16;
- 310 buildings are large-panel 9-storeyed;
- 40 buildings are constructed by the method of lifting of storeys;
- 19 buildings are stone, pre-fabricated.

4 Motivation of the Possibility and Efficiency of the Creation of EWS

For the motivation of the project on the creation of an EWS let us perform some estimations using the locations of seismogeneous epicentral zones around Yerevan and the time of seismic wave-propagation.

As it has already been noted the level of seismic hazard in Yerevan is estimated on average with an intensity of 9 according to the map of general seismic zonation. This level of hazard is determined by the zones of Seismic Source Zones (SSZ) which were constructed by histori-

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Table 2. Possible effects from 5 historical earthquakes in Yerevan

Earthquakes	Year	Magnitude	Distance from Yerevan [km]	Acceleration [cm/s^2]	T_p [s]	T_S [s]
Garni	1679	7.0	26	151	6.5	11
Dvin	893	6.5	23	145	6.0	10
Tsakhadzor	1827	6.5	48	60	9.5	16.5
Ararat	1840	7.5	72	60	13.0	23
Talin-Arouch	972	6.5	53	52	10.5	18

cal sources of strong earthquakes (Fig. 1). The estimations of the possible effects from 5 historical earthquakes in Yerevan in terms of peak horizontal accelerations as well as running time of longitudinal and lateral waves from these sources to Yerevan are listed in Table 2.

The estimation of peak horizontal accelerations was performed by the attenuation model of ground strong motions – Joyner-Boore which was also used during the construction of seismic hazard zonation map of Armenia (Joyner & Boore 1988).

$$\log a = 0.49 + 0.23(M_w - 6) - \log\sqrt{R^2 + h^2} - 0.0027\sqrt{R^2 + h^2} \quad (2)$$

were a – is acceleration in fractions of g; R – is the distance from epicentre and h – is the average depth of the source. The time of lateral and longitudinal wave's propagation listed in the Table corresponds to the regional hodograph (Fig. 4, 5).

From this table it follows that for a given situation the values for propagation time of the most dangerous phase of seismic vibrations – lateral wave – vary from 9 to 20 s, and the values of accelerations from these sources are from 50 to 150 cm/s^2. Proceeding from the mean level of seismic resistance of buildings and structures it is purposeful to set the threshold level of seismic hazard for Yerevan to the intensity of 7. In terms of acceleration the intensity of 7 corresponds to the range from 50 to 100 cm/s^2.

In order to understand how often such an event may occur let us take the following estimations from Balassanian et al. (1997). By one estimation the value of acceleration a = 0.1g can be exceeded on average during 15 years in Yerevan and by the other estimation the time for repetition of an event with f>7 is equal to 35 years.

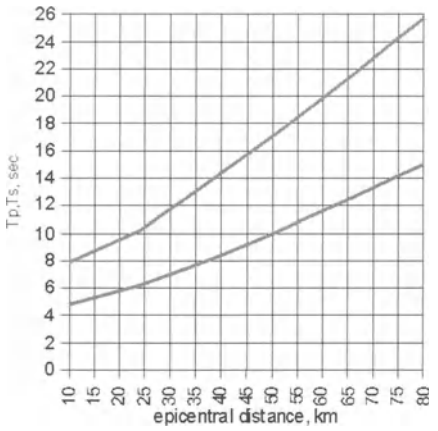


Fig. 4. Time of propagation of lateral and longitudinal waves by regional hodograph

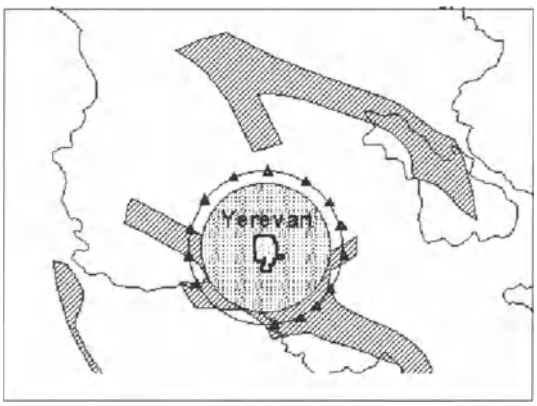


Fig. 5. The zones of the influence with intensity of 7 on Yerevan

An average of T=25 years can be accepted as a medium period for the occurring of an event with f>7 for Yerevan.

The values of maximum epicentral distances for different magnitudes are shown in Table 3 providing the influence with an intensity of 7 and the value of acceleration equal to 50 cm/s^2.

In the second column the distances were estimated by formula (2) and the third column is

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based on formula (3) describing the regional relationship of the intensities attenuation (Schebalin ed. 1997).

$$I = 1.4\,M - 3.5 \log \sqrt{R^2 + h^2} + 4.2 \qquad (3)$$

The results obtained by formulas (2) and (3) are rather similar to each other, except for the values estimated for the magnitude M = 7.0.

In the last column the geometric mean of the results are shown, which is further used for the construction of zones SSZ, to cause an influence with an intensity of 7 in Yerevan.

For the construction of these SSZ zones let us act in the following way: in a general map of the zones of SSZ let us mark concentric circles with the centre in Yerevan and with a radius based on the last column of Table 3. Eliminating those fragments which are rejected by a distance 8 intensity from the sphere of influence with intensity 7 we get the zones shown in Figure 5.

According to this map the zone of influence with an intensity of 7 for Yerevan consists of 3 spatially separated parts – the central fragment, the Pambak – Sevan seismogeneous zone and the small fragment of Balikgiol-Tabriz seismogeneous zone. The central fragment includes several epicentral zones – Garni, Dvin, Talin-Arouch seismogeneous zones and also diffusive seismogeneous zone; the seismic potential of which is estimated based on magnitude M = 5.5. Now let us refer to one of the most important questions, i.e. the selection of distances of control points of EWS from Yerevan. It is clear that the average distance between observed region and control observation sites should be optimal. It cannot be too short, because in that case the time of the alarm will not be enough to initiate protective actions. And it also should not be too long for 2 reasons. First, a lot of seismogeneous zones will be out of range. Second, due to large perimeters of the location of control sites for the control in all directions. Given these arguments, it is useful to set optimal distance to 30 km. Furthermore the estimations will show that the zones of influence with intensity of 7, i.e. the 25 km diffusive zone (the area of which constitutes about 30–40% of the total seismic hazard zones) will be out of range. The circumference of a circle with 30 km radius is approximately equal to 190 km. For the installation of the minimal number of control points necessary for cover in all directions, it is important to take into account the fact that the confirmation of an event should not be based on a positive reaction from a single control point, as the probability of a false alarm will be too high.

The principle of the alarm should be based on positive reactions of at least 2 neighbouring points in a given temporal window. In this case the possibility of a false alarm is almost fully excluded, but there will be a loss of time, depending on where the earthquake occurs.

This condition limits the maximum distance between neighbouring points. It should not be more than 10–15 km. Then in the worst case, if the earthquake occurs directly near to any control point, less than 5–6 s will be lost, but such an event is less probable: in most cases the lost of time will constitute about 1–3 s.

Thus, the quantity of observation points should be about 13–15.

These points on the cycle can be distributed irregularly based on the density of the distribution of hazard zones in different directions.

Now let us refer to the question of the choice of threshold accelerations values above which the installed control point accelerograph must respond. The following formula which follows from (1), estimates the values of peak horizontal acceleration at control points depending on an epicentral distance of seismic source from Yerevan, taking into account the condition that in Yerevan acceleration should be at the level a = 50 cm/s^2.

$$\lg a = \lg a_0 + 0.51 g \frac{R^2 + h^2}{(R - D_0)^2 + h^2} + 0.0027 \left(\sqrt{d^2 + h^2} - \sqrt{(d - D_0)^2 + h^2} \right) \qquad (4)$$

where a = 0.05 g, D_0 = 30 km, h = 10 km. The corresponding diagram for epicentral distances D = 25÷80 km is shown in Figs. 6 a, 7. This diagram shows that for epicentral distances D ~ 30÷35 km the maximum acceleration value is a ~ 190 cm/s^2, this decreases away of the source to the level 90 cm/s^2. This relationship reflects the fact that the attenuation of seismic waves decreases by length 30 km with increasing epicentral distance.

To detect events with an epicentral distance of about 70÷80 km, for example for the Pambak-Sevan seismogeneous source, it is necessary to set the threshold level on control points to 90 cm/s^2.

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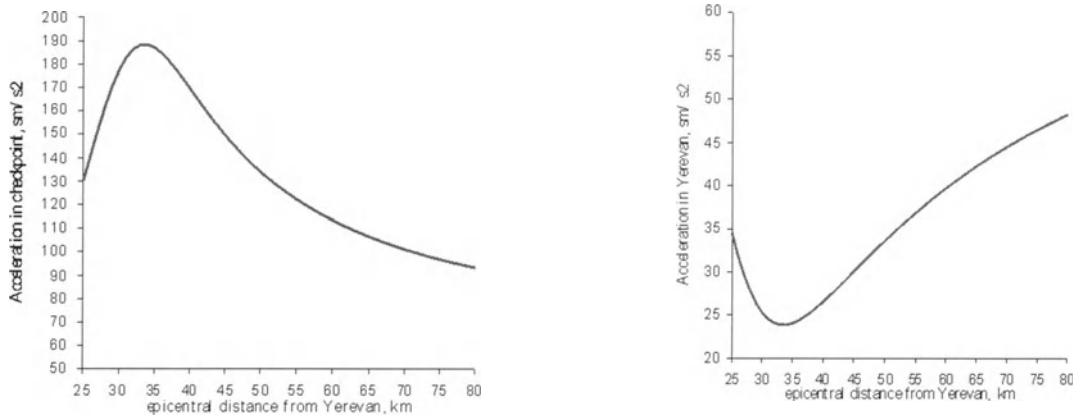


Fig. 6. The threshold acceleration value at the EWS station

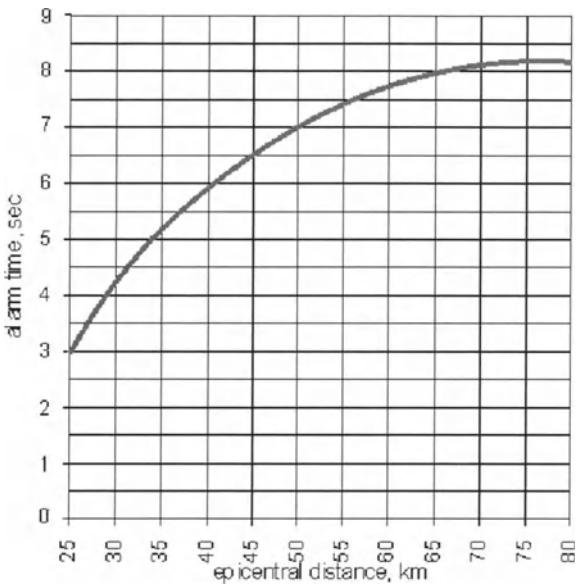


Fig. 7. The dependence of alarm time on epicentral distance

The dependence of acceleration in Yerevan on epicentral distance is shown in Fig. 6b taking into account the fact that this will be equal to 90 cm/s^2 at control observation sites. At this threshold value, acceleration decreases with decreasing distance, and there is a minimum for D ~ 30÷35 km of a ~25 cm/s^2. The installation of threshold values at on control points is therefore necessary to control the earthquakes with great epicentral distances. However for near earthquakes (30÷35 km from Yerevan) the system can register the event, the effect of which will be lowering the fixed level of hazard by about one ball in Yerevan, or by an intensity of 6, or by an acceleration of 25 cm/s^2.

Finally, let us refer to the estimation of mean time of the alarm, taking into account the configuration of the system. The simple estimation including the possibility that the epicentre is superimposed on control points gives the results illustrated in Figure 7. This for minimum epicentral distances the alarm time constitutes 3 s and this value increases to 8 s with increasing distance from source.

5 Technical Description of Early Warning System

The system can be based on 15 radiotelemetric control points located in accordance with Figure 5, which will be equipped by accelerographs (working in a waiting regime), by coding blocks and transmitters of the USW band.

It is suggested that the nets of accelerographs not only be used for EWS, but also for current monitoring of weak earthquakes. For this purpose the transmission band of accelerometers should use the frequency range from 0.4 to 30 Hz for accelerations of 0.005 g and more. The operating threshold of the accelerograph itself should be set rather lower to enable the registration of weak events, and only for accelerations 90 cm/s^2 or more should be coding block give a signal of operation to be translated into broadcast by transmitters.

The reception point of EWS is equipped with receivers, decoders and an interface for the communication with a PC operating under shell – Windows NT. A programme performs a constant analysis of the state of the control points. Upon receiving operation signals from

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no less than 2 neighbouring points it sends an emergency warning signal followed by an audio-visual response.

The information about the state and workability of the system is constantly reflected on the monitor.

Emergency Warning can be transmitted to corresponding stations by different communication systems.

6 Conclusions

1. The seismic hazard and risk of building destruction in Yerevan city is analysed and the feasibility of an an earthquake EWS is substantiated. The analysis is based on microzonation data, actual seismic resistance of dwellings, statistics on seismicity of the region, and historical data relating to destructive earthquakes around the capital of Armenia.
2. The optimal EWS scheme consists of 13–15 control observation sites situated in the area with a radius of 30 km from Yerevan city.
3. The time delay between notification of the population and seismic wave arrival varies approximately between 3 to 8 s.
4. The worst case scenario would constitute a source such as for Dvin's historical earthquake, resulting in 3 s for the notification of the population.
5. Earthquakes with Ararat's, Talin-Arouch's and Tsakhadzor's historical sources would result in a notification time exceeding 6.5 s.

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Can Plate Motion Surveys by GPS Measurements be Considered as an Alert System in Earthquake Occurrence?

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Abstract

Seismic phenomena are one of the important sources of damage and loss of life in Algeria (e.g. the events of: Algiers 1716: Io = X, 20 000 deaths; Blida 1825: Io = X, 7000 deaths; El Asnam 1980: Io = IX, 2633 deaths; Tipasa 1989: Io = VIII, 22 deaths; Mascara 1994: Io = VIII, 171 deaths).

A seismic survey has been carried out since 1990, by means of a telemetred seismological network. A set of 32 stations is spread along the Tellian Atlas region, which is considered the most active zone in northern Algeria. We propose to install a permanent GPS network along the Tellian Atlas (northern Algeria) in order to monitor the displacement of the African plate. We think that the variation in the velocity and stress fields deduced by the GPS survey will enable us to locate the zones where a probable stress drop could occur. These observations must be made over a long time period in order to perform a better survey. We are currently in the first phase of the project, which consists of choose the sites to receive the GPS receivers. The survey will begin by the end of 1998.

1 Introduction

Among all the natural disasters in the world, earthquakes are the most disastrous. The sudden and unpredictable occurrence of this phenomenon is the cause of much damage and loss of life. Many countries over the world have experienced such natural manifestations, and suffered from their consequences. Algeria is one of the countries that has been shaken many times by earthquakes during its history. These events have had many disastrous effects in many areas of the country (Table 1 and 2).

To reduce the seismic risk, and to avoid great catastrophes occurring in any place of the world, all the countries concerned by this phenomenon are engaged in scientific programmes. These begin by studying earthquake mechanisms and the seismotectonics of the regions where seismic risk is present.

In Algeria, we have began by deploying a Seismological Survey Network along the whole northern part of the country. The survey will enable us to follow all the seismic activity along the Tellian Atlas recognised as the seat of seismic activity. Many areas have been well studied by seismological, geophysical and seismotectonic approaches, following the occurrence of large or moderate earthquakes, such as: El Asnam, October 10th 1980, M = 7.3; Constantine, October 27th 1985, M = 6.0; Tipasa-Chenoua, October 29th 1989, M = 6.0; Rouina, January 19th 1992, M = 5.2; Mascara, August 18th 1994, M = 5.6; Algiers, September 4th 1996, M = 5.7.

Other kinds of surveys have been used in Algeria. In the El Asnam faulted area a geodetic network has been installed, and a survey of vertical and horizontal movements has been carried out. It is planned to survey other seismogenic zones by this method.

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Table 1. List of the principal earthquake events that occurred in Algeria between 1365 and 1989

Locality	Date	Io	M	Victims	Observations
Alger	3. 1. 1365	Forte	Forte	Plusieurs	Destructeur[7]: Alger complètement détruite. 100 répliques pendant la nuit. Une partie d'Alger fut inondée
Alger	10. 3. 1673	Forte	Forte	?	Destructeur[7]: Comparable au séisme de 1716. 71 répliques
At. Méti.	3. 2. 1716	X	7.5[1]	20000	Destructeur: Alger: plusieurs maisons détruites. Plusieurs répliques (4, 5 et 26 Février ainsi qu'en mai et juin)
Alger	29. 11. 1722	Forte	Forte	Plusieurs	Violent choc à Alger[7]. Peu de dégâts. A 75 km au SW d'Alger: plusieurs maisons détruites. Plusieurs personnes tuées. Similaire au séisme de 1716
Oran (T)	9. 10. 1790	IX-X[6]	6.5–7.5[1]	2000	Destructeur[6]: Dégâts au pied des monts de Murdjajo. 3 importantes répliques: 19-10 (Io = V); 21/10 (Io = V), 25/10 (Io = VI–VII). Ressenties à Malte
Mascara	3. 1819	IX	6.5[1]	?	Dégâts importants à Mascara. Oran peu de dégâts
Blida	2. 3. 1825	X–XI	7.5[1]	7000	Destruction de Blida et peu de dégâts à Alger. 11 importantes répliques ont été ressenties entre le 02 et 6/03
Djidjelli (T)	22. 8. 1856	X	7.5[1]	?	Destructeur[9,15–17]: Un raz de marée a été observé de long du littoral (Alger, La Calle, Batna, Nice, St. Pierre de Sardaigne, Mahon,...). Le precurseur du (21/08) et le cho principal ont détruit les 3/4 des habitations à Djijelli et le reste de la ville a connu de sérieux dégâts. Des répliques ont été ressenties jusqu'en Octobre. La réplique la plus importante a atteint une intensité Io = VIII
Kherba	9. 3. 1858	IX	6.5[8]	?	Destructeur[8]: La région située entre El Attaf et Alin Defla a été complètement détruite et les dégâts se sont même étendus jusqu'au Nord-Est de Qued Cheliff. Ce séisme a été fortement ressenti à au moins 110 km et jusqu'à la plaine de la Mitidja. Répliques: 12/03 et 14/05
Mitidja	2. 1. 1867	X–XI	7.5[1]	0100	Destructeur[12]: Mouzaïa a été complètement détruite. 160 blessés. Ressentia à Blida, El Affroun, Oued Djer, Bourkika, Koléa, Boufarik, Cherchell, Tipasa, Marengo, Douéra, Alger, Médéa, Duperré.... Des traces de surfaces ont été constatées à Dj. Nador. Plusieurs répliques
Au. Biskra	16. 11. 1869	IX	6.5[1]	0030	Dégâts[13] à Biskra et ses alentours. Ressenti à Batna et Sétif. Mouvement vertical observé. 11 répliques ressenties du 16 au 20/11
Gouraya	15. 1. 1891	X	7.5[1]	0038	Destructeur[14]: Dégât importants: Gouraya et Villebourg ont été complètement détruites. 53 immeubles et maisons détruits ou endommagés. Dégâts à Cherchell, Kherba, El Affroun, Mouzaïa, Blida, Miliana et Orléansville. Mouvement vertical observé à Gouraya. Ressenti à Saïda et Djelfa. Fortes répliques. Rayon macrosismique = 200 kms
El Kalaâ	29. 11. 1887	IX–X (VIII)[4]	6.5–7.5[1]	0020	Destructeur[5]: El-Kalaâ et Dehba: une mosquée ainsi que plusieurs maisons ont été détruites. Thiouanet: importants dégâts (80 maisons ont été complètement détruites). Ressenti à Oran, Arzew, Relizane, Mostaganem et Mascara. Forte réplique ressentie quelques minutes après (voir texte)

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Table 2. List of the principal events that occurred in Algeria between 1365 and 1989 (continued)

Locality	Date	Io	M	Victims	Observations
S. el. Ghouz. (*Aumale*)	24. 6. 1910	X (VIII)[3]	6.4[2] (6.6)[3]	0081	Dégâts importants[3] à El Euch, Tablat et Masqueray. Les villages de la plaine de Gachtulas ont été complètement détruits. Répliques ressenties jusqu'en Janvier 1911, fortes répliques (20/08, M=4.8 et 07/01/1911, M=5.5)
A. el Hassan (*Cavaignac*)	25. 8. 1922	IX–X	5.1[2]	0002	Destructeur: Cavaignac complètement détruite. Mouvement vertical observé (1 m). Ressenti à Flatters Hanoteau, Montenotte, Ténès (VIII) et à Orléansville, Cherchell (VI)...
El At.-El Ab. (*Carnot*)	7. 9. 1934	IX (VII)[8]	5.0[8]	aucune	Dégâts à Carnot, St. Cypriem et El Attlaf. Des glissements de terrain ont été observés au Nord de Ressenti à Alger. 92 répliques entre 07–30/09
Bejaïa	12. 2. 1946	VIII–IX	5.6[2]	0264	1000 maisons détruites. 112 blessés
Chlef (*Orlèansville, El-Asnam*)	9. 9. 1954	X–XI	6.7[2]	1243	Destructeur: 20000 habitations détruites. Effets observés: glissement de terrain et liquéfaction du sol. Mouvement vertical maximum[10] (1.33 m) au voisinage de Ouled Abbas. Plusieur répliques. FM: 254, 30, 266
M'sila	21. 2. 1960	VIII	5.6[2]	0047	Dégâts à Mélouza. 88 blessés
M'sila	1. 1. 1965	VIII	5.5[2]	0005	1300 maisons détruites. FM: 193, 9, 288
Mansourah[1]	24. 11. 1973	VII	5.1	0004	Dégâts à Mansourah, Medjana, El Mehir et Theniet Enasr. 50 blessés. Plusieurs personnes ont été portées disparues. Répliques (24–26/11)
Chlef (*Orléansville; El-Asnam*)	10. 10. 1980	IX	7.3[2]	2633	Destructeur: 8369 blessés, 348 portés disparus, 6778948 sinistrés*, 70% des habitations détruites. Une faille inverse sismogène a été observée (36 km). Un mouvement vertical maximum[11] de 6 m a été mesuré entre Zebabdja et Ouled Abbas. Une forte réplique a été enregistrée une heure après le choc principal (M=6.5) et plusieurs répliques pendant une année. FM: 225, 54, 83, 2.2 10^{26}
Constantine[1]	27. 10. 1985	VIII	5.9[2]	0010	Peu de dégâtes à El-Aria et Béni Yakoub, plus de 300 blessés, plusieurs au voisinage du village d'El-Khroub. Ruptures de surface. Une failure de coulissage. Plusieurs répliques pendant plus d'un mois. FM: 217, 84, 19, 5.2 10^{24}
El Affroun	31. 10. 1988	VII	5.4[2]	aucune	Nombreux dégâts. 500 familles sinistrées et 5 blessés
Dj. Chenoua[1]	29. 10. 1989	VIII	6.0[2]	0022	Nombreux dégâts à Sidi Moussa (*près de la ville de Tipasa*) (au voisinage de l'épicentre) et Nador. Peu de dégâts à Alger (la Casbah). Failure inverse. Plusieurs répliques durant 3 mois. FM: 246, 56, 86, 8.0 10^{24}

[1] Bezzeghoud et al (en préparation); [2] Magnitude instrumentale; [3] Ambraseys et al (1991b); [4] Vogt and Ambraseys (in press); [5] Rapport de presse (1887); [6] Lopez Marinas and Salord (1990); [7] Ambraseys and Vogt (1988); [8] Ambraseys et al (1991a); [9] Ambraseys (1982). [10] Study of 1954 earthquake is being done with the levelling data. [11] Ruegg et al (1982); [12] Cochard (1867); [13] Ollivier (1870); [14] Pomel (1891); [15] Aucapitaine (1856); [16] Senarmont (1856); [17] Glautier de Claubry (1856).

M=Magnitude; Io=Intensité maximale; At. Méti.=Atlas Métidjéen; At. Blid.=Atlas Blidéen; Au.=Aurès; T=Submarine earthquake; Mt.=Monts; Dj.=Djebel; A.=Abou; El At.-El Ab.=El Attaf-El Abadia; FM=Mécanisme au foyer: Azimut, pendage, glissement, et moment sisimique en dyne cm; (*) Rapport de l'Aménagement dans les zones sismiques, Algérie. Cas de la région de Chlef

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We plan to deploy a GPS survey network along the Tellian Atlas, in order to monitor the movement of the African plate. We think that such a survey will enable us to conceive an alert system based on the detection of any suspected change in the velocity field.

2 Seismicity of Algeria

Due to its geographical position Algeria is subjected to considerable seismic activity. This activity, as seen on Figure 1, is related to the collision between the African and Eurasian plates. The entire seismicity available in NEIC and CRAAG data files shows that we have a concentration of this activity along northern Algeria, especially in the coastal zone, which in a way defines the plate boundary zone between Africa and Eurasia between the Azores to the Aegean sea.

It is clearly seen that the epicentres are located along the Tellian Atlas where, during the last decades, the biggest shocks have occurred, such those of: El Asnam, October 10th 1980, M=7.3; Constantine, October 27th 1985, M=6.0; Tipasa-Chenoua, October 29th 1998, M=6.0; Mascara, August 18th 1994, M=5.6 and Algiers, September 4th 1996, M=5.7. These events are located in the seismogenic zones of the El Asnam, Tipasa and Algiers thrust faults and the Constantine Mascara strike-slip faults.

Unfortunately, the seismic crises experienced in Algeria caused thousands losses of life, and injuries. During the El Asnam earthquake, for example, the number of deaths was 2633, and 8369 others were injured (Table 1 and 2). These official statistics were so dramatic that a serious measures had to be taken in order to avoid such catastrophes. We must keep in mind that nearly all the earthquakes that shook Algeria occurred in or around the big cities. Because of the great population concentration in these areas there is a permanent danger of a great catastrophe. When reading the Algerian catalogue and consulting the map of maximum observed intensities (Fig. 2) we can see that all of northern Algeria is characterised by many zone of high seismic risk.

2.1 Seismogenic Zones in Algeria

The maximum observed intensities map of Algeria shows clearly that the seismogenic zones in Algeria are concentrated along the Tellian Atlas. These zones (Oran, Mascara, El Asnam, Tipasa-Blida, Jijel, Constantine) are concen-

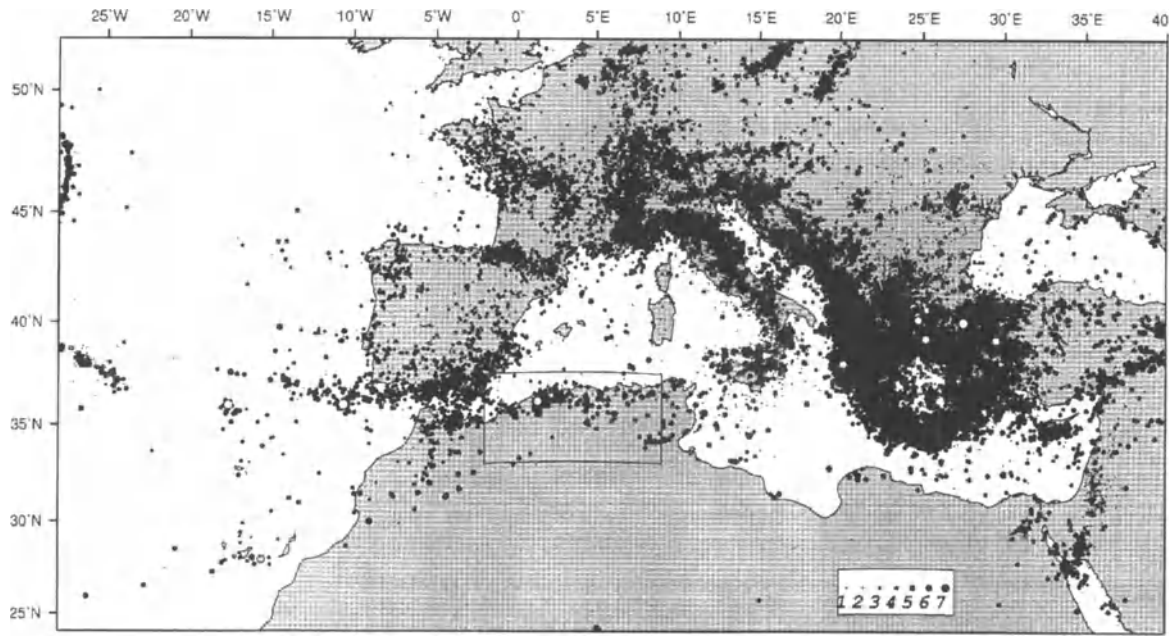


Fig. 1. Seismicity of the western Mediterranean region

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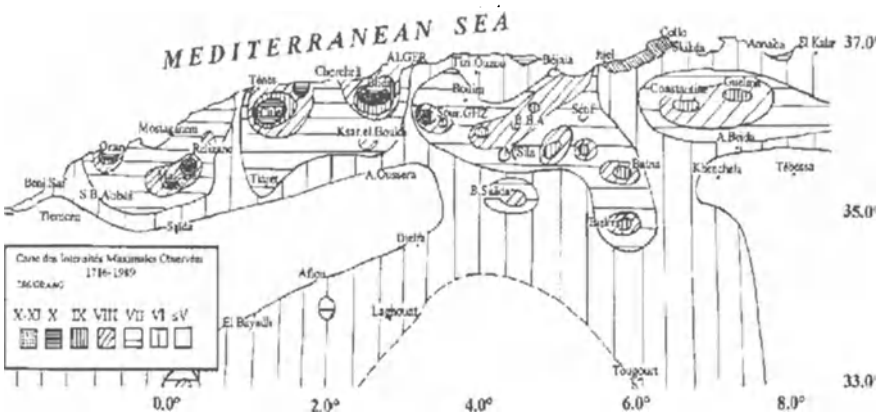


Fig. 2. Observed Maximum Intensities of Algeria

trated linearly from west to east, and roughly define the boundary between the African and Eurasian plates. After having deployed a seismological survey network and after having also installed a geodetic survey network around the El Asnam faulted area, we will deploy a GPS survey network. The combination of all the data provided by these networks will enable us to propose a program upon which a serious alert system could be based.

3 Seismological Survey in Algeria

Seismological surveys of the seismogenic zones in Algeria have been carried out for a long time, by mean of seismic stations. The CRAAG have installed, since 1910, many seismological stations to survey the trembling of the earth. Our seismic station network is composed of 28 telemetred short period (1 Hz) stations, 4 regional three component stations and 4 autonomous long mean period stations and 2 Broad band stations belonging to MedNet and Geoscope networks (Fig. 3). In the near future we plan to install 10 more autonomous stations. The purpose of this network is to enable us to perform a continuous survey of the seismic activity, in order to enhance, as well as possible, the precision of the epicentre localisation. Another goal of this network is to detect any abnormal activity which can be considered a sign of an eventual seismic crisis. The *Algerian Telemetred Seismological Network* experienced such a case with the Rouina earthquake of January 19th 1992 (M = 5.2), (Bezzeghoud et al. 1994).

In addition, a geodetic network has been installed around the El Asnam fault to monitor crustal deformation. This network consists of a

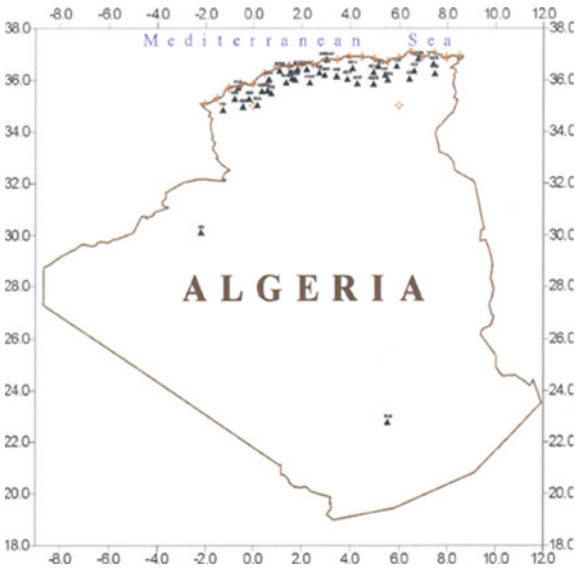


Fig. 3a. Configuration of the Algerian Seismological Network (in Black triangles) and the planned GPS survey network (Red circles)

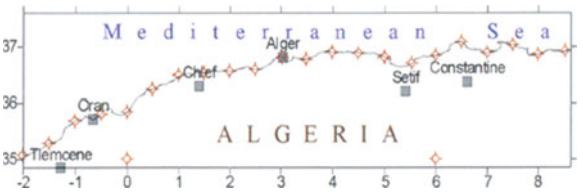


Fig. 3b. Configuration of the GPS network we plan to deploy over the northern Algeria (see also figure 3)

horizontal (Fig. 4b) and vertical (Fig. 4a) geodetic network, which were periodically surveyed from 1981 to 1992. The research program consists of repetitive geodetic measurements (levelling, triangulation and trilateration measurements). It is planned to install similar networks around other known faults in Algeria, such as the faults which generated the Constan-

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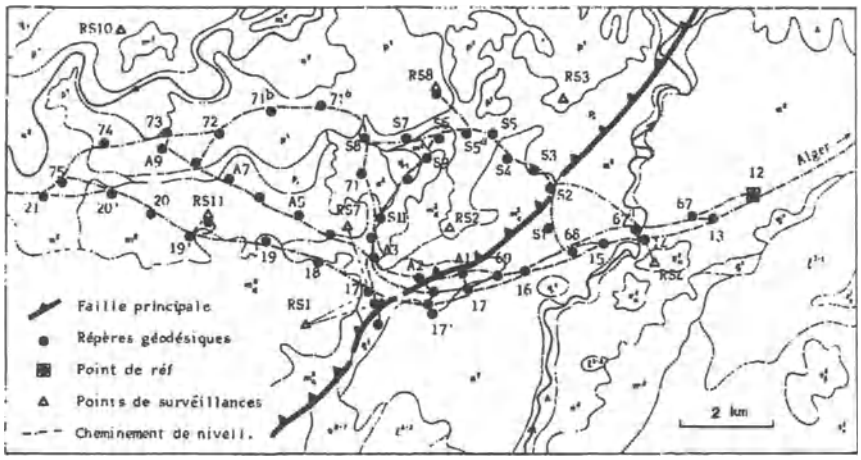


Fig. 4a. Map of vertical network benchmarks and levelling lines settled on a geological map: A, actual alluvial deposits; a2, recent alluvial deposits; q1, ancient alluvial deposits; p1, conglomerates and red alluvial deposits; m2, blue clays; ma3, yellow marls (Tortonian); ec3, shales (Medjanian), md3, Ostrea sandstones; mc3, limestone and lithothamnium sandstones; s, shales; m4. blue marls (Shelian); p, marine Pliocene, c8-7 Senonian; 13-2 Liasic limestones

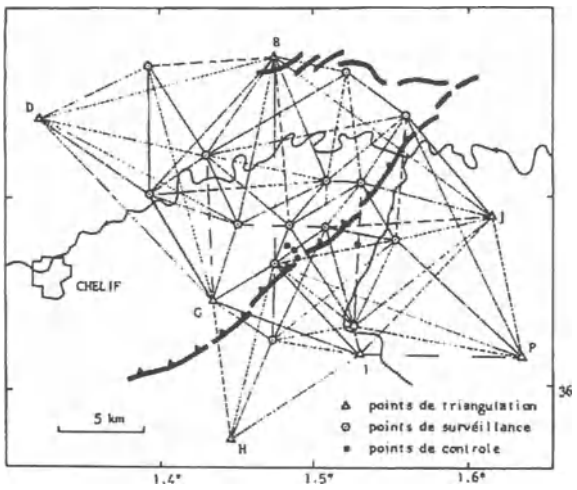


Fig. 4b. Map of the Geodetic Horizontal Survey Network around the El Asnam thrust fault

tine (October 27th 1985, M=6.0), the Tipasa (October 29th 1989, M=6.0), and the Algiers (September 4th 1996, M=5.7) earthquakes.

4 Plate Motion Survey as a Warning System

According to many authors seismic phenomena in Algeria are related to the African-Eurasian plate collision. This plate movement generates stress along the boundary of these two plates. When rupture level is reached, a seismic event occurs. This is the basic idea upon which we want to construct our project, which involves monitoring the African plate movement towards the Eurasian one by evaluating the velocity field. This will later enable us to calculate the stress field along the plate boundary. Any change in this parameter in a given area will enable us to suspect the occurrence of stress drop related to an earthquake. Of course, we must keep in mind that a calibration of the major seismogenic zones is necessary.

The approach we propose is to use bifrequence GPS receivers which we plan to deploy along northern Algeria near or on the seismogenic zones as identified by previous studies. The sites which have been chosen to receive the GPS receivers are located at Alger-Bouzaréah, a permanent and fixed station. A geodetic reference point is available at the site and belongs to the "*Algerian State Geodetic Network*". This point will enable us to calibrate, as well as possible, our new network. 24 other points are proposed to be surveyed twice a year (in the first phase) along the Algerian coast with an interval distance of 50 km. This network (Fig. 3b) will be connected to the network present in the south of Europe (France, Spain, Italy) and with the nearest other IGS networks. We expect to have a precision of about a millimetre by combining our data with those of IGS networks.

Recently, Bezzeghoud et al. (1997), have estimated the average slip rate in the western part of northern Algeria based on scalar seismic moment release for earthquakes (M≥4.0). The horizontal shortening slip is U_h=7.6 mm/yr. This result is comparable with those evaluated by McKenzie (1972, U_h=9 mm/yr), Minster & Jordan (1978, U_h=11.4 mm/yr), Buforn et al. (1988, U_h=11.5 mm/yr). By combining this value of horizontal slip rate with what we observe in the El Asnam region we obtained a value of 10.9 mm/yr, represented by the sum of a

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7.6 mm/yr given for western Algeria and a 3.3 mm/yr which represents the aseismic slip (deduced from geodetic survey) (Fig. 8).

5 Recent and Previous Studies in the Region

The recent/present motion trend of the African plate with respect to Eurasian one is characterised by a convergence trend in the NW to NNW direction in the Ibero-Maghrebian region, confirmed by geological and seismic shortening patterns (see, for example, King & Vista-Finzi 1981; Philip & Meghraoui 1983; Buforn et al. 1988). According to Mantovani et al. 1997, the African plate would have a NE to NNE motion direction given post Tortonian deformation patterns in the Central Mediterranean area (Fig. 6). After Udias' (1982) map (Fig. 5) we can observe that the convergence of the African

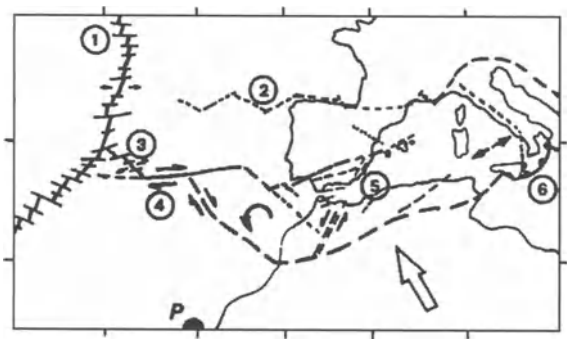


Fig. 5. Geodynamic model of distributed deformation for the Ibero-Maghrebian region, and its relation with the kinematics of the African and Eurasian plates (after vegas, 1991)

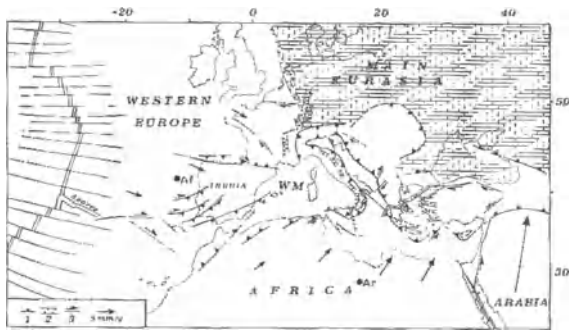


Fig. 6. Relative motions of Africa, western Europe and Atabia with respect to main Eurasia, after Mantovani et al., 1992. Arrows in Africa indicates proposed velocity fields with respect to Eurasia

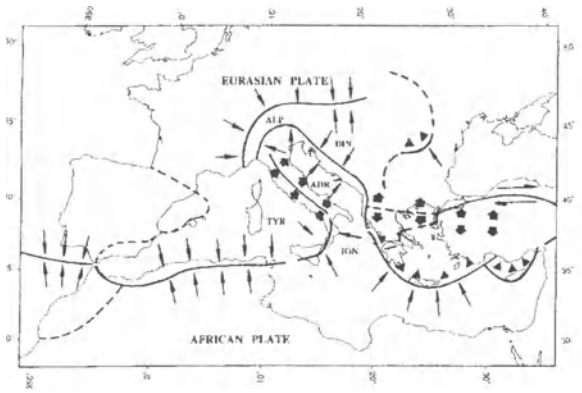


Fig. 7. Principal tectonic features in the Mediterranean after Udias (1982)

to the Eurasian plate has a NNW to NW direction. This is also confirmed by Vegas (1991), who showed a NNW displacement of the African plate relative to Eurasia (Fig. 7). Unfortunately, to date the plate boundary has not been defined with precision. The absence of observation points along northern Africa constitute the main problem in the boundary plate determination. This is why we propose to install a GPS survey network in order to, first of all, determine the plate boundary, and, in a second phase, to survey the velocity field along this boundary to initiate an alert system for earthquake occurrence.

6 Conclusions

In conclusion we can say that, in the case of Algeria, an alert system is very important for at least two reasons: firstly the major part of the Algerian population is concentrated in its northern part, where the seismic risk is high. The population density per square kilometre in the big cities is very high. In the case of a major earthquake such as those of Algiers 1365 and 1716, or that of Oran 1790, a catastrophe could not be avoided.

The second reason is that the principal economical and industrial groups are all located in and around the northern big cities. Furthermore, the whole railway network and all the highways are concentrated in the dangerous part of our country (we have to keep in mind that some of these railways and highways cross tunnels which increase the danger in case of earthquake.

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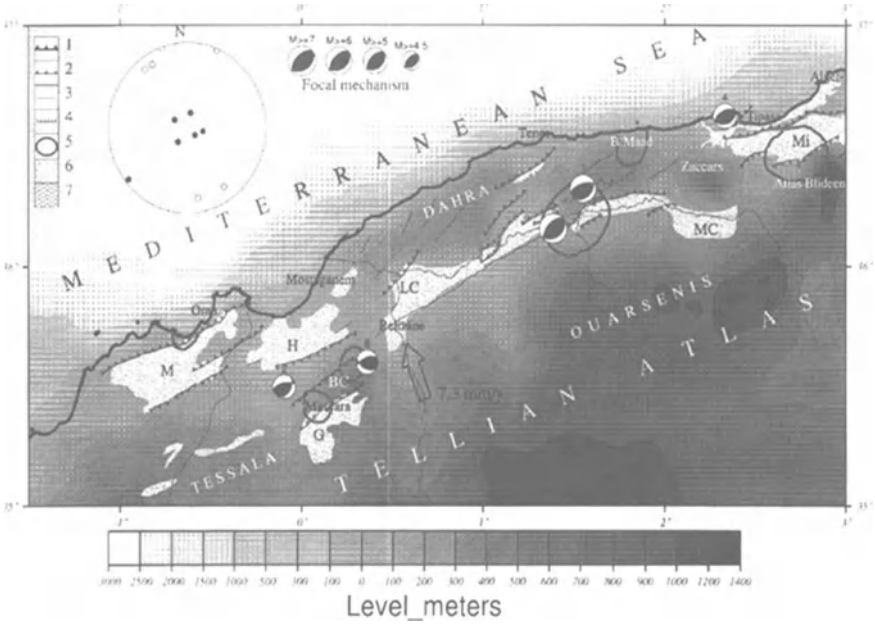


Fig. 8. Seismotectonic map of western Algeria (modified from, Bezzeghoud et al., 1997). EA rev. El Asnam reverse fault, Rev. Reverse fault, QF: Quaternary faults, NF, Normal fault, Io = maximum observed intensity for Io = X, Quat. Basin: quaternary basin, Lake: induced 1980 lake. The focal mecanisms are shown on lower hemisphere projection. In the upper left corner there is a lower hemisphere projection of P-axes (close circles) and T-axes (open circles)... The large open arrow show the average direction with the horizontal shortening slip rate (7.6 mm/yr)

For these reasons, and many others, we have the obligation to develop an alert system. Of course we do not have the pretension that we will succeed in making a perfect alert system in the short term, but we hope that our studies will enable us to do so in the near future.

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Vb Early Warning Systems for Volcano Monitoring and Eruption Warnings

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CHAPTER 5.15

Volcano Monitoring and Eruption Warnings

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1 Introduction

Since AD 1600, more than 260 000 people have died from the hazardous processes of volcanic eruptions. Volcanologists generally recognize two broad categories of volcano hazards: *direct hazards*, those that are immediately linked to, and happen during, the eruptive activity; and *indirect hazards*, those that are not directly related to the eruption itself and/or occur days to years after the eruption ceases. For a cogent summary of the principal types of volcano hazards, the interested reader is referred to Scott (1989). In the 17th–19th centuries, most volcano-related deaths were from indirect hazards, especially tsunami and post-eruption famine and disease (Blong 1984; Tilling 1989a). However, in the 20th century, the principal killers have been direct hazards: namely, pyroclastic flows and surges and volcanic debris avalanches and flows (mudflows). Most of these deaths resulted from only two events, the 1902 eruption of Mont Pelée (Island of Martinique, West Indies), and the 1985 eruption of Volcán Nevado del Ruiz (Colombia); combined, these two eruptions claimed more than 52 000 lives. The many other less deadly eruptions worldwide during the 20th century only killed a few people each.

Data on well-documented historical eruptions indicate that they were all preceded by physical and/or chemical changes in the state of the volcanic system, as noticed by the human senses and/or detected by instruments (Simkin & Siebert 1994). The systematic observations and instrumental measurements of such precursory changes (i.e., volcano monitoring) constitute the scientific – and *only reliable* – basis for anticipating possible impending eruptions and their hazardous impacts (Tilling 1995). Since the first review of volcano-surveillance techniques nearly three decades ago (UNESCO, 1972), and especially with the catastrophic 1980 eruption of Mount St. Helens (Washington, USA; Lipman & Mullineaux 1981), significant advances have been made in volcano-monitoring techniques as well as the science of volcanology (see for example, McGuire et al. 1995; Scarpa & Tilling 1996). Volcano-monitoring studies clearly constitute the core of any effective *early warning system* (EWS) for eruptions. Yet, as emphasized later, for such warnings to be effective, they must be heeded and acted upon in a timely manner by emergency-management officials to save lives and reduce economic loss from volcano hazards.

2 Increasing Risk from Volcano Hazards

By the beginning of the 21st century, world population is expected to reach 6 billion or more (Fig. 1). Population growth will be concentrated overwhelmingly in the developing regions, which also contain most of the world's active and potentially active volcanoes. Population at risk from volcano hazards by the year 2000 is estimated to be at least 500 million (Tilling & Lipman 1993), about 90% of whom live in regions along the circum-Pacific "Ring of Fire," notorious for frequent earthquake and volcanic activity. However, densely populated volcanic areas in Europe and elsewhere in the world are also at risk. For example, Mount Ve-

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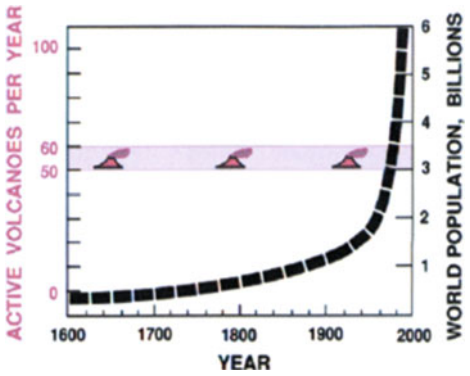


Fig. 1. Schematic diagram showing the exponential increase in world population (heavy dashed arrow) and air travel (solid arrow) against an unchanging global eruption frequency of 50–60 volcanoes active per year on average (shaded bar with volcano symbols). (From Tilling, in press, Fig. 6)

suvius, near Naples, Italy, provides an illustrative specific example of increased volcano risk with population growth. When the volcano erupted catastrophically in AD 79, the combined population of Pompeii and Herculaneum probably was about 25 000. Today, more than 3 million people live in the region around the volcano, whose youngest eruptive cycle began with the AD 79 eruption and presumably lasting at least through its most recent eruption in 1944 (Rosi & Santacroce 1984). Obviously, renewed eruptive activity at Vesuvius, even if relatively minor, would pose a much more serious volcanic threat now than it did back in AD 79. The demographic reality of increased volcano risk at Vesuvius also would apply for many volcanic areas, especially those in the countries rimming the Pacific Basin. Most of these countries are already densely populated and have high growth rates; the mounting population pressures drive further human encroachment into land vulnerable to volcano hazards.

However, people do not have to inhabit or visit volcanic regions to be threatened by volcano hazards. Air travelers can be at risk by simply being on board commercial airliners flying over volcanic regions and possibly encountering a volcanic ash cloud from an explosive eruption. In recent decades with rapidly expanding air travel, such aircraft-volcanic ash encounters have emerged as a significant *indirect* volcano hazard, posed primarily by the ingestion of silicate ash into the aircraft's jet engines (Casadevall 1994). Ash particles, rock-hard with characteristically jagged edges, can severely abrade ("sand blast") engine parts as well as lodge within the engine, clogging critical clearances, openings, and ducts. Also, the operating temperatures of high-performance jet engines are sufficiently high to partially melt the ash to form liquid, which upon re-solidification adheres as glaze-like deposits on critical engine parts and openings. Thus, ingestion of ash seriously degrades engine performance and, in the worst case, causes engine flame out and loss of power. Ash particles can also cause exterior damage, such as abrasion of the windshield and windows, erosion of leading edges, etc.

Since the early 1970s, there have been more than 60 encounters between aircraft and volcanic ash clouds (Fig. 2), several of which have resulted in total power loss, necessitating emergency landings. Most encounters occur within about 250 kilometers of the erupting volcano, but many have happened at greater distances (> 900 km) from the volcano. A very costly incident was during the eruption of Redoubt Volcano (Alaska, U.S.) in December 1989, when a Boeing 747-400 jetliner encountered Redoubt's volcanic ash cloud and temporarily lost all four engines. With good pilot skills and luck, the engines were restarted in ash-free atmosphere to permit a safe emergency landing at Anchorage (Alaska) International Airport, but the repair costs to replace all four engines and repair other damage exceeded USD 80 million (Casadevall 1992). Fortunately, to date no injuries or

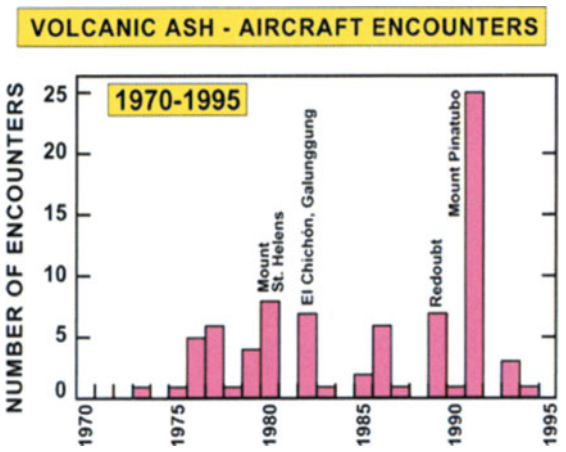


Fig. 2. The number of in-flight encounters between aircraft and volcanic ash clouds; some of these damaging encounters have resulted in the shut-down of one or more jet engines (see text). (Data source: Casadevall and Budding, in preparation)

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deaths have occurred because of volcanic ash-aircraft encounters. However, because air traffic – passenger and cargo – is projected to increase many fold in the coming decades, and because many international air routes cross active volcanic zones (Casadevall & Thompson 1995), this modern-day indirect volcano hazard will become increasingly more severe.

Eruption frequency worldwide apparently has varied little in recent centuries, with 50 to 60 volcanoes in eruption each year on average (Simkin & Siebert 1994). There are no geologic reasons to suppose that this eruption frequency observed for historical times would change in the near future. Thus, assuming that the eruption frequency remains relatively constant with time, the risks from volcano hazards – on the ground *and* in the air – will inexorably increase with continued population growth and economic development in volcanic regions, coupled with the expected accelerating increase in global air traffic in the 21st century (Fig. 1).

3 Early Warning Systems in Reducing Volcano Risk

Against this background of continuing growth in population and air travel, which is unlikely to change for the foreseeable future, what can be done to reduce the risk from volcano hazards? For areas that still are *relatively sparsely* inhabited and developed, we must accelerate basic geoscience studies of volcanoes to make the best possible hazards-zonation maps to guide long-term land-use planning by government authorities. High-density development in the high-risk zones should be avoided or minimized to the extent that is economically practical. Volcano-monitoring data should be collected to determine typical behavior of volcanoes during quiescence, so that *baseline* measurements are available for comparison, if and when volcanic unrest should commence. Such data permit the early detection of excursions from "normal" behavior that might augur eruption and attendant volcano hazards. Because a volcano's behavior typically varies within a certain range over time, the longer the period of volcano monitoring by an early warning system (EWS), the better the characterization of baseline behavior and the more diagnostic and reliable is the detection of possible eruption precursors.

Unfortunately, because many volcanic areas in the world are already densely populated and developed, the option of prudent land-use planning to mitigate the risks of potential hazards generally cannot be exercised. Only the timely warning of impending eruptive activity and the development of effective, tested contingency plans constitute the basic means to reduce volcanic risk. Thus, it becomes even more important to establish or expand an EWS to conduct monitoring studies and to develop an eruption-prediction capability. To be most effective, volcano monitoring should be initiated during quiet periods, *long before a volcanic crisis strikes*. However, the successful experience in responding to the powerful 1991 eruptions of Mount Pinatubo (Newhall & Punongbayan 1996) attests that, even with a volcanic crisis already in progress or even at a previously unmonitored volcano, the immediate initiation of volcano monitoring – by rapid deployment of a *mobile volcano-monitoring system* (Murray et al. 1996) – may still result in timely eruption warnings and life-saving evacuations of people at risk (Tilling 1995).

Since 1980, with the reawakening and eruption of Mount St. Helens (Washington, USA), tremendous advances have been achieved in volcano-monitoring techniques (both ground- and space-based) and in data acquisition, analysis, and interpretation (McGuire et al. 1995; Scarpa & Tilling 1996; and references therein). Such advances have not only significantly improved instrument sensivity for signal-to-noise ratios of the parameters measured, but they also have made possible rapid simultaneous processing and analysis of multiple data streams. Particularly exciting and useful has been the improvement in techniques for continuous "real-time" or near "real-time" monitoring of precursory seismic, geodetic, and geochemical phenomena, holding the promise of increased availability in the 21st century of robust and reliable *early warning systems* to mitigate hazards at high-risk volcanoes. The EWS strategies in the next century will rely increasingly on remotely acquired and telemetered data, thereby reducing the need for scientists to make on-site measurements, often under hazardous conditions that pose a risk to their personal safety.

It cannot be overemphasized that a robust EWS is just one component of an effective pro-

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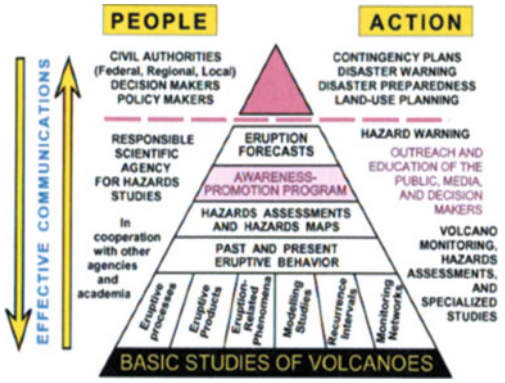


Fig. 3. Any effective program to reduce volcano risk must be built on a solid foundation of long-term basic studies of volcanic systems. The apex is separated from the rest of the triangle to emphasize the division of primary responsibility between the scientists and the civil authorities. (Modified from Tilling, 1989b, Fig. 1.3)

gram of volcano-risk mitigation, and the usefulness of the information acquired by it – no matter how precise and accurate – will be constrained by our fundamental understanding of eruptive phenomena. Thus, the volcano-monitoring, hazards-assessment, and other specialized investigations integral to an EWS must be built on a strong foundation of basic geologic, geophysical, and geochemical studies (Fig. 3). Even more important, however, is a vigorous, far-reaching educational effort to promote official and public awareness of volcanic phenomena and associated hazards (Punongbayan & Newhall 1995). Effective communications between the scientists, the emergency-management authorities, and the populace during the 1991 Pinatubo eruptions was decisive in saving many lives and reducing economic loss. As the eruptive activity escalated, the educational use of a preliminary version of a 30-minute videotape produced for the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) by the late Maurice Krafft (IAVCEI 1995) – graphically illustrating the devastating impact of volcanic hazards – was instrumental in convincing the officials and the populace at risk that Pinatubo posed a very real danger. Even though the 15 June 1991 Pinatubo eruption ranks as the world's largest eruption during the past eight decades and more than 250 000 people were threatened, the fatalities – about 320 – were reduced greatly, and billions of dollars worth of military aircraft and other facilities at nearby Clark Air Base were saved because of the advance warning given by scientists on the scene and effective emergency management by local authorities. The general evacuation order was given on 12 June, three days before the beginning of the climactic eruption.

While the Pinatubo case history represents a genuine success in the use of an EWS in reducing volcano risk, we must never forget the sobering lesson from the 1985 tragic catastrophe at Nevado del Ruiz (Williams 1990a,b). In arguably the most definitive post-mortem of the Ruiz disaster, Voight (1990: p. 349) concluded that the main contributory factor was "*...cumulative human error – by misjudgment, indecision, and bureaucratic shortsightedness,*" rather than any "*technological ineffectiveness or defectiveness...*" of the rudimentary but quite adequate EWS in place at the time. Thus, even though an essential pre-requisite of an EWS is the prompt acquisition and sound scientific interpretation of volcano-monitoring and hazards-assessment information, the efficacy of any EWS depends, in the final analysis, on human judgment and action. No matter how precise and abundant the monitoring data, and no matter how rapidly they are collected and analyzed, the most sophisticated EWS is rendered useless if scientists fail to communicate hazards information – quickly and effectively in understandable language – to emergency-management officials so that mitigation measures can be implemented in time to avert disaster.

4 Challenges for the 21st Century

In an already densely populated area, the primary focus in reducing volcano risk should be to save human lives. We should strive to reach a goal similar to that which has been achieved for hurricane hazards in the U.S. during the 20th century (Fig. 4). While the economic loss from property damage has risen steadily because of increased development along coastal areas, the fatalities have decreased dramatically with time, reflecting a greatly improved hurricane tracking and warning system and effective dissemination of critical hazards information. Similarly, mounting population and economic development pressures also force further unwise and unsafe utilization of land increasingly vulnerable to volcano hazards. Timely, reliable, and effectively communicated warnings of impending eruption by scientists, coupled with

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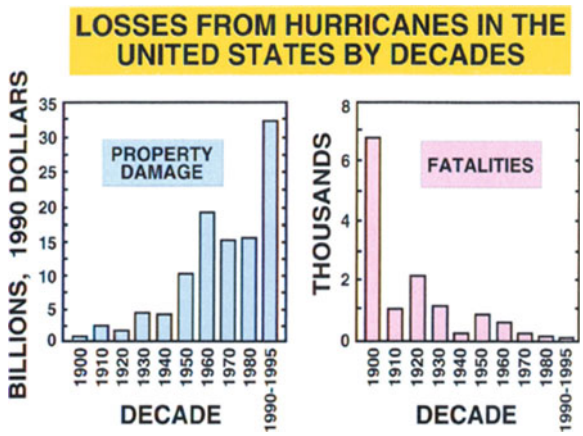


Fig. 4. Losses from hurricanes in the United States during the 20th century. Despite the sharply increasing development and resulting economic losses (left diagram), the number of fatalities has decreased dramatically (see text). (Data source: Hebert et al. 1996)

timely action by emergency-management officials can minimize loss of life even when an eruption causes massive destruction and economic loss.

The encouraging experience at Pinatubo represents a genuine success story in volcano-risk reduction, of which the volcanologic community can be justly proud. But volcanologists must not rest on their laurels and complacently assume that similar successes can be achieved routinely with threatening volcanoes in the future. Burgeoning population growth will continue to pose a formidable challenge to the effective mitigation of volcano risk. The paramount challenge to both the scientific community and decision-making bodies is to prevent volcanic crises from turning into volcanic disasters. This is no easy task given the gloomy demographic projections that point to increasing volcano risks in the 21st century. It is abundantly clear, however, that the establishment of reliable permanent early warning systems (EWS) at known dangerous volcanoes and the rapid deployment of mobile volcano-monitoring systems during volcanic crises at unmonitored volcanoes will be imperative in any effective program of volcano-risk mitigation.

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CHAPTER 5.16

Geochemical Monitoring on Merapi Volcano, Indonesia

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While geophysical methods have become widely accepted as major tools for volcanological forecasting, geochemical surveillance of volcanic activity is still less frequently applied. This might be due to insufficient information on the relationship between volcanic gas composition and volcanic activities. Complete and accurate data sets collected during long periods of time at fumaroles are only partially available.

Within a German geophysical and geological research initiative under the umbrella of IDNDR a volcano gas monitoring device has been constructed and installed at the Woro fumarole on Merapi volcano summit (Fig. 1), a 2967 m high stratovolcano in Central Java in the Indonesian island arc (Schick & Mugiono 1991). The endogen lava dome composed of andesitic magma continues to grow on the west side of the Merapi volcano. Degassing of the dome itself is relatively weak, the main degassing takes place outside the freshly extruded lava, in two fumarolic fields (Woro and Gendol).

The specially designed monitoring unit, consisting of a gas chromatograph, an alpha szintillometer and a temperature sensor (Fig. 2), was successfully installed during May and June 1997 at Merapi summit. The complete unit operates automatically and can be remote controlled by radio link. Concentration levels of H_2O, CO_2, SO_2 and H_2S were measured every 35 minutes and ^{222}Rn and ^{220}Rn as well as the fumarole temperature every 70 minutes, over several days. The data obtained were transmitted via radio link to the Volcanological Technology Research Center (BPPTK) in Yogyakarta. In addition conventionally collected gas and fumarole condensate samples were analysed for He- and H- and O-isotopes.

The composition of gas emitted from Merapi shows relatively strong variations (Figures 3 and 4). From May 14 to May 24, 1997 H_2O ranges between 89 and 99 vol.%, CO_2 between 0.1 and 6.7 vol.% and SO_2 between 0.5 and 4.2%. First results of the on-line gas measurements to date show a clear positive correlation between SO_2 and CO_2 whereas both are negatively correlated with H_2O.

Higher sulphur and carbon dioxide concentrations could be observed prior to distinct seismic events. On May 14, three seismic events were observed by our Indonesian colleagues which they interpreted as rockfall triggered by higher gas pressure in the volcano (Suharno, pers. comm.). This pressure increase may have possibly caused higher SO_2 and CO_2 concentrations and lower H_2O levels prior to the seismic events. Possibly higher gas pressure builds up and is suddenly released causing small seismic events. Higher SO_2 and lower H_2O concentrations where also observed during the explosive eruptions in 1990 and 1992 (Sri Sumarti & Suryono 1994).

Every 3–4 hours, concentrations of SO_2 and CO_2 increase while H_2O amounts decrease. Such rhythmic variations are not uncommon for volcanoes (Tazieff 1970) but have up to now not been observed for the Merapi volcano.

This is accompanied by higher ^{220}Rn and ^{222}Rn activities as well as higher temperatures, gas velocities and fluxes (Figures 5 and 6). The increase of $^{220}Rn/^{222}Rn$ is interpreted as depending on gas velocity. This leads to the conclusion that SO_2 and CO_2 originate from stronger magma degassing instead of variable groundwater fluxes. A relation to tidal influence or regularly varying weather conditions like atmosphere pressure and rain fall intensities could not be observed.

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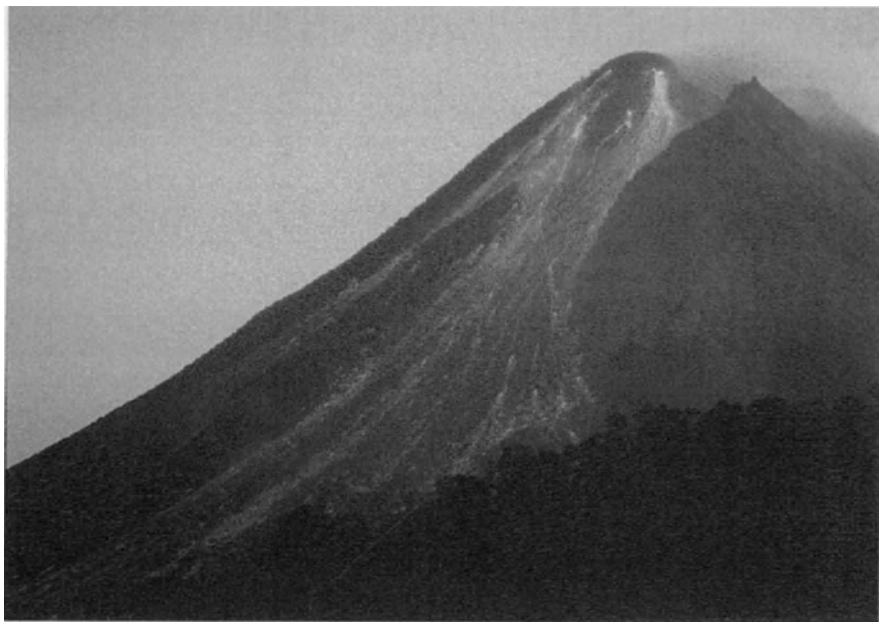


Fig. 1. South slope of Merapi volcano

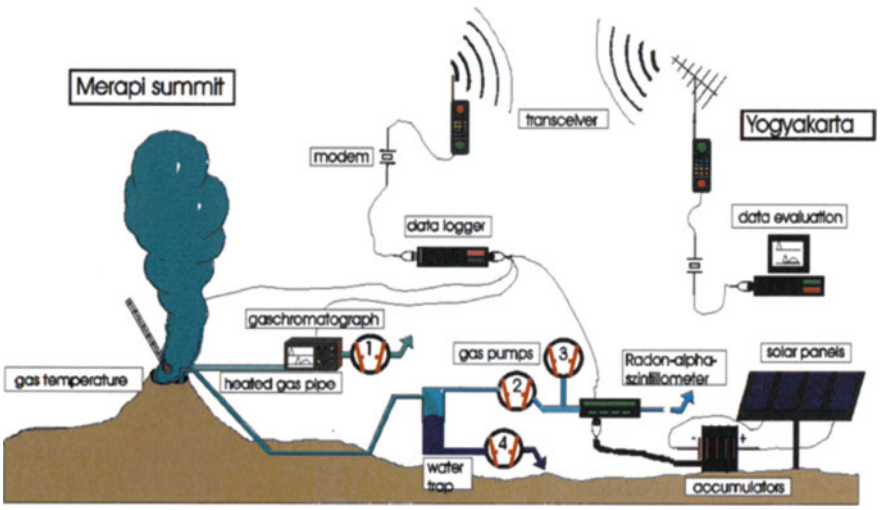


Fig. 2. Sketch of the volcano gas monitoring device

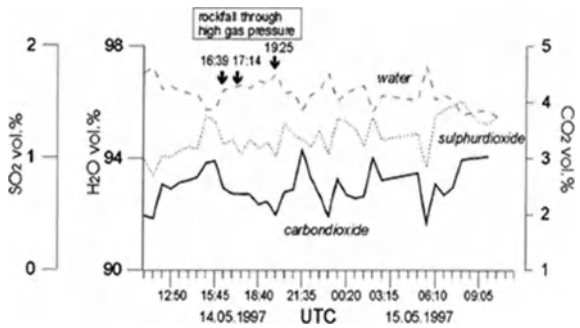


Fig. 3. Gas concentration data versus time (May 14 and 15, 1997)

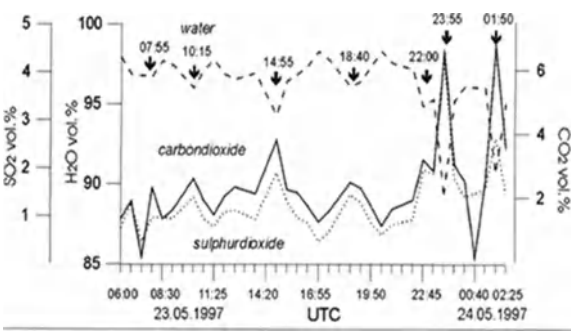


Fig. 4. Gas concentration data versus time (May 23 and 24, 1997)

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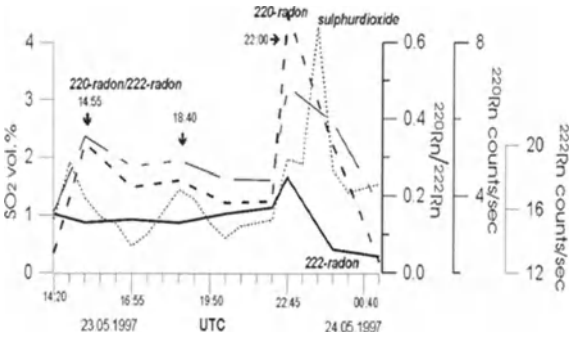


Fig. 5. SO_2, ^{222}Rn, ^{220}Rn (thoron) and thoron/radon ratios versus time

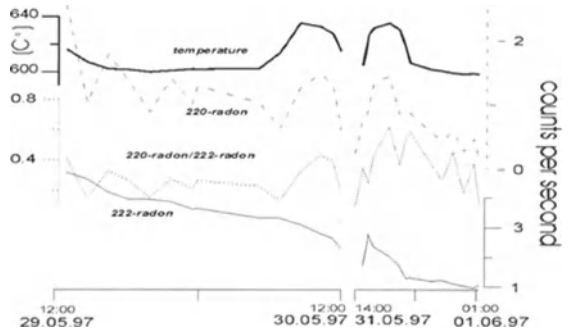


Fig. 6. ^{222}Rn, ^{220}Rn and temperature data versus time (May 29 – June 6, 1997)

Equilibration temperatures of 1046 °C and 991 °C at $fO_2=10^{-11}$ were calculated from the Gendol and Woro gas compositions, respectively. Their calculated temperatures are in the range of melting temperatures of andesites (Carmichael et al. 1974) and are clearly higher than the fumarole surface temperatures (807 °C and 632 °C). This means, Merapi gas equilibrated close to the magma body (melt) and cooled down during the ascent. A new thermodynamic equilibrium did not set up until reaching the surface, which is a general observation at volcanoes (Benhamou et al. 1988). The lower surface temperature at the Woro field can be explained by a longer travelling time through cold wall rock and a stronger mixing with cold meteoric water.

Hydrogen and oxygen isotope investigations on spring water and fumarole condensate samples indicate that the water present in the fumaroles is mainly rain water with variable small amounts of magmatic water. The condensate samples show D/H-ratios between Merapi spring water and SMOW, but an oxygen isotopic signature typical for magmatic rocks (Hoefs 1996). A surficial rather than deep-seated

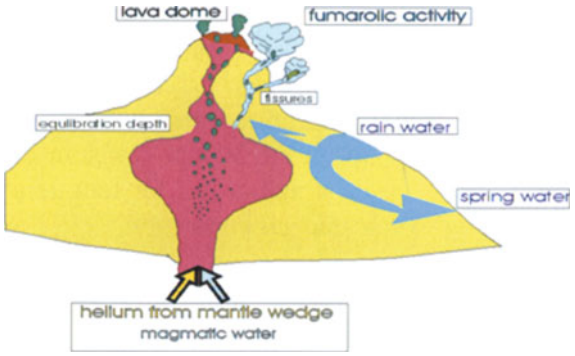


Fig. 7. Fluid model for Merapi volcano

source is also suggested by Allard (1982) for water vapour in Merapi gas. Our investigations show that during decreasing water content in the volcanic gas the D/H-ratios in the condensates increase, which means that the meteoric/magmatic water ratio is getting smaller. In addition, analysis of structural water in rocks from the actual lave dome show values of approx. 0.22 wt.% which is small compared to average island arc andesites (1 to 2 wt.%). Thus we believe that the volcanic gases do contain magmatic water.

$^{3}He/^{4}He$-ratios between 8–8.8*10^{-6} ($R/R_a \cdot 6$) in Merapi off-line gas samples imply that here the same processes take place as occur world wide in similar tectonic settings (Allard et al. 1997). Compared to the atmosphere, relatively light helium is assimilated during the ascent of the magma through the overlying mantle wedge and is transported to the surface. This leads to the typical helium isotopic signatures known from island arcs and convergent plate boundaries (Poreda & Craig 1989).

From this data we propose a first fluid model for Merapi volcano (Fig. 7). We are aware that the variations of furmarolic gas composition are sensitive to variable physicochemical conditions and reactions at depth and in the surficial portion of a volcano edifice (Giggenbach 1996). There are still no general indicators that can be used to the forecast of volcanic activity but we believe that it may be possible in the future to deduce conclusions on the actual amount of ascending magma and herewith crucial data on dome growth and volcanic activity.

The technique used is sophisticated, the equipment is quite expensive, maintenance needs trained personnel, and corrosion is a severe problem. This effort seems to be necessary

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to get to know of Merapi's geochemical behaviour. However, in the near future more simple and less expensive devices based on sensor techniques will be optimised and installed by our working group on the Merapi crater in order to allow the local authorities for long-term monitoring of volcanic gas emanation.

Acknowledgement

We thank Mr. Yustinus Sulistiyo and the staff of the Volcanological Technology Research Center (BPPTK) Yogyakarta for gas analyses and for their support during field work. We would like to thank Dr. Wand (Alfred Wegener Institut, Potsdam) for performing the ^{18}O and D analyses and Dr. Niedermann (GeoForschungs-Zentrum Potsdam) for careful analysis of helium isotopes. We are grateful to Mr. Christian Kujawa (GFZ Potsdam) for his valuable technical assistance in the laboratory and during field work. This work was kindly supported by the Deutsche Forschungsgemeinschaft, Bonn (grant: Er 123/9).

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Remote Sensing of Subglacial Eruptions in Iceland and the Development of Related Warning Systems

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Abstract

The 1996 subglacial eruptions in Iceland and possible future events in the neovolcanic zone serve as a case in point to emphasise the need to evolve effective methods using SAR techniques for the observation of natural disasters and assessment of the magnitude of their impact. Main research objectives are the monitoring, using ERS-1/2 SAR, JERS-1/SAR and RADARSAT data, of surface deformations caused by magmatic movements, the observation of glacier dynamics and their relation to subglacial volcanism, and the surveillance of areas threatened by meltwater drainage following subglacial eruptions. Verification of the results by ground truth involves the determination of geologic-hydrogeologic, geomorphologic, glaciologic and geodetic studies. The ultimate goal is the establishment of an operational long-term monitoring service in cooperation with Icelandic institutions to be employed for risk assessment, early prediction and damage mitigation.

1 Research Objectives

The methodical and application-oriented approach to finding an answer to the complex issues of effective long-term observation of geodynamic processes and the changes they produce, is a distinctive feature of the ESA Project "Monitoring of Natural Land Surface Change in Iceland Using ERS-1/ERS-2 and Other Remote Sensing Systems" (AO.2 D116, PI U. Münzer). This project was initiated in 1995 by the Institute of General and Applied Geology, Munich University, and is funded under the DLR (DARA) Project "Disaster Monitoring as Exemplified by Conditions in Iceland" (50EE9706, PI's U. Münzer, K. Weber-Diefenbach).

Participants are the National Land Survey of Iceland in cooperation with the Science and Nordic Volcanological Institute, the University of Iceland, Reykjavík, the Institute of Meteorology and Geophysics, Innsbruck University, Austria, the Institute of Geography, Nicholas Copernicus University Torun, Poland, the German Remote Sensing Data Center (DFD), DLR Oberpfaffenhofen and the Institute of Applied Geodesy, Leipzig branch, Germany.

Three test sites have been selected in South Iceland due to recent activities within the eastern volcanic zone: the central volcano Hekla (last eruption in 1991), the plateau glacier Mýrdalsjökull (last eruptions of Katla in 1918 and 1955) and the Vatnajökull ice cap (last eruption Sept. 30 to Oct. 13, 1996, see Fig. 1).

The Mýrdalsjökull and Vatnajökull sites serve to investigate the interaction of glacier dynamics and subglacial volcanism using radar data interpretation, amplitude correlation methods and differential interferometry. To achieve this end, monitoring of the central volcanoes Katla (Mýrdalsjökull) and Grímsvötn–Bárðarbunga (Vatnajökull) and their environment was required to determine changes in glacial morphology and tectonics (see Fig. 2a, 2b). Data on geothermal and subglacial volcanic activity were collected, and the study of glacier surges and their impact on the periglacial regions was

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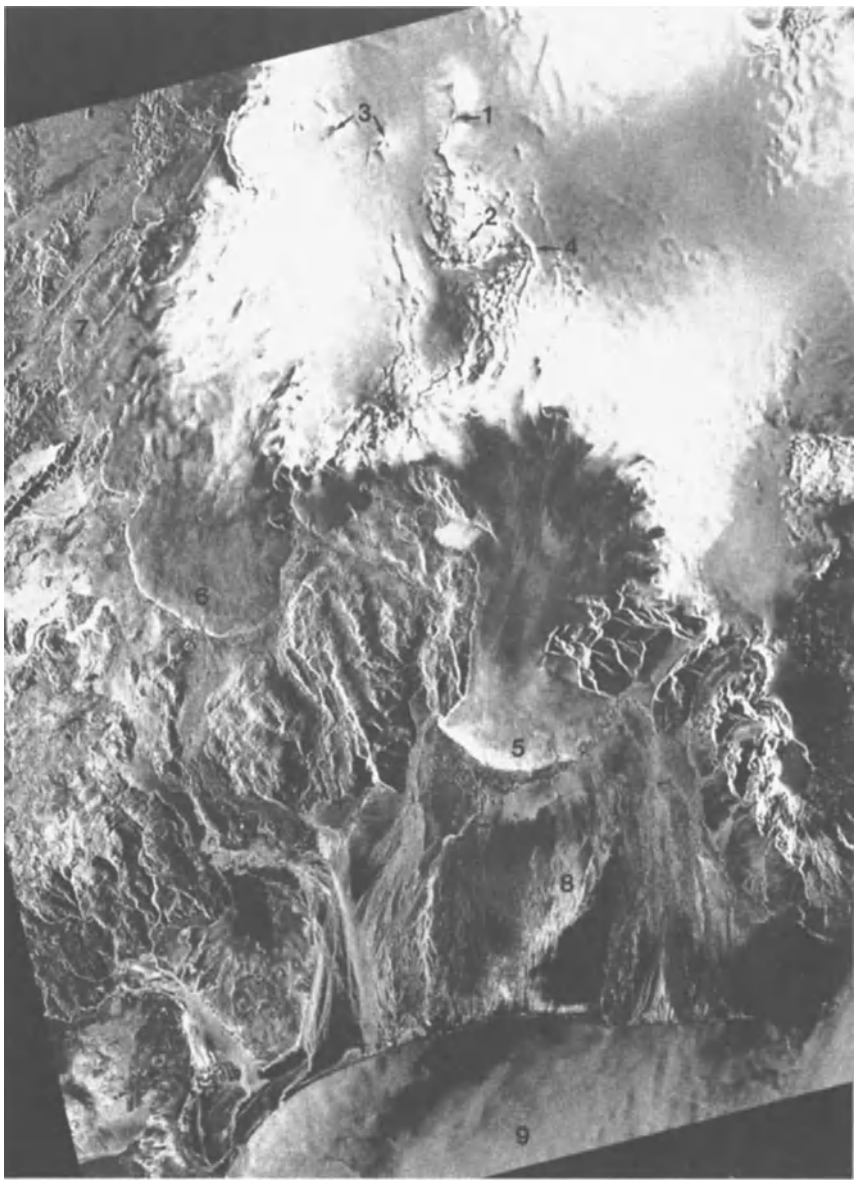


Fig. 1. ERS-2/SAR subscene of Vatnajökull, 09.10.97; area shown 107×84 km; © ESA 9, ① Eruption fissure (Oct. 1996), ② Grímsvötn-Caldera, ③ Skaftá cauldrons, ④ depression of glacial torrent (Nov. 96), ⑤–⑦ glacier tongues Skeiðarárjökull, Síuðjökull, Tungnaárjökull, ⑧ Outwash plain Skeiðarársandur, ⑨ Atlantic Ocean

carried out. SAR-derived flow features and the surface change data will be incorporated into ice dynamics models for interpretation. Finally, the potential risks caused by renewed subglacial eruptions and the resulting meltwater floodings have to be assessed (see Fig. 3).

With regard to the subaerial eruption of the central volcano Hekla differential interferometry is being applied to monitor surface deformation (uplift – subsidence) caused by volume changes in the crustal magma chamber. Deformation maps from 35 days up to annual periods with high spatial resolution are generated. The analysis of spectral surface features is combined with the analytic discrimination of volcanic lava flows and ash layers. The findings thus acquired are to be used for the prediction of future subaerial events and damage control.

2 Methods and Analyses

To achieve the intended aims, the work proceeded in two stages:

Stage 1 is a feasibility study to assess the potential of SAR techniques for long-term disaster monitoring, including field work, image processing and analysis, interferometric and amplitude correlation methods as well as GIS implementation and use.

Two digital elevation models were generated for geocoding the radar data sets, i.e. one

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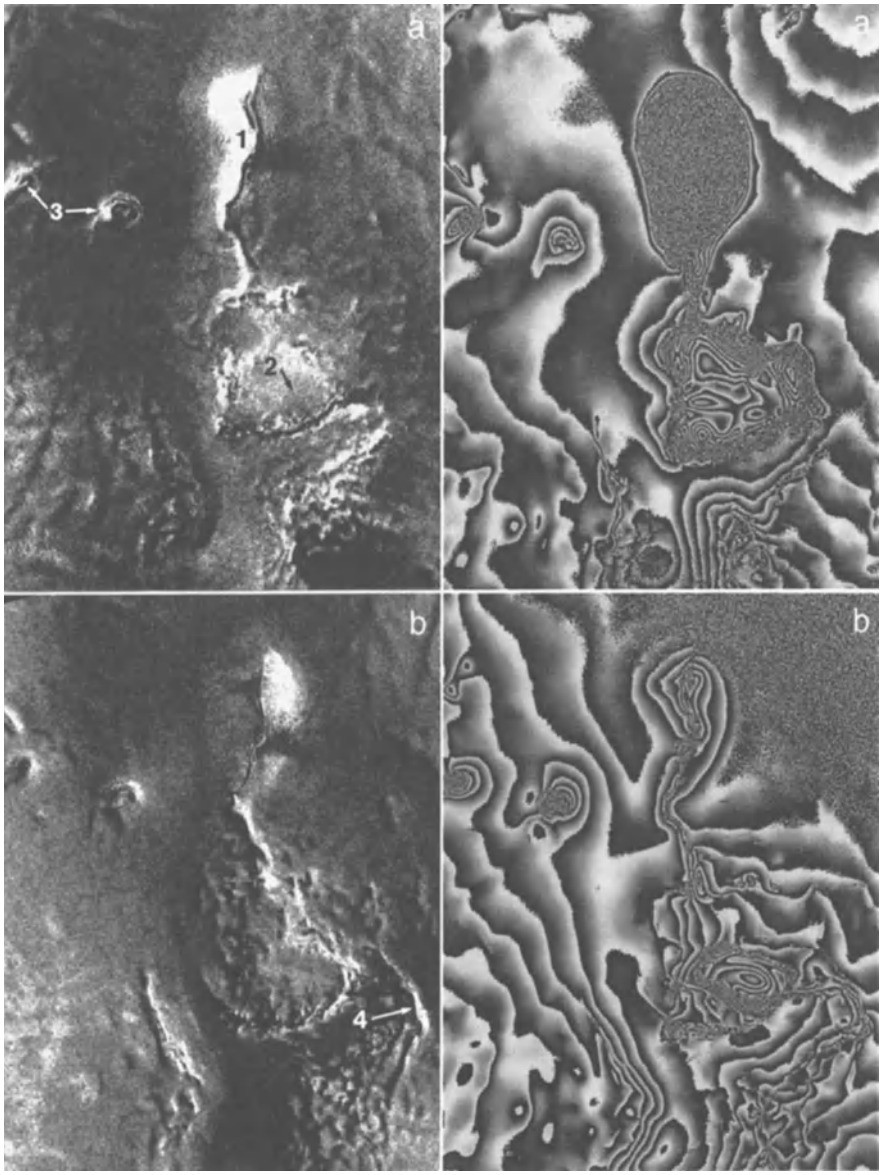


Fig. 2a. ERS-2/SAR subscene (22.10.96) of the Vatnajökull eruption site shortly after the event, and corresponding interferogram (ERS-1/2, 21.–22.10.96); area shown 28×22 km; © ESA 96, ① Eruption fissure, ② Grímsvötn-Caldera, ③ Skaftá cauldrons, ④ Depression of glacial torrent

Fig. 2b. ERS-2/SAR subscene (09.10.97) of the Vatnajökull eruption site one year later, and corresponding interferogram (ERS-1/2, 08.–09.10.97); area shown 28×22 km © ESA 97

derived from 28 topographic maps (scale 1:50000, Hekla, Mýrdalsjökull, Vatnajökull area) with 20 m contour intervals, and a second precision DEM of the 1996 Vatnajökull eruption site, based on digital photogrammetric measurements with a 2 m accuracy.

Furthermore, 30 corner reflectors installed under the AO.2 project are used to assist accurate geocoding and interferogram production. They cover the ascending and descending orbits respectively. Locations are around Hekla, Mýrdalsjökull and the western part of Vatnajökull (see Fig. 4).

Software for differential interferometry developed at the Institute of Meteorology and Geophysics, Innsbruck University, is applied to repeat-pass analyses of up to several years for long-term observation. DEM data will be used. Past experience has shown that on the Icelandic glaciers, the phase decorrelates completely within 35 days, sometimes even within one day (due to snow, meltwater etc.). Therefore, a relatively large number of ERS-1/2 SAR scenes is needed to obtain a reasonable number of coherent interferometric pairs.

A database supports the research effort, containing a large quantity of JERS-1, ERS-1/2, RADARSAT data, seismic data of quakes and tremors, random GPS measurements of crustal movement, contour lines of the test sites" subglacial relief acquired by radio echo sounding, and other source material collected during field

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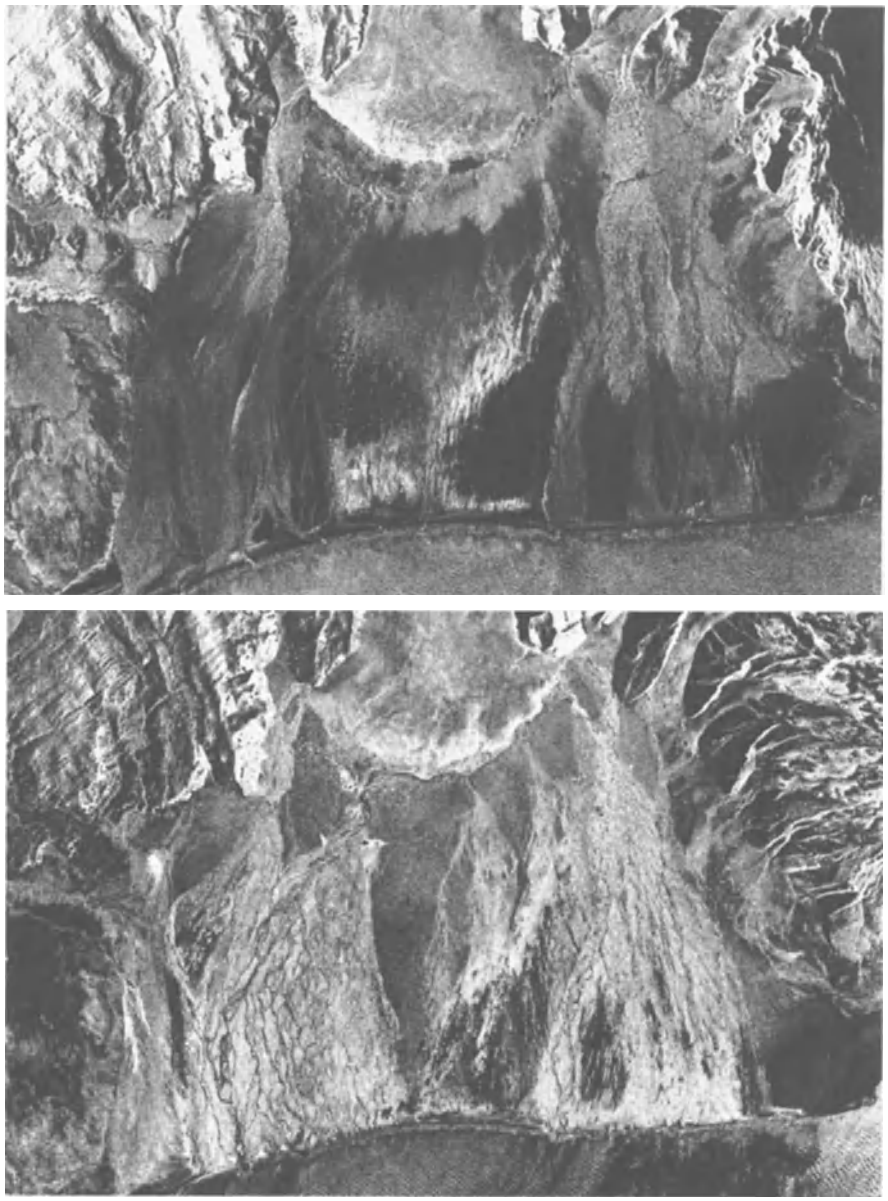


Fig. 3. ERS-2/SAR subscenes of Skeiðarárjökull and the outwash plain Skeiðarársandur; area shown 39×62 km; © ESA 96, above: acquired 24.10.96, 11 days before the glacial torrent, below: acquired 07.11.96, 2 days after the start of the glacial torrent

work from 1992 to 1998, such as geomorphological, hydrogeological, meltwater torrent, meteorological data, etc.

Stage 2 is devoted to the establishment, within the next decade of an operational long-term monitoring service in cooperation with Icelandic institutions to be employed for risk assessment, early prediction and damage mitigation.

3 Outlook

Investigations carried out in conjunction with the 1996 events have shown that dynamic processes can be quickly and accurately recorded with the help of a multitemporal and multisensoral data coverage at close intervals and the implementation of a comprehensive database. Thus, radar scenes obtained on October 1, 1996 clearly register the ongoing changes under the ice, by capturing the outline and the extent of the eruption fissure about 24 hours before the actual Vatnajökull outbreak – an important step towards early warning. Based on the generation of detailed geomorphological and hydrogeological maps and the radar data, an assessment was made of the changes in the drainage system and the coastal morphology of Skeiðarársandur caused by the glacial torrents following the eruption: the Gígjukvísl waters had shifted towards the east in combination with considerable sediment accumulation and reduction of

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Table 1. SAR data used for the monitoring of the subglacial eruption on Vatnajökull

			30.09.96
JERS-1	desc.	01.10.96	
JERS-1	desc.	02.10.96	
ERS-2	desc.	03.10.96	subglacial eruption
RADARSAT	asc.	05.10.96	Grímsvötn/Bárðarbunga
ERS-2	desc.	06.10.96	
RADARSAT	desc.	07.10.98	
ERS-2	asc.	08.10.96	
			13.10.96
ERS-1	desc.	21.10.96	
ERS-2	desc.	22.10.96	
ERS-1	asc.	23.10.96	
ERS-2	asc.	24.10.96	
			05.11.96
			glacial torrent "Jökulhlaup"
ERS-2	desc.	07.11.96	07.11.96
RADARSAT	asc.	08.11.96	
ERS-2	asc.	09.11.96	
ERS-2	desc.	10.11.96	
RADARSAT	desc.	10.11.96	
ERS-2	asc.	12.11.96	
JERS-1	desc.	13.11.96	
JERS-1	desc.	14.11.96	

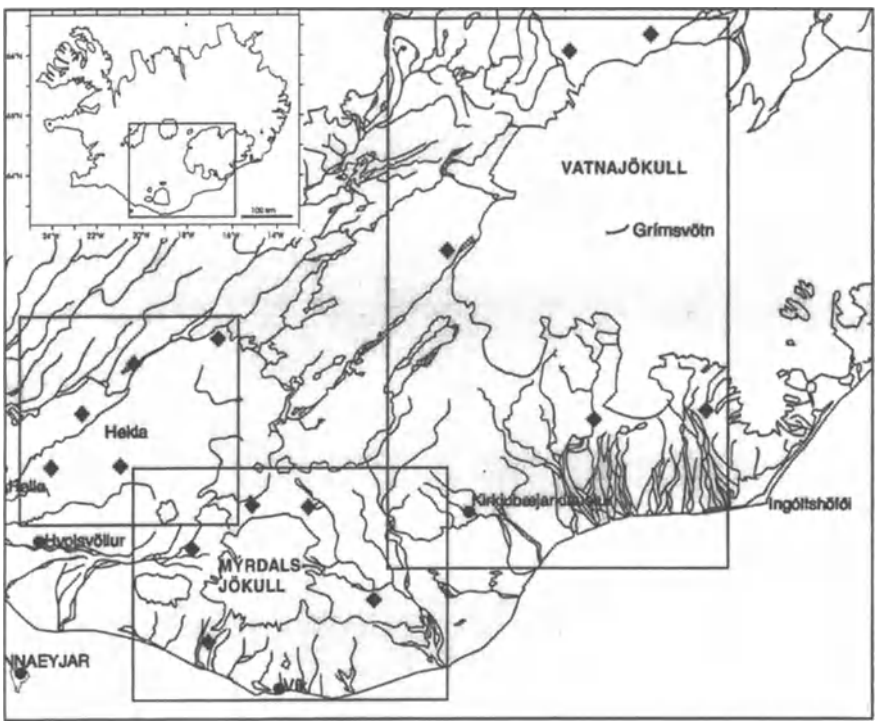


Fig. 4. Test sites Hekla, Mýrdalsjökull and Vatnajökull with location of corner reflectors (◆) (ascending and descending orbits each) © National Land Survey of Iceland, LMÍ

soil moisture content; the coastline, the size of deposits and surface erosion were redefined.

The data continuity over a period of almost 8 years, made possible by the ERS-1/2, JERS-1 and RADARSAT sensors and in the near future by ENVISAT-ASAR, provides long-term information on deformation processes. This continuity is an essential element in developing an operational monitoring system for a geologically dynamic country such as Iceland. The methods applied in this project may be used for other endangered areas as well.

Satellite remote sensing is proving to be an effective tool for risk assessment, damage miti-

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gation and even early prediction of land surface changes.

The ERS-1/2 Tandem Missions have played a very important role, especially in the field of interferometric research. Repeat performances, therefore, would be of great help.

Acknowledgements

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Information and Warnings to Authorities and to the Public About Seismic and Volcanic Hazards in Iceland

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1 The Methods of Providing Hazard Warnings and Information

Earthquake and volcanic hazards of various types can be expected over a large part of Iceland (Fig. 1). Providing information and warnings about possible seismic or volcanic hazards in Iceland is not based on rigorous rules. Rather, it is based on a common understanding, which has gradually been developed, based on experience gained over several years.

Warnings on a short-term basis for a possible impending dangerous seismic or volcanic hazard in Iceland would most probably be issued by the National Civil Defence of Iceland in consultation with a scientific observatory who would describe the possible impending event. The scientists would explain what could be expected, and provide information which would help in deciding on preventive or rescue actions. On the basis of that, the National Civil Defence could declare a state of alarm of some previously defined level. The lowest level of alarm would only be sent to civil defence committees in the communities concerned to advise them to test if they would be ready for action should dangerous event take place. If the declared event cannot be considered as imminent, rather a situation that should be watched or studied better, a meeting of a scientific advisory committee, connected to the National Civil Defence is called. During situations that are considered by the public, the authorities or the scientists as being potential forerunners of a larger event, there is quite often a direct contact between the scientific institution and the public or local authorities. Information or explanations of what is going on in the earth during such periods is considered a very significant service. This is the key to educating the public potentially confronting a natural hazard. Sometimes people sense small earthquakes or other possible forerunners of larger events. We take all such information seriously, and explain as well as we can the reason for the sensed events. In some cases we deny that these events are a part of an impending larger event. Sometimes we have to denounce widely distributed "predictions" of catastrophic events, "predictions" based on, say, dreams, or on Nostradamus. Even if such "predictions" are not taken seriously by many, they can cause widespread uneasiness.

2 Role of Institutions

The Icelandic Meteorological Office, in particular its Department of Geophysics shall, by law, monitor seismic activity and provide an information service. It has developed and built up an effective and permanent monitoring system to do so. As the seismic system and its associated alert system is the system which also most effectively monitors the volcanic activity, monitoring and alerts related to volcanic activity are a part of the duties of the Meteorological Office.

Some parts of the monitoring system are operated by other institutions in Iceland, such as the Science Institute of the University of Ice-

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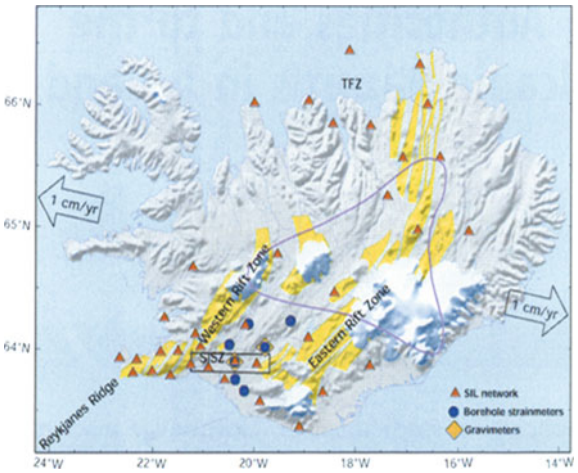


Fig. 1. Most of the earthquakes and volcanic activity in Iceland are related to the boundary between the Eurasian and American plates. The Mid-Atlantic ridge passes through Iceland from the Reykjanes ridge along the South Iceland seismic zone (SISZ), along the rift zones to the Tjörnes fracture zone (TFZ) in the north. The most destructive earthquakes occur in the transform zones, SISZ and TFZ. There has been widespread active volcanism during the last few thousands of years, mostly confined to the rift zones shown in yellow. Around 30 active volcanic systems are known, each having several volcanic craters. The outlines of the Iceland mantle plume at depth are shown in purple. The permanent geophysical monitoring network is also shown

land and the Nordic Volcanological Institute. Hazard-related monitoring of these institutions should also reach the monitoring system of the Meteorological Office. Cooperation exists between the Meteorological Office and these and other earth science institutions in Iceland regarding interpretation of the observations.

Assessment of seismic hazard as it applies to building codes and construction rules, is in fact the responsibility of the Meteorological Office, although other scientists and institutions participate in that work. Earthquake prediction research, with the objective to better inform how, where and when a dangerous earthquake might take place, is a natural and significant extension of classical hazard assessment, which is mainly based on magnitude and number of earthquakes in bulletins or historical documentation. Very significant work in this direction has been going on in Iceland, especially during the last 10 years. The most recent large-scale project is the PRENLAB project. It is a multidisciplinary project for *Earthquake-Prediction research in a Natural Laboratory* carried out by research institutions in 6 European countries. This project, supported by the Commission of the European Communities, started in 1996 and is coordinated by the Icelandic Meteorological Office. The results of such research are gradually being included in the alert system used for warning purposes and for decision making in situations of declared and ongoing hazards.

Warnings and other services related to seismic or volcanic hazard are not based on predefined algorithms, but rather on scientific interpretation. The alert system operated by the Meteorological Office is based on simple algorithms. The alerts are now primarily used for the routine day and night watch of seismic or volcanic activity. Scientists are automatically provided with reports. If they consider them appropriate, they place a closer watch on the reported activity, and may start what we call real-time research. The alert system provides alerts if certain predefined parameters of activity exceed predefined levels. Station alerts, i.e. alerts from individual stations, are received within a second after a "large phase" has been detected. Multi-station alerts, or regional alerts, are received 2–3 minutes after an event, i.e. after multi-station analysis, including information on the earthquake hypocenter and other significant source-related parameters.

3 The SIL System

The SIL seismic system is the basis for warnings and other information regarding seismic or volcanic hazard. It is a system which is currently based on 36 3-component permanent seismic stations, which are distributed, in particular, near seismic zones and the rift zones (Bodvarsson et al. 1998). This is an automatic seismic evaluation system with the aim of using microearthquakes to monitor crustal processes in real-time (Fig. 2). Examples of such applications are to detect when minifaults within the fault system and main faults are activated or become unstable, or to detect if and how stresses are building up in the system. Microearthquakes occur very frequently in the seismically active areas. To utilise information carried by these, almost continuous data is obtained in space and time.

Noteworthy significant data already provided by the SIL system in real-time includes:

- Spectral amplitudes and corner frequencies of all detected phases.

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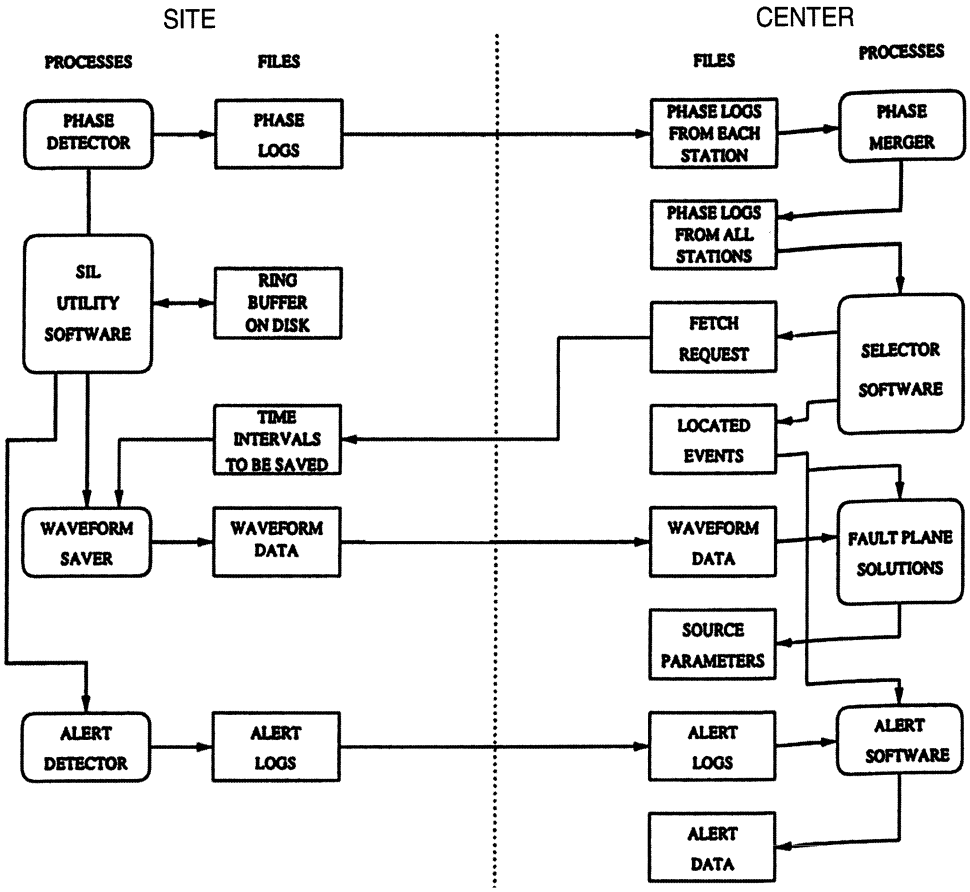


Fig. 2. Automatic analysis in the SIL seismological system. Single-station analysis performed at the site stations produce information about all incoming phases, including onset time, duration, reference to previous and following phases, signal and noise averages, maximum amplitude, type of wave (P or S), P-wave azimuth and coherency, and spectral parameters including DC-level of the phases and corner frequency. Multi-station analyses, carried out automatically at the SIL center, use phase reports from site stations and produce information about all detected events, including estimates of hypocenter, magnitudes, fault-plane solutions, peak slip, slip area and static stress (Böðvarsson et al. 1998)

- Continuous information about tremor in 3 spectral bands.
- Hypocenter locations of all identified seismic events.
- Fault plane solutions including radius of focal sphere and slip.
- Moment magnitudes and "local magnitudes".

Methods are applied in the system on a routine basis to use multi-evaluation of microearthquakes to map minifaults with a relative accuracy of 10 meters.

Orientation directions of individual fault plane solutions can also be monitored routinely, and work is under development to use multi-evaluation of these to obtain rock stresses and their changes in real-time.

Currently, the automatic information regarding onset times and direction of first motion is controlled manually, before a final daily bulletin is issued. A software package called ACIS is under development, which uses the experience of manual readings and the experience gained in multi-event analysis of similar signals to obtain an automatic bulletin in real-time which will at least be as accurate as the manual checking.

Stress-induced changes in S-wave splitting time related to stress changes in the ray path have been recognised in Iceland. Work is going on to analyse this for several ray paths, and to automise the monitoring of such changes. This opens the possibility to use the area around some seismic stations as a huge stress meter.

Automatic real-time information carried by microearthquakes about source and wave path changes is of enormous significance for alerting purposes. In this respect, it will be possible in real-time to monitor processes related to hazardous events in a way never possible be-

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fore. It is, however, no less significant for research purposes. The earthquake activity during seismic swarms and volcanic activity is so intense that, in older systems, it is usual to not even try to separate individual events, let alone to read from them high-level information about detailed crustal processes. This becomes possible using automatic evaluation, with microearthquakes giving the most detailed information on what is going on in the crust, where the faults are, and where the stress concentrations are, which will eventually contribute to the large earthquake or large eruptive process.

The SIL system, the main objective of the SIL project (1988–1995), was developed in the "Iceland Geophysical Laboratory". The SIL project was an undertaking of the Nordic countries, based on an initiative from the Council of Europe, which in a resolution in 1983 encouraged multinational cooperation in earthquake prediction research in selected test areas. The South Iceland seismic zone was among these test areas (Stefansson et al. 1993). The SIL microearthquake system and its extension to Iceland as a whole was then to become the basis for the PRENLAB project (Stefansson et al. 1998). Its main objective is to study earthquake processes. It includes microearthquake studies, geological field studies, deformation studies, borehole studies and modelling. The results of this project will gradually be applied in warnings and information activities, especially in the alert system.

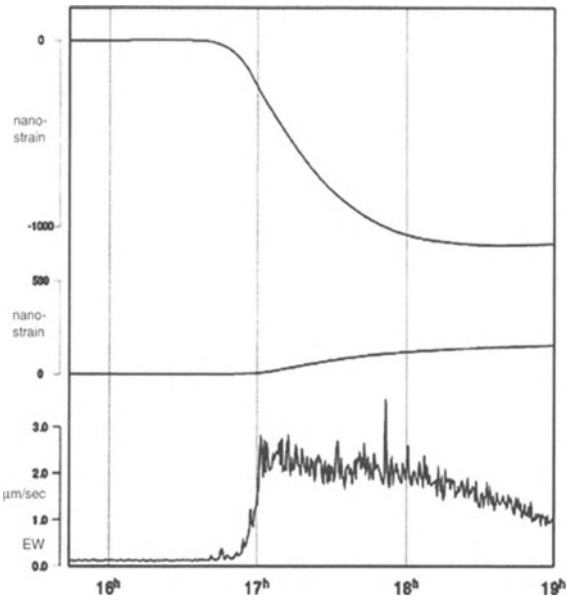


Fig. 3. An example of observed premonitory changes. A strain pulse and high-frequency noise was observed only half an hour before the start of the eruption of Mt. Hekla, South Iceland, on January 17, 1991 at 17:01 GMT. Examples are shown from two borehole volumetric strainmeter stations at 15 and 35 km distance from the volcano. At the bottom, there is a noise average of the EW component of a SIL station at 35 km distance. The largest earthquakes preceding the eruption were only around 1.5 in magnitude (Stefansson et al. 1993)

4 Other Monitoring Systems

Other systems operating in Iceland which are of great significance for warnings are:

- The highland seismic system which provides, via radio transmission, information regarding changes in seismic activity near the seismic stations at particular significant points in the highlands of Iceland. It does not give as much information as the SIL system. It still, however, complements the SIL system, being cheaper in remote operation.
- Borehole volumetric strainmeters in the South Iceland Lowland, installed in 1979, have provided significant information related to earthquakes and eruptions (Agustsson et al. 1998; Stefansson et al. 1993). They have shown precursors to both (Fig. 3).
- Other continuous monitoring on a permanent basis is carried out by gravimeters at two sites. Monitoring of hydrological changes are in a initial testphase, as well as continuous monitoring by GPS, and of changes in electrical conductivity by the MT-method. Regular radon monitoring is in preparation at some sites.
- Repeated measurements by SAR, GPS and of gases are being carried out, and are of a great significance for the necessary warning-related research.

5 The Alert System

An alert system has been in operation since 1992. It is primarily based on the SIL system information and evaluations. Gradually, the algorithms of the alert system are being enhanced by new well-established monitoring, and new understanding in evaluating measured earth processes. The alerts, as previously mentioned, are either station alerts, provided within

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Fig. 4. An alert system to provide station alerts and regional alerts. The objective of the alert system is to notify scientists of changes in a priori defined parameters of seismic activity. Regional alerts related to 29 alert regions of Iceland are provided in a few minutes after an event. Station alerts are released in a couple of seconds. The alerts are based on various parameters, i.e. size of amplitudes, directivity of signals, magnitudes, increase in the rate of strain release, or number of events. The alerts are based on information and are gradually enhanced, as a result of experience and research

seconds, or regional alerts based on multi-station evaluation which become active in 2–3 minutes. The country is divided into 20 alert regions, and several kinds and several types of alerts and alert levels are issued for each region (Fig. 4). The 24-hour watch at the Icelandic Meteorological Office is utilised for first overview of the alerts, if they reach high enough levels, to determine whether it is necessary to contact the scientists. The scientists do their evaluation, and then begin a kind of real-time research, in an attempt to understand what is going on, and to decide on actions to be taken.

6 Types of Warnings and Hazard Information

Warnings for expected earthquake or volcanic activity in Iceland are not based on algorithms, which automatically state that a certain type of hazard is impending. Such warnings are based on scientific evaluation and real-time research of a scientist, or a group of scientists. The only warning algorithms applied thus far in real-time are the simple algorithms of the alert system which inform the scientists that a closer look might be necessary.

As an example, Figure 5 describes briefly the warnings and information services related to an earthquake episode. The episode occurred in the Hengill area, 25 km east of Reykjavík, and 5 km west of the town Hvera-gerði.

Warnings and information that were given were very vague, and they did not include a number estimation to indicate the probability of the hazard occurring. However, these warnings and information have been useful.

We cannot state that predictions of future volcanic eruptions and earthquakes will be possible. The only thing that we can state is that better understanding of crustal processes will gradually increase our changes of providing useful information on a short- or long-term basis regarding where, how and when a dangerous hazard will occur.

Based on experience over several years, we consider it likely that we will be able to issue useful information and warnings on the following types of impending hazard at several places that could be hit, or that preparatory work is underway to enable us to do so:

- Short-term warning about impending eruptions. Useful for air traffic and for escaping some of the dangerous effects of floods and

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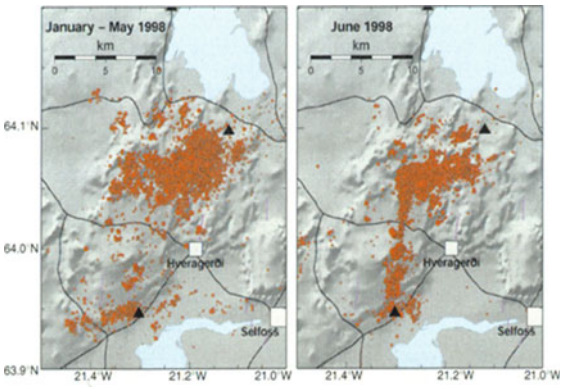


Fig. 5. In the summer of 1994, high seismic activity began in the Hengill area, SW-Iceland. The map on the left shows origins of small earthquakes during January–May 1998. From 1994 to May 1998 the activity was mostly concentrated in the area north of Hveragerði. During the evening of June 4, 1998, and the early hours of June 5, the area to the south of Hengill was broken through and a sequence of earthquakes reaching magnitude 5.1 were released on a narrow, 10 km-long line, as shown on the map to the right. Already in 1994 it was stated, on various grounds, that it was probable that this earthquake sequence would last for a few years, and that it might end with an earthquake of magnitude 5.5 on a line towards the south of Hengill, similar to what actually happened on June 4. How, exactly, this would occur was not clear. The possibility that the activity might be a forerunner to an eruption in the area was also considered. The main threat considered was that if a magnitude 5.5 earthquake might break through the town of Hveragerði or its close vicinity, it might cause abrupt and dangerous changes in the fumarolic activity inside the town. An information link was created between the community, the civil defence committee of the town, and the Meteorological Office to follow the development of events. The activity after 1994 was variable, strongly felt earthquakes occurred frequently. The activity culminated during the evening of June 4, with maximum earthquake magnitude of 5.1. It could be seen in real-time how small earthquakes migrated towards the south, and after the magnitude 5.1 earthquake a special warning was issued that a magnitude 6 earthquake might be expected. This lead to additional preparations by the National Civil Defence, as a magnitude 6 earthquake could be dangerous. Ten hours later, this preparation stage was lifted, after declarations from scientists that the danger of such an earthquake was over. It was considered that most of the moment that could release a magnitude 6 earthquake on the fault had already been released in small earthquakes

ash flows expected to accompany some eruptions. This would also be significant for instigating preparations in the case of possible impending lava flows.

- Increased probability of large earthquakes in some of the seismic areas. Foreshocks have been observed before several large and intermediate earthquakes in Iceland. It is hoped that modern real-time monitoring and evaluation will create information on which we can base earthquake warnings, useful for undertaking various preventive measures.
- It has been observed several times that intense swarm activity lasting weeks to years results in a large earthquake. It has been shown that it is possible to provide useful information and warnings related to such activity, and further evaluations and research will make this even more probable.
- According to history large earthquakes in the South Iceland seismic zone are often followed by other large earthquakes in this area. Even if it is not possible to issue a warning for the first large event, it is possible that the place and the size of the following large earthquake and its general time can be predicted, especially if the real-time evaluation of our seismic system does not collapse during the first large earthquake. We are, based on experience, doing much to secure the operations of our observational systems in such cases.

Acknowledgements

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The Merapi-Project – Interdisciplinary Monitoring of a High-Risk Volcano as a Basis for an Early Warning System

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Abstract

Merapi volcano in Central Java is one of the most active volcanoes in the world. Located at the eruption zone between the Eurasian and the Indo-Australian Plate, Merapi shows andesitic character, which is currently demonstrated by active dome formation, accompanying dome-avalanches and pyroclastic flows up to distances of 2 to 8 km. This type of volcanism exhibits a high degree of explosivity. Even small volcanic events are a permanent danger to life within the densely populated area at the flanks of the volcano. A large eruption like >6000 years ago would immediately endanger more than one million of inhabitants in the region around Yogyakarta, about 35 km from the summit. Due to this reason Merapi has been classified as a high-risk volcano and included into the list of 16 Decade Volcanoes by IAVCEI.

In co-operation with the Volcanological Survey of Indonesia and other institutions in Indonesia and Germany, the GeoForschungsZentrum initiated an interdisciplinary monitoring program in 1994, supplementing a number of ongoing national and international activities on this volcano. The so-called MERAPI project (*M*echanism *E*valuation, *R*isk *A*ssessment, *P*rediction *I*mprovement) is supposed to contribute to the development of prediction and warning strategies on different time scales, including intermediate and short-term prediction of volcanic events as well as early warning at different stages of the volcano's activity. Investigations of the internal structure of the edifice, of the magmatism and of the explosive history of the volcano form the basis for a better understanding of the complex processes prior to an eruption and, thus, for the improvement of hazard assessment as well as for improved warning capabilities.

Special emphasis has been put on continuously monitoring the most important activity indicators of the volcano such as seismicity, deformation and gas emanation. Directional microphones are expected to facilitate a discrimination between shallow volcanic earthquakes and rock avalanches, which would be of basic importance for an automatically working early warning system. All the data is transmitted by radio to the office of the Volcanological Technology Research Centre (BPPTK) in Yogyakarta. Following the last catastrophic eruption in November 1994 (66 fatalities), the BPPTK has considerably improved the infrastructure for information and protection of inhabitants. It is planned to install a central online data bank at BPPTK that incorporates any volcanological data including the results from all national and international groups working at Merapi.

1 Merapi Volcano

Merapi Volcano in Central Java belongs to the most active volcanoes in the world. Located at the subduction zone between the Eurasian and the Indo-Australian Plate (Fig. 1), the dominant magmatic mechanism of Merapi is andesitic, i.e. explosive. Large eruptions, usually classified by a volcanic eruption index (VEI) of 3, occur every 30 years. The largest event in historical times was a VEI = 4 eruption in 1872. Pyroclastic flows with a length between 2 km and 8 km

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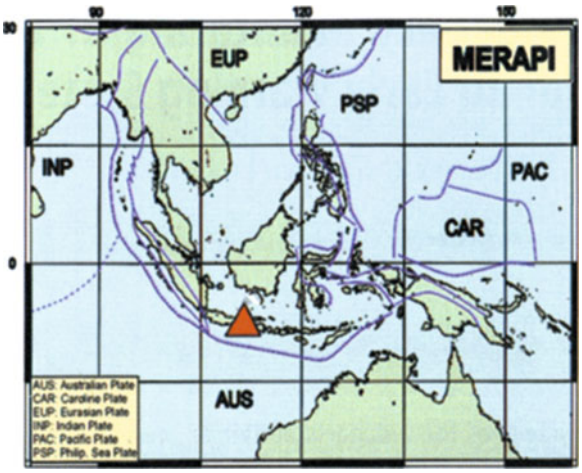


Fig. 1. Location of Merapi Volcano and sketch of the Southeast-Asian tectonics

occur about once per year. Even small volcanic events are a permanent danger to life and limb within the densely populated area at the flanks of the volcano. A paroxysmal eruption like in 1006[1] would immediately endanger more than one million of inhabitants in the region around Yogyakarta, about 35 km south of the summit. Another potential danger are mudflows (*Lahars*) that occur during the rainy season and may reach distances of up to 20 km. Due to these reasons Merapi has been classified as a high-risk volcano and was included into the list of 16 Decade Volcanoes by the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI).

Despite its permanent activity, documented by a continuous series of small and intermediate eruptions, Merapi's lava dome was effectively increasing during the past 60 years. Presently, it has reached a critical height (Bahagiarti and Sayudi, 1995). The current state of instability is indicated by an increasing number of eruptions of 'Merapi-type', consisting of block-and-ash flows, hot ash clouds and surges that are triggered by a gravitational collaps of part of the dome. Five of these pyroclastic events occurred between November 1994 and January 1997, about one eruption every five months. They were followed by an explosive event on January 17, 1997, demonstrating that different mechanism are operating at Merapi.

After the explosion the dome was growing towards the northern part of the summit where it was supported by massive lava rims of a predecessor of Merapi that surrounds the active dome like a collar from the East to the North-West (Fig. 2). The phase of apparently decreased activity was terminated when the western part of the lava rim collapsed, followed by two Merapi-type eruptions on July 11 and July 19, 1998. In contrast to the time before, when the preferred direction was towards the South, the recent pyroclastic flows were directed towards the West, actually endangering two monitoring clusters at the western flank and one observation post of the Volcanological Survey of Indonesia (VSI) (see Fig. 3). The rapid and unexpected change of the hazard situation puts serious problems especially on continuously monitoring experiments at Merapi.

2 Research and Monitoring Activities

Since more than 60 years Merapi's state of activity is observed systematically. During the 30ies the Dutch colonial government established five observation posts around Merapi at an elevation of about 1200 m, equipped with seismographs and meteorological sensors. From here, observers monitored Merapi's activity visually and acoustically, a procedure that is kept until nowadays. Hartmann (1935) and Van Bemmelen (1949) comprehensively described and classified Merapi's magmatism, eruption mechanism and -history. International cooperation featured a considerable enhancement of the observation capabilities at the beginning of the 80ies. In 1984, a 3-station telemetered seismic array, operated by the Gadjah-Mada University, Yogyakarta, was installed in the frame of the Bilateral Cooperation in Physical Volcanology between Indonesia and Germany (Schick and Mugiono, 1991). Two years earlier, the VSI started to set up a telemetered seismic network consisting of 8 analog recording stations in the frame of an Indonesian-French Cooperation on Volcanology (Purbawinata et al., 1997). French researchers also installed a magnetic network around Merapi in 1977 and started to investigate the composition of fumarolic gases. In the following years, scientists from USA and Japan joined the international research efforts employing deformation experi-

[1] Recently, this eruption has been backdated by more than 6000 years due to C^{14}-investigations (see Gertisser et al., 1998

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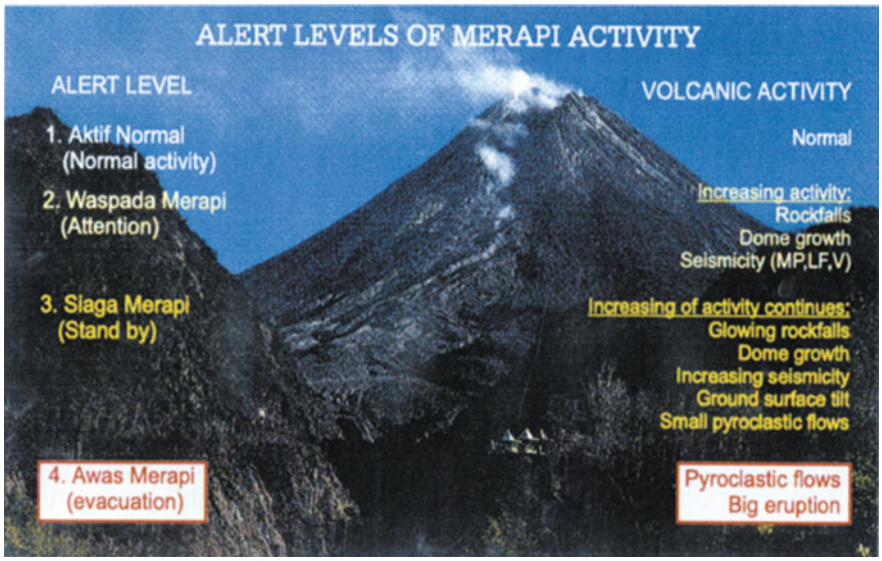


Fig. 2. The 2961 m high Merapi from the South. The lava dome forms a rounded hilltop on the southern edge of the summit. Clearly visible is the massive crater rim of a Merapi predecessor in the East. The presently operative 4-level alert system classifies Merapi's activity and provides information flow towards the local authorities

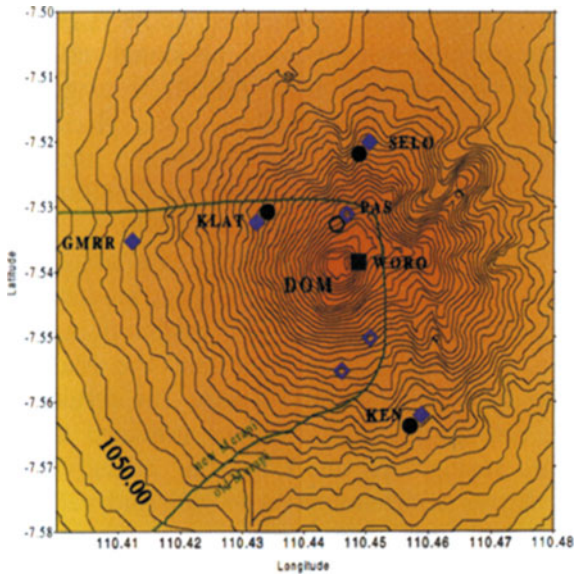


Fig. 3. Location map of the monitoring stations of project MERAPI. *Circles*: seismic broadband stations incl. shortperiod arrays; *Rhombs*: deformation and meteorology; *Rectangle*: gas chromatography. *Open symbols* denote possible locations for future or rescued stations

ments and Lahar sensors. Their main interest was directed towards the active dome of Merapi.

In co-operation with the VSI and other institutions in Indonesia and Germany, the GFZ-Potsdam initiated an interdisciplinary monitoring program in 1994, supplementing the ongoing national and international activities on this volcano. Since March 1997, this research initiative is also supported by the German Research Foundation (DFG). Aims of the *MERAPI* project (*M*echanism *E*valuation, *R*isk *A*ssessment, *P*rediction *I*mprovement) are (i) an increase of our knowledge on volcanic mechanisms and processes, (ii) a contribution to hazard assessment and (iii) an improvement of prediction capabilities. A dense network of *monitoring clusters* is designed to continuously monitor any relevant parameters such as seismic signals, temperature and composition of volcanic gases, deformation of the edifice, magnetic and geoelectric fields, and meteorological observables. Complementing the efforts of the international working groups, also the flanks of Merapi are included into the observational network (Fig. 3). The continuously recorded data are used for

- Classification
- Localisation
- Source modelling

of volcanic activity parameters and, thus, contribute to an improved insight into the internal processes. Figure 4 gives an impression of the variety of seismic signals recorded at Merapi volcano. With the installation of sensitive broad band stations, combined with arrays of short period instruments the number of recorded seismogramms was considerably increased. Development and employment of algorithms for an automatic discrimination and classification of seismic events is of crucial importance for a fast and comprehensive understanding of Merapi's seismic activity and energy release. A precise localisation of the hypocenters as a basis for a modelling of the seismicity generating processes is done by means of the small scale

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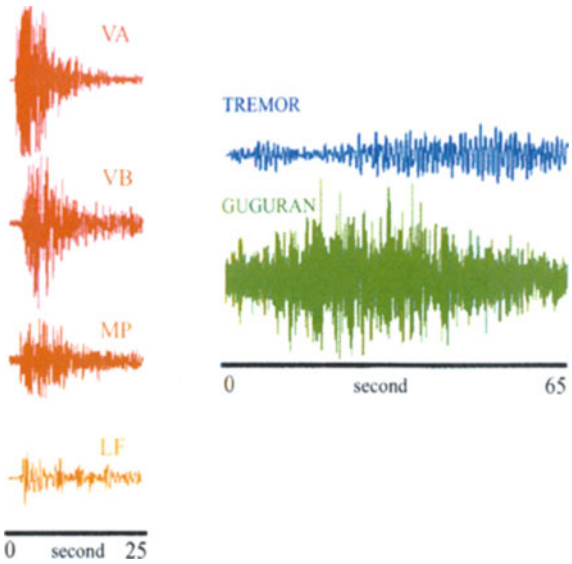


Fig. 4. Classification of Merapi's seismic events (taken from Purbawinata et al., 1997). *VA, VB*: volcanic eqs., *MP*: multiphase eqs., *LF*: low frequency eqs., *Guguran*: rockfall

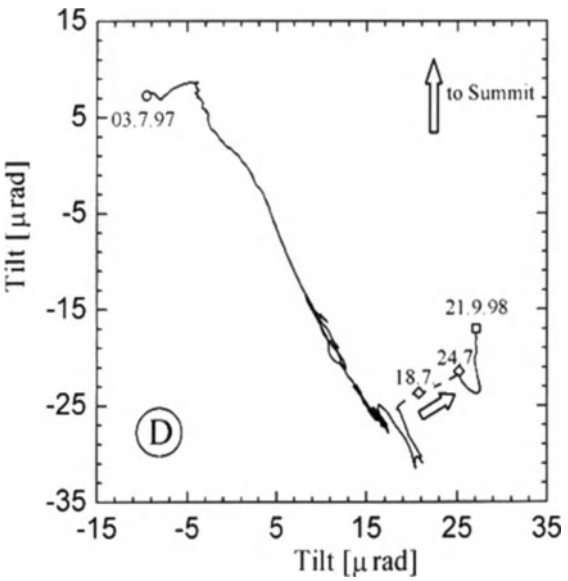


Fig. 5. Hodograph of tiltmeter no. 1 at Gemer, showing a significant step during the eruptions of July 11 and 19, 1998

seismograph arrays (Wassermann et al., 1998). A non-seismic example for the above scheme is the discrimination of environmentally and volcanically induced tilt anomalies and the localisation and modelling of the pressure- or loading source for co-eruptive tilt steps as observed during the eruptions of July 11 and 19, 1998 (Fig. 5). An important innovation of volcano monitoring tools is a continuously operating gas chromatograph. The monitoring of various fumarolic gas components revealed a five-hours periodicity of degassing that is observed at Merapi for the first time (Zimmer et al., 1998).

An important requirement for the interpretation of volcanic activity parameters is the knowledge of the *internal structure* of the edifice. This is achieved by seismic- and geo-electric tomography, electromagnetic and magnetotelluric investigations as well as a precise determination of hypocenters and localisation of tremor sources. During their first campaigns the structure related experiments concentrated on the north-western flank of the volcano's edifice. Two-dimensional inversion of the geoelectric data reveals low resistivity values below a depth of 500 m, which are tentatively explained by a transition zone of Merapi's hydrothermal system (Friedel et al., 1998). The model is essentially corroborated by one-dimensional resistivity models derived from the electromagnetic (LOTEM) and magnetotelluric data, placing a conductive layer in a depth between 1 km and 3 km below the observing station (Hoffmann-Rothe et al., 1998; Mueller et al., 1998).

The geophysical experiments are accompanied and completed by geological studies including investigations of *the magmatic evolution, magma fragmentation* and the *eruptive mechanisms* of Merapi Volcano. The results of the first geological campaigns provided a detailed stratigraphy and C^{14}-dating of the volcanic layers (Gertisser et al., 1998) and verified the significantly increased surge energy released from block-and-ash flows triggered by terrain steps (Fig. 6, see also Schwarzkopf et al., 1998).

Based on an improved understanding of the volcano's history and the complex internal processes prior to eruptions, project *MERAPI* is supposed to contribute to the development of prediction and warning strategies on different time scales, including intermediate and short term prediction of volcanic events as well as early warning at different stages of the volcano's activity. Presently, a system of 4 alert levels exists (Fig. 2), classifying the state of Merapi's activity and providing information flow to the local government. The alert levels are connected with clearly defined instructions. *Awas Merapi* (level 4), for example, automatically results in closing off and evacuation of endangered areas. The system relies on rockfall activ-

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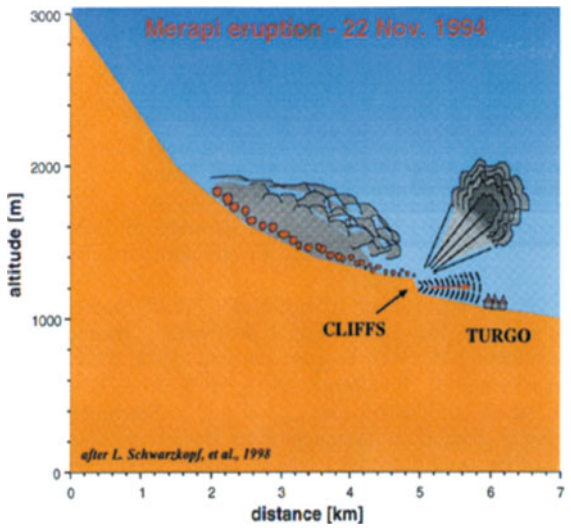


Fig. 6. Reaction of the block-and-ash flow of Nov. 4, 1994, to sudden changes in topography (after Schwarzkopf et al., 1998)

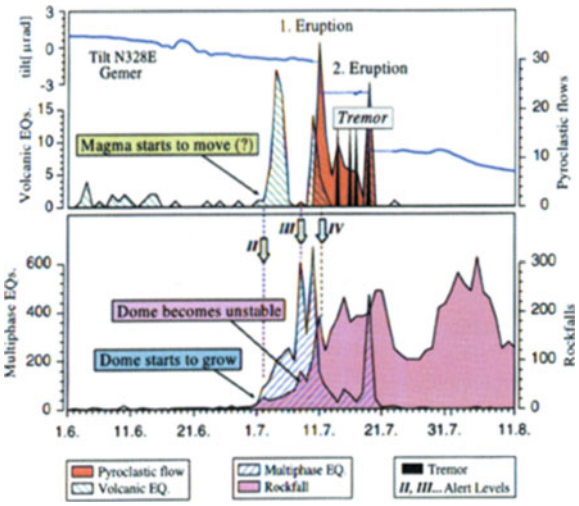


Fig. 7. Chronology of Merapi's activity and alert level determination during the eruptive phase in July 1998

ity, seismicity, and tilt and strain measurements near to the active lava dome. A significant increase of volcanic activity prior to the recent eruption in July 1998 led to a twofold raising of the alert levels from I to II on July 2 and from II to III on July 8, respectively (Fig. 7). A shortcoming of the existing alert system became visible when stage IV was declared just after the onset of the first pyroclastic flows. Inclusion of a more representative set of volcanic activity parameters and a better knowledge of the internal volcanic processes, which is the main aim of project *MERAPI*, is supposed to lead to an improvement of this situation.

3 Partner Institutions

The project *MERAPI* is based on a contract between the GeoForschungsZentrum Potsdam (GFZ), Potsdam, and the Volcanological Survey of Indonesia (VSI), Bandung. Further participants come from the following institutions in Indonesia and Germany:

Indonesia

- Volcanological Technology Research Centre (BPPTK), Yogyakarta
- Gadjah-Mada University (UGM), Yogyakarta
- Department of Geodetic Engineering, Institute of Technology, Bandung
- Geological Research and Development Centre, Bandung
- Geotechnology (LIPI), Bandung

Germany

- Bayrisches Geoinstitut, Uni. Bayreuth
- Geologisches Institut, Uni. Bonn
- Institut für Physikalische Geodäsie, TH Darmstadt
- Institut für Mineralogie und Geochemie, Uni. Freiburg
- Institut für Geowissenschaften, Uni. Jena
- Kernforschungsanstalt Jülich
- Institut für Geophysik, Uni. Kiel
- GEOMAR Forschungszentrum für Marine Geowissenschaften, Kiel
- Institut für Geophysik und Meteorologie, Uni. Köln
- Institut für Geophysik und Geologie, Uni. Leipzig
- Institut für Allgemeine und Angewandte Geophysik, Uni. Potsdam
- Institut für Geographie und Geoökologie, Uni. Potsdam

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Vc Early Warning Systems for Tsunami

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CHAPTER 5.20

Early Warning Systems for Tsunami – an Overview

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The convenor delivered an invited lecture on "The Development of a Tsunami Early Warning System in the Pacific" during the morning session on Theme 2, "Early Warning Systems for the Mitigation of Geological Hazards." This lecture described the evolution of the International Tsunami Warning System in the Pacific (ITSU), which was established 30 years ago, and its operations center, the Pacific Tsunami Warning Center, which was established in August 1948. The convenor also described those factors in tsunami understanding that made possible the establishment of a warning system that could deliver an "early" warning for tsunamis of distant origin. The convenor ended his presentation by pointing out that since the establishment of ITSU there has been no tsunami that has been significantly destructive Pacific-wide, and he made a plea for continued efforts in the establishment of regional systems that are the real Tsunami Early Warning Systems. This set the stage for the afternoon session.

During the afternoon session, five papers were presented that reported on various aspects of tsunami early warning systems established or under development in North, Central, and South America, and in Asia and Europe. The opening paper of the session, delivered by Eddie Bernard of the NOAA Pacific Marine Environmental Laboratory, described the three elements of a U.S. national tsunami initiative. He felt that methodologies for the elements of tsunami preparedness and mitigation were reasonably established and he presented examples of mapping and educational projects to illustrate this point. He believed that more work is necessary to define a reasonable methodology for the regional warning element. He proposed four goals for such a system, namely, a 2 to 5 minute warning, confidence in reliability, low cost implementation, and acceptance of a certain level of false alarms. He also expanded his presentation to include a discussion on the more general need for regional tsunami early warning systems to take advantage of the rapidly expanding variety of ways becoming available for the exchange of information. They should be seeking out those methods that can help them perform their early warning mission more efficiently and economically.

The second paper by Keiji Doi of the Japan Meteorological Agency described the present structure of the tsunami warning system in Japan. The system consists of six subregional centers each with a network of real-time seismic and tide stations. Each subregion is equipped with a standardized processing system, ETOS, that gives these subregions the capability to issue either warning or advisory messages within 3 minutes after the earthquake origin time. The appropriate message is based on an empirically derived relationship between earthquake location and magnitude. Work is currently underway to develop a data base of modeling information that will supplant the empirical procedure. It is believed that this approach will let the JMA define smaller evacuation areas, and thus impact a much smaller portion of its population should a warning turn out to be unnecessary.

Dante Gutierrez of the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA) described the tsunami warning system of Chile. Within the last few years SHOA has had installed a single station earthquake location and moment magnitude system know as TREMORS. This system gives SHOA the capability to independently determine local earthquake parameters without having to rely on external sources, which nevertheless remain as a back up. SHOA issues its warnings to the various naval installations on its coast and to ONEMI, the national civilian protection agency.

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In addition, SHOA has undertaken the task of preparing tsunami inundation maps of the major port cities on the coast for use in tsunami hazard planning by the ONEMI. SHOA is using the TIME technology developed by Tohoku University of Japan for this project.

The next paper by Gerassimos Papadopoulos of the Institute of Geodynamics of the National Observatory of Athens described a prototype rapid response tsunami warning system that is being developed for the Kythira Strait region in the southwest Aegean Sea. This region was chosen because of its past history of being a source area for large destructive tsunamis. The system will consist of a network of seismic stations plus two tide stations whose data will be telemetered in real time to the Institute in Athens. The system will investigate the response times involved in locating earthquakes in the study region as well as the time involved in setting up to disseminate an appropriate tsunami message. Operation of the system, including data collection and processing, will be conducted on a 24-hour basis by the Institute of Geodynamics in Athens.

The final paper of the session was given by Wilfried Strauch of the Nicaraguan Institute of Territorial Studies (INETER). In this paper Strauch described the situation in Nicaragua at the time of the 1992 Nicaraguan earthquake and tsunami that took about 200 lives on the country's Pacific coast. Only one or two seismic stations were running and there was no rapid response system in place to process earthquakes. Since those days a 20 station seismic network has been installed to monitor seismic activity on a 24-hour basis for both tsunami and volcanic hazard mitigation. Lines of communication between INETER and the National Civil Defense Agency have been established, and that Agency is, in turn, establishing radio links to coastal population centers for the purpose of transmitting tsunami alerts. INETER will be installing 6 digital water level stations this year, 3 on the Pacific coast and 3 on the Caribbean coast, to complete the Nicaragua Tsunami Warning System.

Following the session the convenor and the speakers met briefly to consider lessons learned from the exchange at this meeting. All were in agreement that regional centers were really the only way to provide early warnings for tsunamis. They endorsed the idea that there is also a need to exchange information rapidly with other tsunami warning centers nearby so that tsunamis source between centers could be dealt with in a timely fashion sufficient to provide early warning. There was also a consensus that dialogue, not just one-way communication, needs to exist between the regional center and the ITSU operations center. In this way the PTWC can provide better information in a more timely manner to all participants in ITSU. Finally, the session participants agreed that it was worthwhile to explore recent innovations in communications methodologies and technologies that may be applicable to improving transmission and exchange of the data ultimately used to issue tsunami warnings. Communications could be those within a region, between regions, or between the regions and the ITSU operations center.

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Tsunami Warning System in Japan

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1 Introduction

Japan is situated in one of the most tectonically active areas in the world, where the Pacific and Philippine Sea Plates are subducting the Eurasian Plate and thus stress and strain of the crust are accumulated (Fig. 1). This occurrence causes a lot of earthquakes, tsunamis and volcanic eruptions striking towns, cities, and coastal areas sometimes followed by destructive disasters. Therefore, efforts for the prevention and mitigation of disasters caused by such phenomena have been continued as one of the most important national programs in Japan (Fig. 2).

The Japan Meteorological Agency (JMA) is the unique agency in the Government of Japan which is responsible for tsunami forecasts (warnings/advisories), the short-term prediction of a large-scale earthquake, and the information services for earthquakes, tsunamis and volcanic activities. Such information as well as tsunami forecasts are issued immediately after the occurrence of earthquakes or volcanic eruptions, and used as a trigger for emergency response taken by related organisations of the national government, polices, fire departments, and municipalities. They are also disseminated to residents through municipalities and the mass-media. To accomplish the above-mentioned responsibility of JMA, maintenance and operation of nation-wide seismological and volcanological observation networks as well as cooperation with related national and international organs and universities has been cultivated.

2 History of Tsunami Warning and Information Service

A tsunami-forecast service first began in Japan in 1941 by JMA for Sanriku coast of Tohoku region, taking into account experience of the casualties and damage caused by the Sanriku Great Tsunami in 1933. In 1952, JMA broadened the forecast area to the whole coastline of Japan for tsunamis generated near the Japan Archipelago. After the Great Chilean Tsunami in 1960, which brought extensive damage to Japan, the service has been extended since 1962 to tsunamis in the Pacific Ocean caused by distant earthquakes. This service cannot be achieved without close cooperation with the Pa-

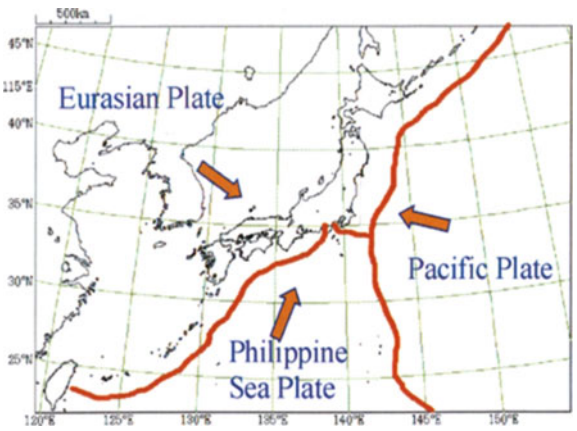


Fig. 1. Tectonics around Japan

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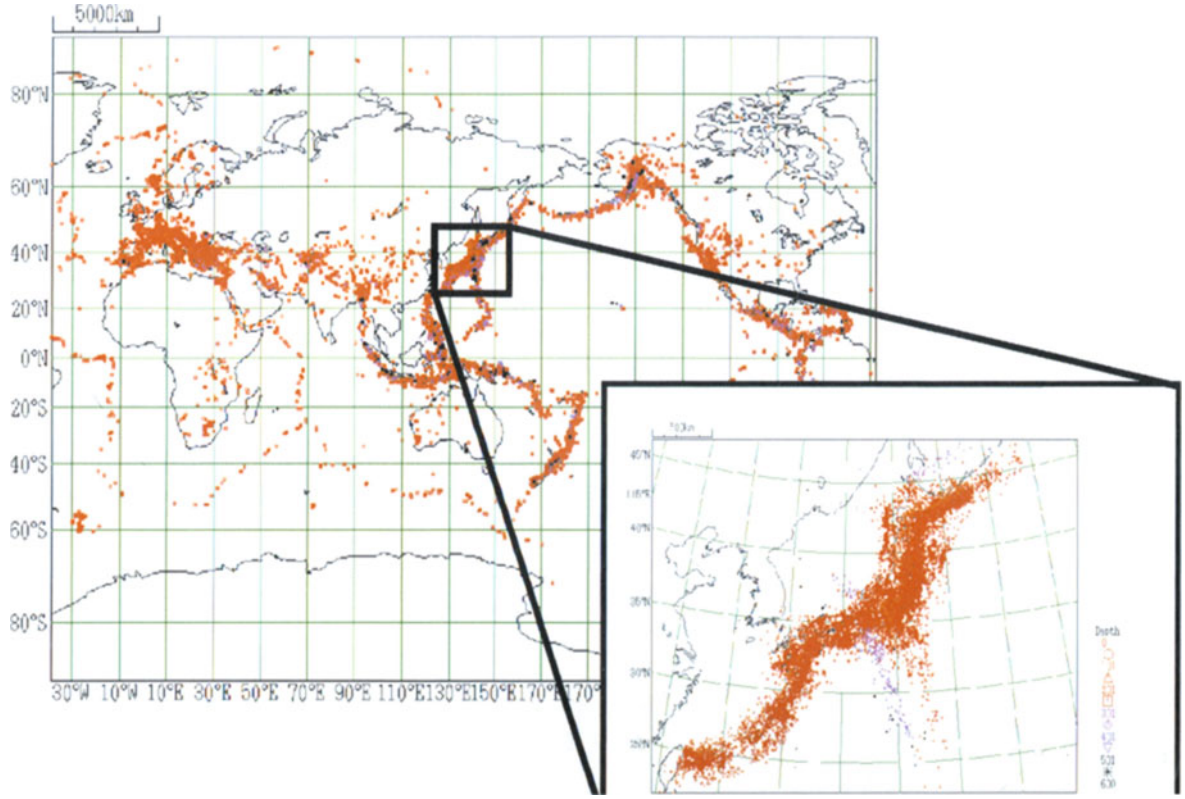


Fig. 2. Seismicity of the world and Japan, using bulletins of JMA and International Seismological Center (ISC)

cific Tsunami Warning Center, Hawaii, the United States of America under cooperation among member states of the International Coordination Group for the Tsunami Warning System in the Pacific.

In 1993, JMA renewed its earthquake monitoring network and its processing system to provide tsunami forecasts in 3 minutes after an earthquake occurrence in view of the experience gained from the Southwest off Hokkaido Earthquake Tsunami in 1993 (Okushiri Tsunami), which struck Okushiri Island only 5 minutes after the actual occurrence of the earthquake.

3 Overview of the Present Tsunami Forecast Procedure

The JMA has six Regional Tsunami Warning Centres (RTWCs), Sapporo, Sendai, Osaka, Fukuoka and Okinawa District Meteorological Observatory with its Headquarters at Tokyo. A Japanese coastline was also divided into eighteen tsunami-forecast regions as of September 1998. Each of these RTWCs is responsible for issuing

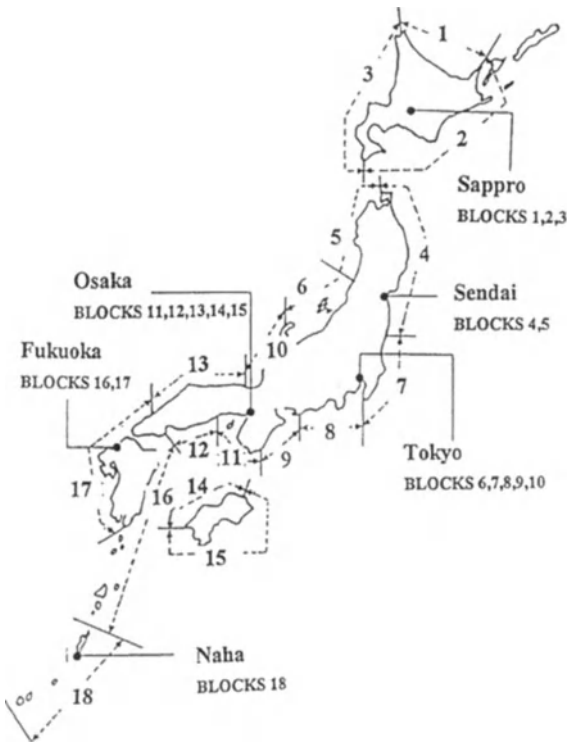


Fig. 3. Tsunami Forecast Areas in Japan (As of September 1998). Six Regional Tsunami Warning Centers (RTWCs) and eighteen areas for tsunami forecasts are shown. The block numbers attached to each RTWC show the responsible coastal areas, to which the Center issues tsunami forecasts

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Table 1. Tsunami Forecast Category

Category	Message	Explanation
Tsunami Warning	Major tsunami expected	Major tsunami is expected. Height of tsunami is *more than 3 meters* in the worst places and generally up to *1 meter*. Greatest caution is required for tsunami.
	Tsunami expected	Tsunami is expected. Height of tsunami is up to *2 meters* in the worst places and generally up to *several tens centimeters*.
Tsunami Advisory	Tsunami attention	Some minor tsunami may be expected. Height of tsunami is up to *several tens centimeters* in the worst places.
	Warning/ Attention cleared	Danger or Threat of tsunami has been cleared.

tsunami forecasts to respective responsible coastal regions which are shown in Fig. 3. In addition, the JMA Headquarters, as the national centre, is also responsible for issuance of tsunami forecasts to the whole Japanese coast and nearby maritime regions regarding tsunamis in the Pacific Ocean caused by earthquake occurring in distant regions.

Tsunami forecasts issued by JMA are classified broadly into two categories, namely, a tsunami warning and a tsunami advisory. Table 1 shows the types of tsunami forecasts, tsunami grades and explanations. Only the message shown in the Table is used in the process of dissemination of a warning or a advisory. The message accepted by receivers such as polices, municipal offices and mass media is translated accordingly as listed in Table 1, before its distribution to the public.

In order to estimate tsunami occurrence and forecast its arrival to coasts, it is important and necessary to determine a source region and a magnitude of an earthquake accurately by analysing seismic data with a dense observation network. For this purpose, JMA has developed a seismological observation network consisting about 180 seismic stations all over Japan, equipped with seismometers of different types, namely, 150 standard seismic stations with a combination of short period, velocity type and strong motion accelerometer, which were installed in 1994 as the Network of Earthquake

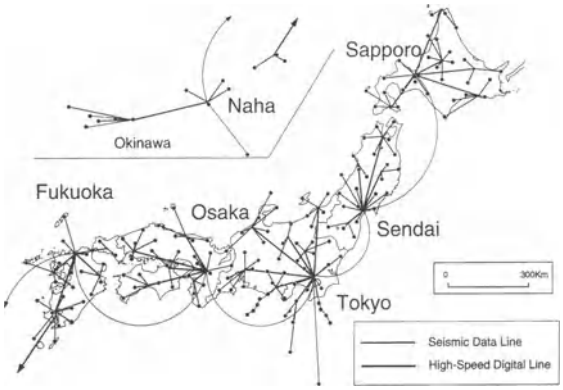


Fig. 4. Seismic Observation Network by JMA

Observation System, and 25 high-magnification seismometers (magnification 3000–10 000) and others (Fig. 4).

All the data observed by each seismometer are continuously transmitted to the computer system[1] at each RTWC. Soon after an earthquake occurs in and around Japan, the seismic data are immediately analysed at the respective RTWCs to determine a hypocenter and a magnitude of an earthquake by the automatic reading of P waves. Watch-standers, who work in shifts of 24-hour operation, examine the accuracy of the position of the hypocenter. If they determine insufficiency in its accuracy, they can modify manually P onsets and pick up S wave arrivals by man-machine interactive operations and computer system calculate to get a more accurate hypocentre and magnitude of the earthquake.

The possibility of tsunami generation is examined based on the empirical relationship between the location and the magnitude of the earthquake. The computer system suggests the type of tsunami forecast with the appropriate wording of a warning and/or an advisory. After a person in operation verifies the final result of the forecast, then the tsunami warning/advisory message is automatically issued through the system. The tsunami warning/advisory is transmitted through the computerised telecommunication system (Automated Data Editing and Switching System: ADESS) to the authorities related to disaster mitigation of central and local governments, broadcasting media and others

[1] Earthquake Phenomena Observation System (EPOS) is installed in Tokyo RTWC (Headquarters of JMA). Earthquake and Tsunami Observation System (ETOS) is also installed in the respective RTWC.

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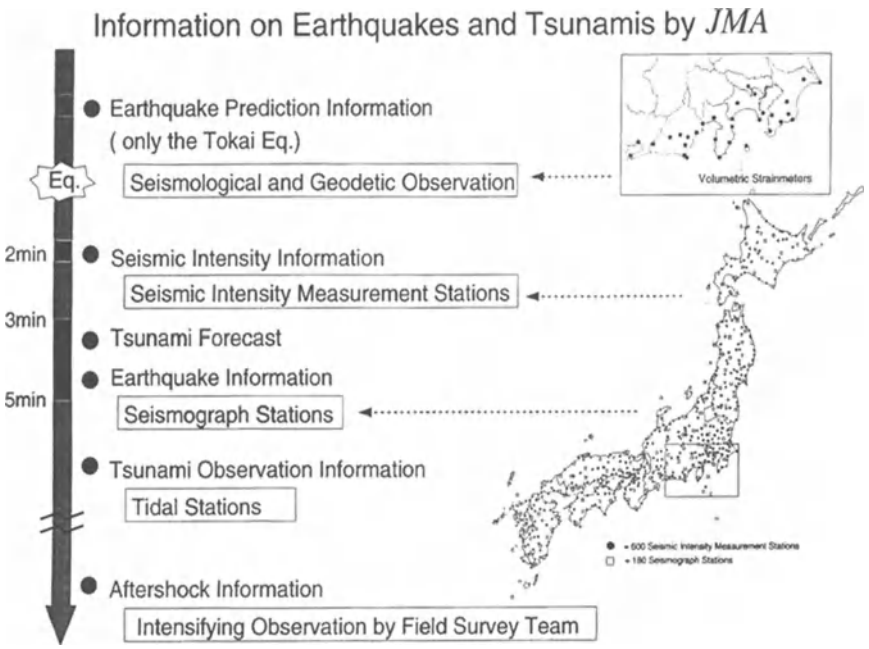


Fig. 5. Time Chart of Tsunami Forecast and Earthquake Information Provision

within 3 minutes after the earthquake occurrence. All of the organisations and broadcasting media disseminate the warning/advisory as quickly as possible to people in coastal region and vessels near the shore (Fig. 5).

4 Tsunami Observation and Tidal Wave Monitoring

JMA deploys 77 tidal gauge stations along the coast around Japan. The monitoring of arrival time and the height of a tsunami will be initiated at these stations soon after the tsunami warnings are issued by JMA. The tidal data are, of course, continuously transmitted through a telemetry system to the RTWCs from the stations (Fig. 6).

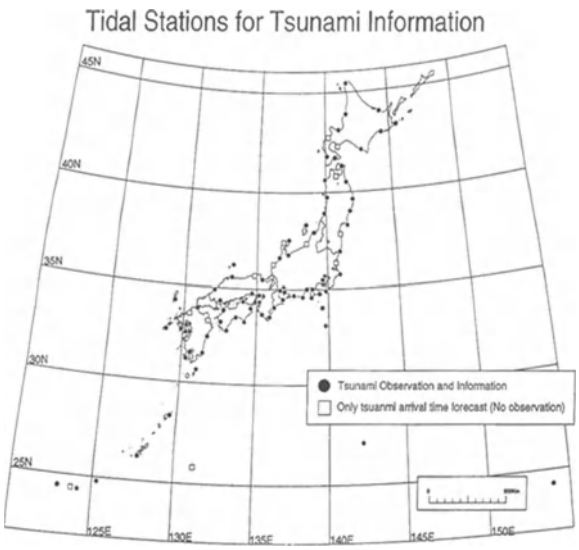


Fig. 6. Tide Stations in Japan (As of September 1998)

5 Dissemination System

When the tsunami warning/advisory is issued, the forecast of the arrival time and the expected maximum height of the tsunami at the related tidal gauge station will be issued subsequently as tsunami information. If the tsunami is observed, its arrival time and height will also be issued as tsunami information.

Tsunami information is issued and disseminated through dedicated lines to authorities related to disaster mitigation of central and local governments and broadcasting media. Tsunami forecast and tsunami information are also transmitted through a satellite dissemination system, which is prepared against shutdown of the land-line communication system (Fig. 7).

6 Education

It is also very important to educate people to provide them with basic knowledge on earthquakes and tsunamis, and on the warning and information system, in order for them to re-

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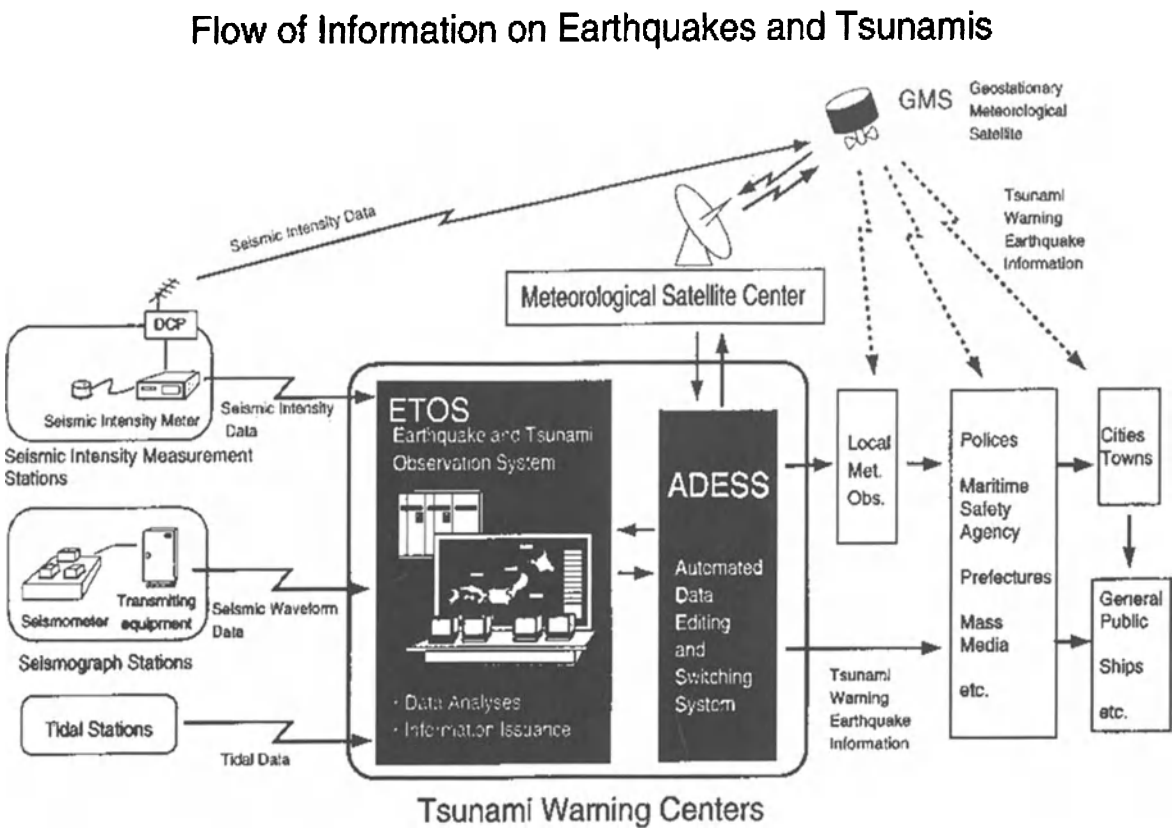


Fig. 7. Dissemination of Tsunami Forecast and Related Information

ceive warning and information without misunderstanding and, in turn, to use this information effectively.

7 Future Plan for Advanced Tsunami Forecast

JMA has been developing a new tsunami forecast procedure using a database of tsunami wave heights and arrival times, which are calculated with a numerical model of generation and propagation of tsunami for 10000 cases of tsunami-genic earthquakes with various magnitudes and depths around Japan. The calculation is made considering the characteristics of focusing and defocusing, and amplifying of tsunamis by bathymetry.

When a large earthquake occurs, tsunami heights and arrival times on the specified coasts are estimated by retrieving an appropriate result of the calculation in the database.

This new method for tsunami forecasting enables us to provide objectively estimated tsunami heights and to reduce the extent of present tsunami forecast blocks to the dimension of the coasts respective prefectures. A number of tsunami forecast blocks will increase from 18 to 66. The length of the forecast coastline is 200–600 km at present, but it will be reduced to almost less than 100 km in the future.

JMA plans to start the new tsunami forecast as of early 1999.

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Advances in the Chilean Tsunami Warning System and Application of the TIME Project to the Chilean Coast

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Abstract

The Chilean coast is frequently exposed to the effects of near and far field tsunamis generated in the Pacific Ocean. For instance, the catastrophic events of 1868 and 1877 overwhelmed the coast of the northern region of the country. During this century, the most significant disaster was the 1960 Valdivia earthquake and tsunami. It is well known that this event had a great impact on the coasts of most of the coastal states in the Pacific Ocean, mostly in Hawaii and Japan. The most recent event recorded in the Chilean coast was the "good tsunami" which occurred in Antofagasta, 1995.

This historic situation has contributed to an awareness of the tsunami threat and therefore to the development of research on several aspects of this phenomenon in Chile. In the last few years, new developments in technology have made it possible to improve the quality of the information to assess the potential risk of a tsunami event off the Chilean coast. Since 1996, the TREMORS system has been operating in Chile. This is a seismic monitoring system that improves the existing seismic network and tsunami warning system in Chile, giving information in real time of seismic parameters and their relationship with some of the parameters of tsunami generation to estimate the risk.

As a very important complement to the operative work, inundation maps by tsunamis for the Chilean coast have been developed, following the techniques of the TIME (Tsunami Inundation Modeling Exchange) project. The first maps for the four largest port cities in the northern part of Chile, namely Arica, Iquique, Antofagasta and Mejillones have been completed during 1997 and 1998. It is well known that the two northern most cities, Arica and Iquique ports, are located in a "seismic gap" zone. These inundation maps are being used for tsunami hazard planning by the national civil protection agency (ONEMI) and other governmental institutions.

1 Introduction

Tsunamis are one of the natural hazards that cause important losses of lives and considerable damage to the coastal communities of the Pacific Ocean. The West Coast of South America is the site of the subduction of the oceanic Nazca Plate under the continental South American Plate. The result is a narrow band of strong seismicity running the length of the continent and roughly paralleling the axis of the Peru-Chile Trench.

A long history of strong and shallow tsunamigenic earthquakes has occurred along this zone, all of them being of the subduction type. Such events have not occurred often, but the continued seismicity of the region and its history of great earthquakes of the type which have produced tsunami, mean that this region continues to be a possible source of destructive tsunamis. The following table (Table 1) shows the local tsu-

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Table 1. Tsunamigenic earthquakes along the Chilean coast from 16th century until present

Year	Max. run-ups estimated (meters)	Area affected
1562	–	VIII°–IX° Region, Concepcion to Arauco
1570	–	VIII° Region, Concepcion
1575	–	VII°–IX°–X° Region, Concepcion to Chiloe
1604	–	North of Chile
1657	–	Valparaiso
1730	–	Valparaiso
1751	–	Concepcion
1819	–	III° Region, Caldera
1822	–	Valparaiso
1835	–	Concepcion
1837	–	Valdivia to Chiloe Island
1868	20 (Arica)	I°–II° Region, Arica to Antofagasta
1877	20 (Iquique)	I°–II° Region, Arica to Antofagasta
1906	–	V°–VI° Region, Papudo to Pichilemu
1922	8 (Caldera)	III°–IV° Region, Chañaral to Coquimbo
1960	20 (Mocha Island)	VIII°–X° Region, Concepcion to Chiloe Island
1995	1.8 (South of Antofagasta)	II° Region, Antofagasta and Mejillones

namigenic earthquakes occurred along the Chilean coast since the XVI century until today.

Several seismic gaps have been identified along the coast of Chile. The main one is located in the northern part of the country (18°S–20°S). This region, with a history of destructive earthquakes and tsunamis, the last one in 1877, and with the significant amount of seismic potential allocated by several authors, mainly Kelleher (1972), Stauder (1973), McCann et al. (1978) and Nishenko (1985), is nowadays considered a candidate for a major or great tsunami earthquake in the near future.

The numerical model of the TIME Project IOC/ITSU have been used to simulate the generation and propagation out of the source area of the 1868 and 1877 tsunamigenic earthquakes. The result shows that a maximun impact for local tsunamis will affect this area with expected run-ups of 12 meters in Arica and 18.5 meters in Iquique. From earthquake-tsunami delay time, these simulations give time responses for the planning of the disaster agencies. No more than 15 minutes and 20 minutes between earthquake and maximum tsunami waves arriving to the coast have been estimated for Iquique and Arica respectively.

2 The National Tsunami Warning System (NTWS)

Due to disastrous events originated by the tsunami earthquake of May 22, 1960, the need for a NTWS was evident. The system started in 1964 and its organization, direction and control were given to SHOA (Hydrographic and Oceanographic Service of the Chilean Navy). Furthermore, SHOA was appointed as the official representative of Chile before the International Tsunami Warning System for the Pacific.

The functioning of the NTWS is based on the seismic data delivered via fax and Internet, by the local seismological network operated by the Seismological Service of the Geophysics Department of Universidad de Chile and sea level data given by the tidal network of SHOA along the continental and insular Chilean coast and/or information of the Pacific Tsunami Warning Center (P.T.W.C.) from Hawaii. At present, a great number of SHOA tide stations give data via satellite in real time, and they are collected at the receiver station located at SHOA. In addition, when the occurrence of a seismic event $Ms \geq 5.5$ generated at the Pacific Basin is detected by the world seismic stations network of the Geological Service of the United States (U.S.G.S.), an official communication by e-mail in tsunamis@shoa.cl at SHOA is automatically received.

Recent efforts have been made to improve the existing National Tsunami Warning System. Since 1996, the Tsunami Risk Evaluation through the seismic Moment from a Real-time System (TREMORS) has been integrated to operations of the NTWS. This system was developed by DASE/LDG (France).

TREMORS is an integrated automatic system, based on a single three component broad band seismic station linked to a compatible IBM-PC in a recording station. In Chile, the broad band seismic station is located at the El Roble hill (ELRO Station) and data transmission is received in an IBM-PC at SHOA office. The algorithm of the TREMORS software includes automatic detection of P, S, Raleigh and Love waves, location of the epicenter and determination of the seismic moment.

The latter is estimated exclusively from long period data; epicentral distance is obtained from S-P delay times and source azimuth from the polarity of P waves in the horizontal plane. The detectability is a function of the magnitude

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Mw and of the epicentral distance ($M > 4.8$ in near field and 6.2 if $\Delta > 90$ degrees). The accuracy of the location is a function of the horizontal signal to noise ratio (< 5 degrees if S/N > 25 dB for the far field).

The Seismic Moment (Mo) is calculated through the Mantle Magnitude (Mm) computed from spectral amplitudes of Raleigh and Love waves over a broad range of periods (50 to 300 s). Mo is then used to compute an expected tsunami height, taking in account corrections due to epicentral distance and local effects such as run-up and resonance of bays. Therefore, TREMORS gives a Tsunami Warning on Mo measurement (threshold = 5.0×10E+19 N.m. to 1.0×10E+20 N.m.).

No near or far field tsunami has been recorded along the Chilean coast during the last two years. Nevertheless, a good instance for the ELRO station's capability of recognizing a tsunami earthquake in real time, was during the 21 February 1996 Chimbote, Peru event. However, the TREMORS ELRO station has not shown satisfactory results for the near field seismic events. In order to solve this problem, the future plan for the TREMORS system is to add new seismic sensors at the ELRO station and improve the TREMORS software. It will be implemented next December.

Emergency Managers Weather Information Network (EWIN) has just been incorporated to the NTWS from the National Weather Service. EWIN can also provide other types of emergency data such as Flood and Tornado. It is a wireless computer satelite data broadcast system that continuously provides live warnings, watches and graphics to a computer at SHOA.

The operation of the NTWS is made up of 4 stages; these are:

1. Preparation Stage
2. Data Gathering
3. Emergency Assessment
4. Information Stage

The NTWS is activated, once a sensible seismic event on the national territory or on the Pacific Basin is detected.

3 Application of the TIME Project to the Chilean Coast

Under the auspices of the TIME Project, an international cooperative effort to transfer tsunami-modeling technology based on the Tohoku University Numerical Analysis Model for investigation of Near-field Tsunamis was carried out by means of a Latin American training course on Numerical Simulation of Tsunamis. It was given in Spanish by Mr. Modesto Ortiz, Oceanographer M. S., associated with the Centro de Investigaciones Cientificas y de Educacion Superior de Baja California, Mexico (CICESE).

The technological transfer was possible thanks to an agreement between SHOA and CICESE, under the auspices of the Intergovernmental Oceanographic Commission (IOC).

After the course, SHOA has been working on the elaboration of tsunami inundation charts for the Chilean coast in order to formulate a comprehensive map for both civilian protection and urban planning.

The first maps for the four largest port cities in the northern part of Chile, namely Arica, Iquique, Antofagasta and Mejillones have been completed during 1997 and 1998.

For Arica, the numerical simulation gave results that agree with the available historical data. For the 1868 Tsunami event the maximun wave height was 11 meters and the inundation surpassed the 5-meter topographical level. For the 1877 Tsunami event the maximun wave height was 12 meters and the inundation also surpassed the 5-meter topographical level.

For Iquique, there is no available historical background. For the 1868 Tsunami event the maximun wave height was 7 meters and the inundation surpassed the 5-meter topographical level. For the 1877 Tsunami event the maximun wave height was 18.5 meters and the inundation also surpassed the 15-meter topographical level.

Regarding Antofagasta and Mejillones, the simulated events correspond to the tsunami earthquakes of 1877 and 1995. For the Antofagasta 1877 Tsunami event, the maximun wave height was 7 meters and the inundation surpassed the 5-meter topographical level. For the 1995 occurrence, the maximun wave height was 0.7 meters and the inundation surpassed the 5-meter topographical level.

For the Mejillones 1877 Tsunami event, the maximun wave height was 18 meters and the inundation surpassed the 10-meter topographical level. For the 1995 occurrence, the maximun wave height was below 1 meter and the inundation was not significant.

The development of new charts for Tocopilla and Caldera is scheduled for the near future. Ad-

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ditionally, the inundation charts for the most important ports cities of the country, namely, Valparaiso and Concepcion, will be elaborated next year. The final objective of this project is producing charts for every port city of the country.

4 Future Projects

In April, 1998, an agreement was made for the development of a PC-based Interactive Computer Program for the Calculation of Tsunami Travel Charts (TTTC) and a CD-ROM "Tsunamis in South America, 1513–1999 A.D.", between the Hydrographic and Oceanographic Service of the Chilean Navy and the Tsunami Laboratory of the Institute of Computational Mathematics and Mathematical Geophysics, Siberian Division, Russian Academy of Sciences.

The first project is directed to the development of a PC-based interactive software system for fast calculation and plotting of Tsunami Travel Time Charts (TTTC), which can be used for computation of propagation time between regional tsunamigenic areas and threatened coastal sites in the Pacific coast of the South America as well as for the estimation of propagation time for possible distant tsunamis originated in any other part of the Pacific. These charts can be obtained between any given source and observation areas provided that realistic bathymetry of the region is available in digital form.

The CD-ROM "Tsunamis in South America, 1513–1999 A.D." is directed to improve the catalog of historical tsunamis in the South America region by means of organizing them in the form of a database containing all the meaningful historical tsunami data along with additional reference information related to the tsunami problem. This database will summarize the long-term efforts of several research groups and individuals in collecting, refining and digitizing the tsunami related data and will represent the updated, revised and homogenous tsunami data set.

5 Conclusions

From what we have analyzed we can reach at least three important conclusions:

First, for all its advantages as an operative tool, the TREMORS system needs to be improved, so as to deliver accurate data on epicenters and seismic moments (Mo) to correctly assess the potential risk of tsunami on the Chilean coast.

Second, the numerical simulation model has proven to be a useful tool in its application to real-life historical situations, making it possible to accurately predict future events in high-risk zones, such as Arica and Iquique.

Third, the future projects to be developed by SHOA include incorporating software aimed at improving the operation of the NTWS.

6 Inundation Maps for Iquique

6.1 1868 and 1877 Tsunamis Earthquake

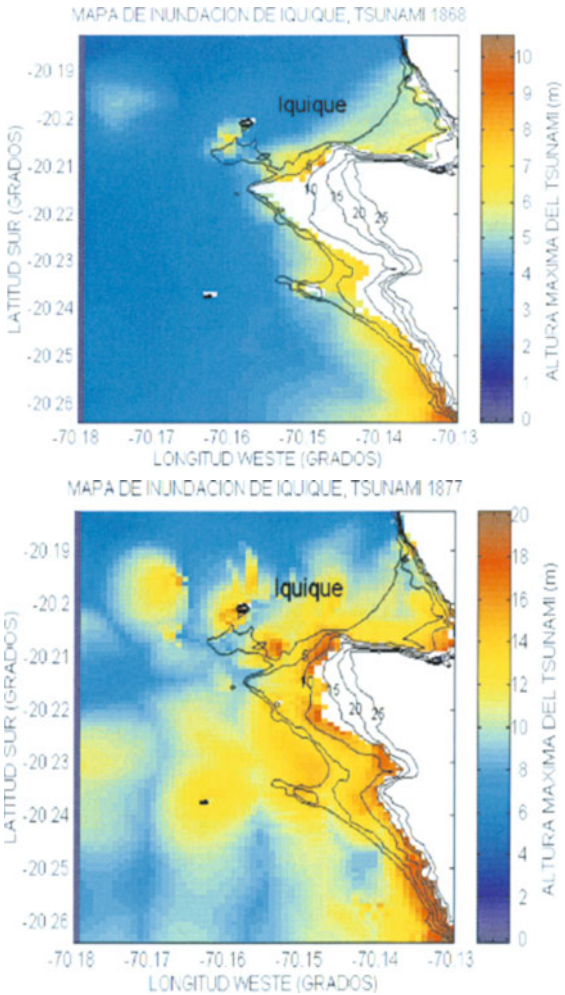


Fig. 1. Indundation maps of Iquique – Tsunamis earthquake of 1868 and 1877

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A Tsunami Warning System in the SW Aegean Sea, Greece

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Abstract

The state of the art is given for the Tsunami Warning System (TWS) which is under development in the South Aegean Sea. The TWS consists of a digital seismograph and tide-gauges subsystems both telemetrically connected with the central acquisition unit in Athens which is capable of processing automatically almost real-time data. The TWS is supported by an earthquake and tsunami data base of the area.

1 Introduction

Large submarine earthquakes or volcanic eruptions occurring in the Greek area generate large tsunamis from time to time (e.g. Galanopoulos 1960; Ambraseys 1962; Papadopoulos & Chalkis 1984). The Greek tsunamis have proven quite destructive such as the 9 July 1956 large tsunami in the South Aegean Sea triggered by a Ms = 7.4 submarine earthquake. However, the tsunami hazard mitigation not only in Greece but also in the Euro-Mediterranean area has been rather neglected. It has only been very recently that this aspect was considered seriously within the framework of the EU-DG XII research projects GITEC (1992–1995) and GITEC-TWO (1996–1998).

One of the main contributions of the Greek team involved in GITEC-TWO has been the establishment of an experimental Tsunami Warning System (TWS) covering the regions of Kythira Strait and Santorini in the South Aegean Sea. This paper is devoted to a state-of-the-art description of this TWS as for August 1998.

2 Tsunami Warning System in the South Aegean Sea

The Kythira Strait (Fig. 1), located in the Western Hellenic Arc between Peloponnisos and Crete Isl., is characterized by very high seismic activity (e.g. Papadopoulos & Kijko 1991). Large earthquakes that occurred in the past were often associated with large, catastrophic tsunamis like those of 365 AD, 1630 and 1866. The generation of a large tsunami in the Kythira Strait implies a wave propagation not only towards the near-field coastal areas and further to the Aegean Sea but also to remote areas of the Mediterranean Sea. On the basis of these peculiarities the Kythira Strait has been selected for the construction of an experimental TWS which could constitute the "core" of a future operational TWS. Moreover, the volcanic region of Santorini (Fig. 1) is also an important tsunamigenic source in the South Aegean Sea. Large tsunamis produced in the past by either volcanic eruptions (c. 1630 BC, 1650 AD) or earthquakes (1956 AD) caused extensive destructions in South Aegean coastal places. Therefore, this region is also covered by the South Aegean TWS.

The South Aegean TWS has been designed so that it consists of two independent subsystems, the seismograph and the tide-gauges, and a Central Aquisition Unit (Fig. 2).

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The selected design of the TWS in the South Aegean Sea is quite similar to the systems operated in Japan by the Japanese Meteorological Agency for tsunami warning in cases of near-field tsunami occurrences with short tsunami wave travel times.

The digital seismograph subsystem, supplied by Nanometrics, Inc., Canada, includes five remote field stations, the telemetry system, the data acquisition system and the data analysis software. Specifications and possibilities of each one of these systems are shown in Table 1.

The geomorphology of the area of the South Aegean Sea is not the best one so that to deploy a network with an ideal geometry. The geometry that has been selected is illustrated in Fig. 1. It is evident that the five stations are installed in SW and SE Peloponnisos, in west and central Crete as well as in the island of Santorini. In these areas proper locations have been selected after field inspection and noise level measurements. All five field stations have been equiped with digitizer, GPS and 1-component, short-period seismometer of S-13 type and via modems and dedicated telephone lines, supplied on charge by the Greek Telecommunications Organisation, have telemetrically connected with the Central Acquisition Unit installed in Athens. In at least one of the field stations the installation of a 3-component seismometer is scheduled for the very near future.

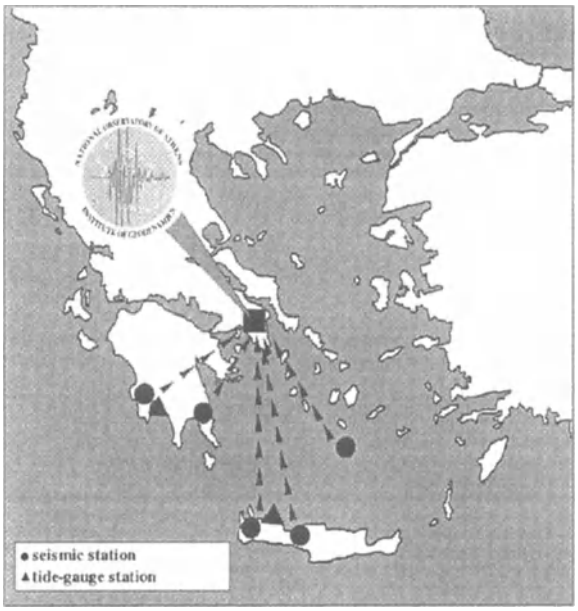
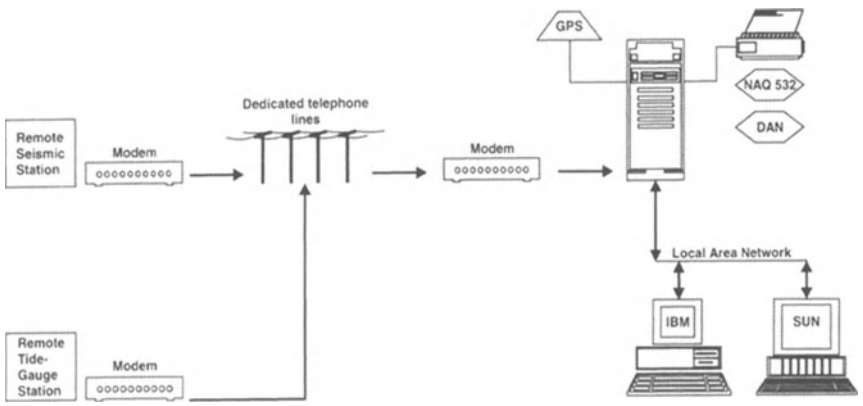


Fig. 1. The TWS covers the area of Kythira Strait in the west and the Santorini area in the east

The telemetric connection of the stations with the National Observatory of Athens, Institute of Geodynamics (NOAGI) was decided to be made by dedicated telephone lines after having examined other options like mobile telephone telemetry, satellite and radio links. The final decision was taken on the basis of a number of technical and economic parameters.

In the NOAGI the Central Acquisition Unit has been installed consisting of a single IBM PC300 Pentium System with a maximum addressable memory of 128MB and an OS/2 operating system. This computer runs the Nanometrics NAQS32 acquisition, the AutoLocate real-time processing and DAN data analysis software packages. Data acquisition and analysis can be performed on the same computer system. The Nanometrics AutoLocate software for automatic event location and display has been optimised for speed and is able to provide preliminary locations and magnitude estimates within 8 sec of the forth trigger displaying the resulting location graphically on a map of the area. In addition to the initial location the software calculates a final determination within about 30 s using all of the network information for the event.

Fig. 2. Schematic represantation of the TWS



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Table 1. Specification of the seismograph system

Remote Field Stations	Telemetry Systems
• RD3, 16 bit gain ranged, 132db dynamic range • HRD-24, Wide range digitiser • Rugged field packaging • Three or six channels • State of health system	• Radio, Telephone and Satellite telemetry options • RM2 repeater electronics ensure reliable radio repeater operation • Nanometrics radio modems offer high data through puts
Data Acquisition Systems	**Data Analysis Software**
• Accepts data from 100 or more digital stations • Event detection and ring buffer data storage • On-line access to all ring buffer and event data • Automatic data archiving to optical or tape systems • Automatic event location and map display software	• Graphical environment for data analysis • Choice of two epicentre location programs with graphical output • Signal filtering and spectral analysis routines • Support for SEED and SUDS data formats • Available for PC and SUN computer systems

The second subsystem of the TWS is the tide-gauge one. Two pneumatic water level sensors ID7700 supplied by SIAP-MECH-EL s.r.l., Bologna, have installed in coastal locations of the SW Peloponnisos and NW Crete (Fig. 1). The sensors are connected via modem/telephone line with corresponding seismograph stations so that their signals to be sent also in a real-time to the Central Acquistion Unit in NOAGI with a sampling rate of 30 s.

In the very near future a full experimental operation of the system is expected to show the possibilities and limitations of the system and its capabilities for a real time tsunami monitoring in the future.

3 An Earthquake and Tsunami Data Basis

The existence of a tsunami and earthquake data base is of great importance for developing an overall algorithm for the tsunami hazard mitigation incorporating the TWS and decision taking procedures. Therefore, our attention has been concentrated on the revision and updating of the earthquake and tsunami data basis, particularly the historical ones, of the Kythira Strait.

Existing tsunami catalogues like those of Galanopoulos (1960), Ambraseys (1962), Antonopoulos (1980), and Papadopoulos & Chalkis (1984) were taken into account along with new, historical documents regarding the earthquake history of the island of Kythira (Fig. 1).

Table 2 summarises the collected information on the most sizeable historical earthquakes reported to be felt on the island of Kythira or in other places of the Kythira Strait, like south Peloponnisos and west Crete, as well as on tsunami waves reported to be associated with some of these earthquakes. A detailed bibliography of the new events and the already known ones will be given elsewhere (Papadopoulos & Vassilopoulou 1998).

The following comments apply to Table 2:

- There is no specific information that the 66 AD and 365 large events were felt on the island of Kythira. However, there is little doubt that both earthquake and tsunami sources were located in the area of the Kythira Strait.
- The 800 event is cited in only one source (Kassimatis 1978) without further citation of the original source of information. Possibly this event has been confused with that of 365. The reliability of the occurrence of this event deserves to be further investigated because the estimation of the mean recurrence time of the large earthquakes in the Kythira Strait is of great importance for assessing more reliably the tsunami frequency of occurrence as well as for better understanding the mechanism of tsunamigenesis.
- The source of the 1856 earthquake is located somewhere in the South Aegean Sea. It is a well-known event that caused heavy damage to Crete and other more remote places of the Mediterranean Sea (e.g. Papazachos & Papazachou 1989). It is, however, the first time that particular information was found on its strong perceptibility on the Kythira Island.
- In at least four cases (66, 365, 1630, 1866), and may be in one further event (800), large tsunamis were generated by the corresponding earthquakes. The 1856 and 1903 big earthquakes were of intermediate focal depth and, therefore, it is quite understandable why they were not associated with tsunami waves.

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Table 2. Historical earthquakes felt or located in the area of Kythira strait

New event	Date	Ms	h	Reported Consequences
	66 A.D.	7.0	n	Destruction in Crete, strong tsunami
	365 07 21	8.2	n	Extensive destructions in Crete, large tsunami
*	800	?	?	Extensive destructions in the east Kythira coast, large tsunami
	1630 03 10	7.0	n	Strongly felt, large tsunami
	1750 06 07	7.0	n	2000 victims, ruins
	1754 06 12	7.0	n	Strong EQ
	1798 06 11	6.7	n	Destructions
	1798 06 18	?	n	Destructions
*	1806 09 28	?	n	"Big EQ"
*	1808 04 14	?	n	"Big EQ"
*	1815 08 03	?	n	"Terrible EQ"
*	1838 07 20	?	?	"Strong EQ"
	1856 09 30	8.2	i	"Big EQ"
	1866 02 06	6.8	n	Destructions, tsunami (H = 8 m) in Avlemon (Kythira island)
	1867 09 20	7.1	n	Destructions in S. Peloponnisos, strong tsunami
*	1889 10 05	?	n	"Strong EQ"
*	1894 03 29	?	n	
*	1894 05 18	?	n	
*	1894 05 27	?	n	
*	1894 07 05	?	n	
*	1895 01 29	?	n	"Generally felt"
*	1896 08 18	?	n	
	1903 08 11	7.9	80 km	Destructions, 2 victims
	1910 02 18	6.9	90 km	Destructions in W. Crete

4 Future Planning

Apart from the TWS experimental testing in the immediate future the following further developments are scheduled:

1. the increase of the number of stations,
2. the incorporation of a software component able to determine automatically the focal mechanism of the earthquake event in an almost real time,
3. elaboration of inundation senarios in selected coastal places on the basis of tsunami numerical modelling, and
4. the construction of an overall algorithm for the probabilistic tsunami warning decision based on the TWS determinations, on the tsunami history of the area as results from the data base, and on the inundation scenarios.

Acknowledgements

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Vd Early Warning Systems for Mountain Hazards

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Early Warning Systems Related to Mountain Hazards

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Abstract

Mountain hazards, such as snow avalanches, rockfall, landslides, debris flows and torrential processes are responsible for disasters and catastrophes in mountainous areas every year. In many densely populated mountain regions, governmental agencies or the inhabitants themselves try to protect settlements and traffic routes by active measures (for example check-dams, etc.) and/or passive measures (for example hazard zoning, planning of evacuation, closing of railways and roads in case of acute danger). All these measures, especially those last mentioned require early warning. We should differentiate between early warning and observation measures, concerning either (1) the basic disposition of an area for dangerous processes (e.g. long-term preconditions, such as the general instability of a slope), or (2) the variable disposition (e.g. short-term state of the snow cover on an avalanche slope), or (3) the immediate effect of triggering events (i.e. thunderstorms triggering flash floods). There is a wide range of technical realisations of early warning systems for this. In many cases the most adequate solution is a traditional warning by watchful attendants; in other cases sophisticated electronic devices provide better safety.

In all cases, however, it is essential that the early warning systems are very well applied by the involved experts, by the regional and local authorities, and by the population. The best concepts, the most sophisticated instrumentation are useless if the alert is not transmitted to the menaced people at the right time and if there is no accurate planning of emergency measures provided.

1 Mountain Hazards – Mountain Risks

Natural hazards comprise all forces of nature that are hazardous to man and/or to his property, for example earthquakes, droughts, locust plagues, etc. In this paper the term *mountain hazards* is used. This term is restricted to the processes resulting from the mass movement of water, snow, ice, debris, and rocks at the surface of the earth, including snow avalanches, rockfall, landslides, debris flows and torrential processes. These processes are considered to be hazardous when directly endangering man and goods, causing death, injury, destruction of property and ecological damage within a short time. These natural hazards are also referred to as geomorphic hazards or as mountain hazards.

Mountain hazards are inherent in the nature of mountainous regions. However, this hazardous situation is further influenced, positively (as countermeasures) or negatively, by man. In the Alps for example, widespread deforestation in the 17, 18 and 19th centuries had a negative effect. Surface runoff flowed much quicker and in greater quantities (almost no retention) on

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deforested slopes. On pastures this effect was intensified by compacting of the soil. The danger was, that the smallest surface damage could have caused surface runoff. Wide sources of sediment were generated through erosion and mass movements. Many floods and debris flows would have had a smaller extension without deforestation. Snow avalanche hazards have been intensified by felling trees particularly in areas near the timberline. There are many places where one tries to correct such mistakes and, where, in general, steps are undertaken against natural hazards by reforestation or technical measures.

Man estimates the damaging effect of dangerous natural or quasi-natural processes in terms of human and material loss (potential loss), whereby the significance of hazard damage depends on what is damaged. If only rock debris and bushes are flooded when a mountain torrent breaks out of its channel in the debris cone, the damage is considered to be slight. However, if houses, campgrounds, roads and cultivated land are damaged or destroyed by a similar event, the damage is estimated in a different way and considered to be much bigger.

Based on a systematisation of German terminology Kienholz (1984) has proposed the scheme shown in Fig. 1. This scheme shows a symmetry of two components determining the risk ("Risk" here is used as identical with Varnes 1984 term "total risk").

At a particular site the potential damage caused by a dangerous process is a function of the possible magnitude (extension, impact pressure, range) of the hazard and the vulnerability of the elements at risk (potential loss) in that area.

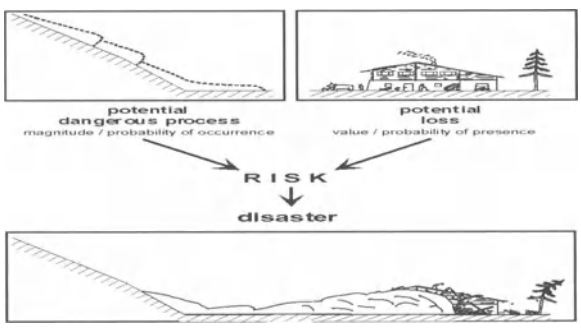


Fig. 1. Risk and damage

The dimension of a damaging risk depends on the type of hazardous process, that means on the probability of its occurrence and its magnitude, as well as on the extent (value) of the potential loss and the likelihood of its occurrence at the "risk site" at the time of the event ("Risk site" refers to the area potentially affected by a hazardous process).

Referring to Fig. 1 it is obvious, that besides other measures men's life as well as mobile goods could leap to safety, if early warning would be provided. Thus, early warning is an integral part of handling mountain hazards.

2 Preventive Measures – the Demand for Early Warning Concepts

For ethical (the inestimable value of human lives) and material reasons, man strives for a certain degree of security: he wants to eliminate risks or at least to minimise and control them.

If a risk contains both components i.e. a dangerous process and a potential loss, an attempt can be made to influence either one or both factors: *active measures* are aimed to impair the hazard, *passive measures* are aimed to reduce the potential loss.

Permanent active measures attempt to:

- prevent (i.e. defences to stabilise the snow and reforestation in the avalanche release zone),
- slow down (i.e. cones in the track to break the avalanche),
- or divert (i.e. avalanche deflectors and deflecting dikes) the hazardous process.

Temporary active measures are attempted to influence the course and the effects of hazardous processes during periods of acute danger (for example by artificially releasing avalanches).

Passive measures are attempted to reduce or, if possible, to prevent the damaging effects of a hazard but these do not influence the hazardous process itself. An example for a *permanent passive measure* is the demarcation of hazard zone in which constructing is prohibited. Well-known *temporary passive measures* are the closing of railroads, of roads or of ski-runs, or – very important in some places – the evacuation of settlements.

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It is obvious that especially *temporary passive measures* require well organised early warning and alerting systems. This includes:

- the basic knowledge of the general danger and risk at a given place,
- the knowledge of the critical situations and the related indicators,
- the criteria for raising alarm,
- installation and maintenance of adequate alarming devices,
- an adequate communication network,
- organisation of services for order and rescue, etc.

However, also the permanent active or passive measures require an early warning in a long-term sense: In any case at least the basic knowledge of the general danger and risk at a given place is absolutely necessary.

All kinds of measures, and early warning as a part of it have to be implemented in diverse complicated environments and in urban societies where more and more people live in virtual worlds, far from nature.

Complex natural and quasi-natural environments:
The generation of most of the mountain hazards depends on manifold long-term preconditions (basic disposition, see chapter 5) of the considered mountain slopes such as topography, geology, hydrology, vegetation cover, etc.; it further depends on several factors influencing the variable disposition, such as changes in the hydrogeological and hydrological conditions, microclimate, weathering processes in general, etc. The actual triggers are changes in the hydrostatic pressure, short-term freeze-thaw effects, shocks, etc.).

In many cases there is not only one single process that threatens a certain site. The channel of a mountain torrent is also used by snow avalanches during winter; or, landslides very often are connected with fluvial erosion processes and vice versa. In the latter case, it is absolutely necessary to know of the influence of the landslide on the torrential activity, especially on the bedload discharge or the possibility of triggering debris flows. Therefore, each hazard assessment absolutely requires a synoptic view of all possibly involved hazards.

Societies living in virtual worlds:
While in former days people were less mobile, the native rural population knew by experience quite a lot about the natural hazards within their environment. Nowadays this is often no longer the case. Inexperienced inhabitants, population pressure, increase in potential loss, etc., all this leads increasingly to institutionalised land-use planning. That is why hazard-maps based on accurate and objective hazard assessment, are essential.

Therefore, considering the complexity of nature and the innocence of the societies, it is necessary in many parts of mountainous areas, to carry on adequate measures. These, first of all, require accurate hazard assessment. To have accurate and comprehensible hazard assessment demands to apply a full set of methods, that includs on one hand methods, that are looking to the future (i.e. forward directed indication like detailed evaluation of the situations in the terrain as well as application of models describing the processes), and on the other hand methods, that are looking to the past (for example "silent witnesses" that is documents about former events in the terrain as well as the evaluation of written documents).

The purpose of all this work carried out by experts and possibly documented in hazard maps, is the knowledge transfer to the responsible authorities and the population regarding the implementation of passive and active measures. And, depending on the situation, this also may include early warning and alerting concepts. Even if the land-use is adequate, if the settlements and communication routes are in relative safe places, and even if there are sophisticated and reliable active measures, emergencies may still occur. Satisfactory emergency planning again must ask for adequate alerting concepts.

In order to understand some difficulties of hazard assessment, of designing proper mitigation measures, and in order to make concepts for adequate early warning and alarming measures, some temporal and spatial characteristics of mountain hazards are discussed, and the concept of "disposition and trigger" is described (chapters 3–5).

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3 Temporal Characteristics of Mountain Hazards

Many of the dangerous processes "are of sufficiently short duration to be considered as instantaneous events in time" (Scheidegger 1975). For any dangerous process higher or equal to a certain magnitude in a given place the relative frequency can be determined in relation to a defined period due to the empirical distribution function. It is usual to indicate the reciprocal value of the relative frequency per year, the middle recurrence interval (expressed as number of years) of events with a given magnitude.

The recurrence interval of xx years concerns a purely statistical value, that says nothing about the effective number of years between two concrete events. Sometimes an event with a theoretical recurrence interval of 100 years can take place several times within some few days. For this reason it might be better to express the same as probability: An event with a recurrence interval of 100 years is an event with a probability of 0.01 per year.

Such analyses of the middle return interval of former events of a given magnitude provide an overview of the frequency of the dangerous process determined so far. The frequency for future events can be extrapolated, if one assumes that the probabilities do not change. However, such assumptions may be somewhat arbitrary. It is to consider, that in many cases reliable data are only available for the last 50–100 years. Only relatively frequent events, that exceed a given magnitude, may be entered into such statistics. Excessive real, but not reported events, that occurred some centuries in the past, are probably missing in statistical records.

Table 1. Temporal characteristics of mountain hazards and related aspects of early warning

Temporal type of event	Example	Considerations for early warning
Continuous, permanent	Large deep-seated slow landslides	Usually no direct threat for human lives; often damage to property (buildings and infrastructure); attention is drawn by the continuous process itself; early warning has to be considered • if acceleration of the process itself is possible, • if secondary processes such as small or medium-sized landslides or debris flows may occur at oversteepened slopes; • if the large landslide may clog a river channel; due to the habituation people may not pay enough attention.
Singular	Large rockfall ("Bergsturz")	Very hazardous processes, that may occur in many places, but in very low probability; in many case nature provides early warning during days, weeks or months ahead by increasing frequency and activity of small rockfall events, by noise due to internal creak, by opening cracks, etc.; often, attentive people get aware of these signs; then in many cases, it is still possible to install observation devices (for example extensometers) and to get early indication of dangerous acceleration.
Repeated, periodic	In many cases snow-avalanches, torrential activity, flooding, rockfall (small, single blocks), etc.	Danger depends of the process; • if the events are frequent (recurrence interval few years only) and if the events reach an important magnitude, people and authorities pay attention and may be well prepared; this also may include the installation of alarming systems; the periodicity of the events may provide some help in forecasting the next event; • if the events are less frequent, peoples attention may be minor; in such cases, there may be no adequate measures, or the maintenance of existing measures including alarming systems may be neglected, or people and authorities have forgotten, how to react ...
Repeated, episodic	The same as repeated, periodic	The same as repeated, periodic; however, there is no periodicity, that may provide some help in forecasting the next event; the attention of people and authorities, in some cases may even be less.

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Extrapolations into the future are to be implemented carefully, if possible environmental changes should be considered.

Many events do not occur within given return intervals. There are also dangerous processes, that are singular for a long-term (for some centuries or even the whole Holocene period). This is the case for many large events such as large landslides or rockfall ("Bergsturz").

The temporal characteristics of mountain hazards cannot be neglected for the consideration of early warning and alerting. Some general aspects are drafted out in Table 1.

4 Spatial Characteristics of Mountain Hazards

All considered dangerous processes are characterised by the fact that water, snow, ice and/or soil and rock material are driven down the mountain by the force of gravity. A clear distinction between starting, transition, and deposition zones can be made, except in many cases with landslides. In the starting area (release area) with a given disposition and appropriate triggering event, the material loosens. Then it usually passes through a longer or shorter transition zone. There are processes, that move in full width over the slope down the mountain (often snow avalanches, in addition, falling rock). Other processes (of course torrents, debris flows, but also many snow avalanches as well as rockfalls with rather small components) often concentrate in steep runs and channel systems.

Then, in the valleys, the more or less rapidly moved material meets fields, settlements and traffic routes where it can cause damage in different manners.

Accurate hazard assessment as a precondition for any counter-measures requires the analysis of the kinetics and kinematics of all considered processes at all mentioned places (starting, transition and deposition area). Of course early warning and alerting measures, in most cases, are planned to protect settlements and traffic routes that often are situated in the deposition and runout areas of the considered processes only. However, to design accurate alerting systems and early warning concepts one has to consider the disposition and triggering situation in the release area as well as the trajectories and the kinematics of the process in the transition zone.

In the context of early warning, especially of short-term alarming in case of emergency, where the alarming devices are actually placed plays an important role. The closer they are placed to the deposition zone, the more reliable the indicators work, but then there is a shorter reaction time. The further up they are, the earlier the alert is triggered, but the higher is the risk of false alarm (Fig. 3).

Table 2. Where to analyse and to assess what? Example of mountain torrents

	Different scenarios of threat		
	Basic disposition	Variable disposition	Triggering event
Starting zone (upper catchment)	Subsoil relief water vegetation climate	Water saturation state of vegetation cover weather conditions	Kind of disturbance earthquake weather man
Transition zone (channel and its slopes)	Subsoil relief trajectories transportation capacity vegetation cover	State of soil and subsoil state of trajectories (for example clogging situation)	Disturbance (for example clogging situation)
Deposition zone (runout zone) (debris fan)	Subsoil relief trajectories deposition capacity vegetation cover obstacles	State of soil and subsoil state of trajectories	

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In the case of mountain torrents the best place to trigger a most reliable warning would usually be the apex (place 2 in Fig. 2). All waters and debris have to pass here. Thus, here in principle it is possible to measure the amount of water and debris as well as the speed. However, because this place usually is very close to the potential loss (settlements and communication routes) an alert triggered here is probably far too late.

From this point of view, warning should be triggered at a proper place in the upper catchment area (area 1 in Fig. 2). This can ensure some minutes delay less. However, the information gathered here is much less reliable for what shall happen in the debris cone area.

For "pure" slope processes, such as rockfall or snow avalanches, this consideration may be true in some cases. However in many cases of impending rockfall, early warning and alerting devices (for example extensometers) are to be installed in the release area (area R in Fig. 2).

These general considerations, of course, should be modified for each single case, depending on the various natural factors and the involved risks. In addition to the place, where alarms should be triggered within a system of dangerous processes it is also important to define, in which phase of the process the warning is possible, sensible and reliable.

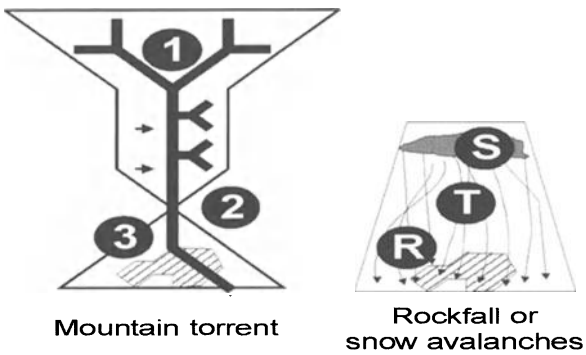


Fig. 2. Spatial components of a channeled process (mountain torrent) and for a "pure" slope process (rockfall). 1 Catchment area of mountain torrent with side channels, steep runs and slopes; 2 Apex; 3 Debris fan with settlement; sedimentation zone of the mountain torrent in case of outbreak of the channel; S Release area (for example: rockfall); T Transition zone; R Runout zone with settlement

5 Disposition and Trigger

The preparatory phase of a dangerous process is usually characterised by a more or less constant disposition for the dangerous process and by a releasing event.

The disposition for dangerous geomorphologic processes in mountain areas is the tendency or readiness of water, snow, ice, soil and rock masses to move (in pure form or mixed) down the mountain possibly causing damage. Thereby "basic disposition" and "variable disposition" are appropriately kept apart:

The "basic disposition" for dangerous processes is the general, long-term tendency or readiness for dangerous processes. The basic disposition is defined by parameters, that remain more or less constant over longer periods. Such parameters are topography, geology, climate, vegetation cover, etc. However it is notable, that some parameters can undergo a long-term trend towards a certain direction. Thus the tendency for elevation of the permafrost belt in the Alps, means in some areas an increase in the basic disposition for erosion and mass movements.

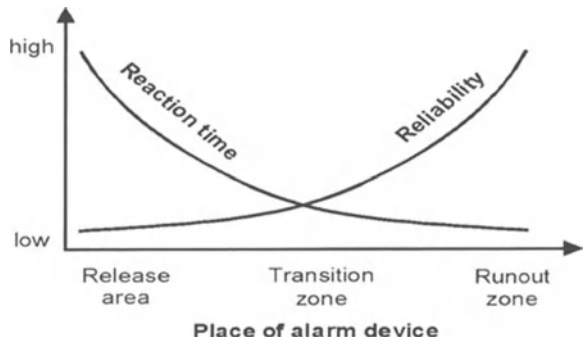


Fig. 3. Reliability and reaction time of early warning depending on the place of the alarm devices

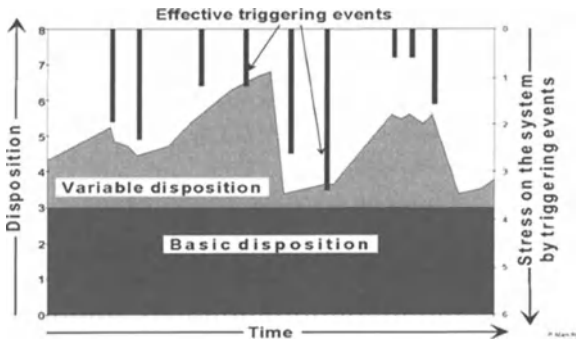


Fig. 4. Disposition and triggering events for dangerous processes (modified after P. Mani in Zimmermann et al. 1997)

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The "variable disposition" with given basic disposition, is the temporally, to a certain extent alternating disposition for dangerous processes. The variable disposition is defined for example by parameters, that are varying seasonally (e.g. snow cover, state of vegetation, etc.) or that are controlled by the meteorology (e.g. water-saturation of soils, etc.).

Finally a "triggering event" may trigger the dangerous process if the dispositions (basic disposition+variable disposition) are on a high level.

The preparatory phase of a dangerous process can be illustrated with the example of snow avalanches as a typical seasonal phenomenon in many mountain regions:

For example an unforested slope in the Swiss Alps, at 1500 m a.s.l. with an inclination of 35° is basically disposed as avalanche release area. The variable disposition for snow avalanches depends on the snow cover. Thus, in summer, if there is no snow, no snow avalanches will occur. However, during winter the proneness for snow avalanches depends on the thickness of the snow cover and on its complicated and variable physical properties. If – at a certain time – the snow cover gets very unstable, a snow avalanche may start just due to its internal instability, or with strength reduction by heating up, or by an external trigger, for example by a skier.

The evaluation of early warning concepts for any dangerous process has to consider the different phases of the process. In one case it may be decided to get indicators from the actual state of disposition, in other cases the triggering event or the dangerous process itself may be used as an indicator only. The basic relation between time delay and reliability for these different concepts is drafted out in Fig. 5.

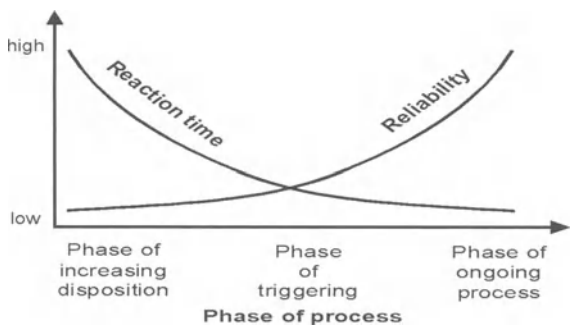


Fig. 5. Reliability and reaction time of early warning depending on the phase of process used for indication

6 Warning

6.1 General Concepts of Warning

Dangerous processes in mountain ecosystems show a great variety of phenomena and processes as it has been outlined in the previous chapters. They may occur in various frequencies and magnitudes. The population in such areas has to deal with these threats in a manner that provides an optimum of security at a minimum of internal costs. Depending on the organisational framework, and on the pattern of perception of individuals and the societies, there is an extended scale delimiting what magnitude of risk is accepted or not, and what the society is willing to spend for risk mitigation. Depending on the level of mitigation measures, of both, passive or active measures, early warning must be involved.

There is an essential difference between *permanent settlements* on one hand, and *communication routes* on the other hand. Settlements generally have to be protected in a long-term sense, either by avoiding endangered zones, or by permanent and effective active measures. However, there are also towns and villages where evacuation plans, that depend on early warning systems, are provided. For communication routes in many cases it is not possible to avoid endangered areas. Considering that the probability of presence (of persons, of cars, of trains, etc.) is $\ll 1$, it makes sense, to close the railroad or the road in case of acute danger. It is mainly in these cases, where early warning in a short-term sense is crucial.

Any hazard assessment, that is just thinking about possible risks, can be considered to be a kind of early warning; it may be defined as a "low level concept of warning". The next level may be, that people just relay on accidental observations. Starting from this, there are several levels of early warning concepts, as drafted in Table 3.

Another concept is the *well-aimed observation*, that was manifested in former days for example by the railroad companies in the Alps, when linesmen worked and lived every one or two kilometres. Those knew their environment very well, and they were able to interpret the important indicators of threatening hazardous events. At least they were able to alert the trains at the right time, if the track was

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Table 3. Some concepts of early warning about mountain hazards

Concept	Example
No	(Many)
Consideration of possible risks only in a long-term sense	Hazard zoning and/or active measures, but no alerting concept for the case of acute danger
To relay on accidental observations	Traditional conduct of well rooted mountain communities
To relay on well-aimed observations	Linesmen working and living along railroad tracks or roads (in Europe and North-America until the 1960s)
To relay on well-aimed observations and/or simple mechanical and electric alerting devices	Railroads and roads in mountainous areas
To relay on sophisticated electronic alerting devices	Railroads and roads in mountainous areas; ski resorts

blocked by debris or snow, etc. These well-aimed observations are being replaced or supported more and more by mechanical, electrical and sophisticated electronic devices.

This development generally may lead to earlier, more reliable and more comprehensive information and related early warning. However, if direct observations by individuals, who are very familiar with the natural environment of a given area, is fully replaced by sophisticated technical devices, probably the best and often most sensitive "neuronal network" is missing. This is one reason, why the author and some of his colleagues sometimes also recommend "antiquated" measures to communities, to railroad companies, etc.. For instance they recommend maintaining a high quality network of trails within steep forested slopes, that, for example, are release areas for rockfall. A dense network of good foot-paths may be the most important precondition to enable regular inspection tours, and to get early warning of imminent rockfall.

6.2 Places and Indicators

As already outlined in chapters 4 and 5, for each alerting concept the following must be defined where, at which place (starting, transition, and run-out zones), and in which phase of process (disposition, triggering event, running process itself) the indication must be gathered. As it is drafted out in Figures 3 and 5, there are some essential contradictions between reliable and timely warning.

In many cases the most emphasis is given to *reliable warning*. This is the case for several sections of railroads in mountainous areas. Avalanche warning devices at the Gotthard or the Lötschberg railroads (Switzerland) are installed in the track of channeled snow avalanches (transition zone). Here, wires or wire meshes are triggered by the avalanche itself, thus in the phase of the ongoing process only. The place of the device has to be chosen, so that there is enough time, to allow a train, already passing the endangered place, to still leave or that an approaching train can stop.

A similar device, for instance, is installed at the Mont Cenis railroad (France) to prevent debris flow disasters. Here the alarm is triggered by a pendula (installed below bridges), that are risen by the passing debris flow.

This type of warning must be automated to a high degree, because immediate reaction (e.g. to put signals on red) is required. Especially for railroads, it is also crucial to have reliable alarms. This is not only for safety reasons, but also to avoid false alarms, that would cause a lot of trouble to the traffic system and finally to the whole economy, depending on it.

There are other situations, where more emphasis is given to early warning. Here it is necessary to relay on indicators, that give information on the current disposition.

The triggering of dangerous processes takes place if the threshold value of a relevant factor of influence is equalised or exceeded. The more pronounced the current disposition for a dangerous process is, the closer the possibility that the threshold value of the crucial releasing factor is exceeded.

In practice, the difficulty in hazard assessment, is first to know the relevant factors, and, secondly to know the appropriate critical threshold value.

For example it is proven that many landslides occur in connection with intense and long-duration rainfall. The crucial factor, however, is not the precipitation, but the hydrological status of the soil of the concerned slope. Thus the threshold values of the pore water

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pressure should actually be determined. This involves high expenditure, which can be justified only in rare cases. On the other hand, it is relatively easy to look for threshold values in the amount and the intensity of rainfall. Therefore already numerous appropriate correlation attempts have been made (e.g. Crozier 1986). However these values only consider indirectly one effective factor on the dangerous process. Such threshold values can at best be used as an approximate information.

There are similar problems with other dangerous processes, for example with the correlation "precipitation – discharge of water – sediment discharge" in a torrential system.

However, despite such difficulties there is a high demand for early forecasts. For example this is the case for an early forecast of the regional snow avalanche situation. This requires the analysis of meteorological parameters and parameters indicating the state of the variable disposition of the snow cover. An automated system has already been reported by Armstrong, Ives (1976).

An important task is the new Swiss avalanche warning and information system (IMIS) that includes some 60 automated stations in the altitudinal belts related to the usual avalanche release areas (Russi & Stucki 1998). Here the relevant meteorological and snow-cover-related data are gathered. Of course one aspires to high reliability here. This task requires much experience and well-based models describing the relation and correlation between such data and the real avalanche situations. It must be emphasised, that IMIS is not used for automated avalanche forecast, and that the forecast is carried out by expert teams, applying their own "neuronal network".

Another example is the *flood warning along the Rhine* including Switzerland, Germany, France, and the Netherlands. Operational discharge forecast centers, calculating their own discharge forecasts, exist in all countries of the Rhine basin. These forecast centres cooperate closely in exchanging information and know-how. At a certain critical discharge level, a flood alarm will be transmitted to an alarm centre. The centre is then responsible for disseminating the alarm to the interested bodies. The forecast period is between 6 and 66 hours. An extension to longer forecast periods is not possible today because of the lack of meteorological forecasts of sufficient accuracy. Up-dates of the forecast are made every hour or daily. In the mountainous region of the basin, mainly rainfall-runoff models are used for forecasting. In this case the forecast is based on a three-day quantitative precipitation and temperature forecast. Rainfall radar is used for qualitative assessment. Downstream forecasts are mainly based on statistical approaches and on flood routing procedures.

Both examples, IMIS and Rhine, show the importance of a combination of automated data gathering on one hand, and analysis and interpretation by experts on the other hand. Such a combination, is of course only possible, if there is enough reaction time.

7 Information – Information Transfer – (Re)action

The best and most sophisticated alarming concepts and systems are useless, if the information transfer to the relevant target people is not guaranteed. And it is useless, if appropriate reaction models are not prepared.

There are optimal preconditions within organized systems, like railroad companies with imparted responsibility for track and operation. From the technical point of view it is also easy to close roads. However there may be individuals, truck or taxi companies, that do not understand, why roads are closed. In threatened settlements people may agree to temporal mitigation measures such as building dams with sandbags against floods. However they may be very reluctant to be evacuated.

Thus it is important, to not only consider the scientific and technical aspects of early warning, but also the psychological and sociological aspects: It is essential, that early warning systems are very well applied by the involved experts, by the regional and local authorities and by the population.

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Movement Studies to Forecast the Time of Breaking off of Ice and Rock Masses

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Abstract

The prediction of the time of breaking off of unstable ice or rock masses can be important if settlements or other fixed features (roads, railway etc.) are located within the potential hazard zones. Two such events happened recently in Switzerland. The first one was an icefall from a hanging glacier situated on the west-facing slope of Eiger (Bernese Alps). A large icefall has the potential of impinging on tourist facilities located in the immediate vicinity of the Jungfraujoch-railway station Eigergletscher. The second case concerns a rock destabilisation which occurred from a rock wall in the vicinity of Jungfraujoch. This unstable rock mass threatened the exit of a tunnel used by tourists leaving the Jungfraujoch railway station. In both cases, movement surveys were undertaken soon after first signs of a destabilisation. An almost perfect regularity by which such unstable masses accelerate prior to the time of breaking off could be recognised. The time of failure can be predicted quite accurately by extrapolation of the deformation-time function, which has been approximated by a hyperbola.

1 Introduction

Although large icefalls from steep glaciers or large rock falls in the Alps are rare, the consequences of such events can be dramatic. Often they are restricted to inhabited and remote areas. Sometimes this is not the case. The main objective is then to look for means by which damage to property can be reduced and loss of life avoided. While the most important factors responsible for the destabilisation of large ice or rock masses are known in principle, the complex feedback mechanisms influencing the relationship between these factors make an accurate assessment of the stability of ice or rock masses difficult. Furthermore, direct measurements on such glaciers or rock walls remains a difficult and dangerous task. The distribution and development of crevasses and, more generally, the flow pattern can help to delineate an acutely unstable ice mass. Aerial photographs combined with photogrammetric investigations are very useful to recognise potential ice falls. Major rock falls are usually preceded by a noisy opening of joints accompanied by increased debris fall activity. The deformations prior to the main breaking off are much smaller in rock falls than in ice falls and a precise terrestrial survey (geodetic, joint opening, extensometers etc.) of the unstable rock masses is necessary.

A warning by an expert is difficult to use for hazard mitigation unless it includes a forecast of the time of final rupture. At present the most promising approach for such a prediction is the regularity by which certain large ice or rock masses accelerate for a long time prior to the instant when the avalanche begins. In the case of a hanging glacier on the Weisshorn (Valais, Swiss Alps), the village of Randa was severely damaged in 1819 by a very large com-

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bined snow and ice avalanche. This led to a detailed study in 1972/73 of a seemingly threatening situation. A volume of approximately 5×10^6 m^3 of ice was accelerating in a characteristic way on a slope of about 45°.

2 The Weisshorn Case Study

In 1972 the formation of a prominant crevasse on the hanging glacier on the Weisshorn gave cause for alarm, leading to movement surveys at the surface of the hanging glacier. A hyperbolic law has been found to best fit the data on change of velocity with time (Flotron 1977; Röthlisberger 1977). The following hyperbolic function:

$$u = u_0 + a(t_\infty - t)^n \qquad (1)$$

(u is the velocity at time t; the other parameters are constants) was used to interpolate the measurements at different times t. Based on 20 measurements from 1970 and February 1973, the predicted time of breaking off $t_\infty = 4$th September 1973 ± 40 days was obtained (with $n=-1$, $a=1420$ cm and $u_0 = 3.0 \pm 0.5$ cm day^{-1}). The failure occured on August 19th, which was within the forecasted time interval. Figure 1 illustrates these results.

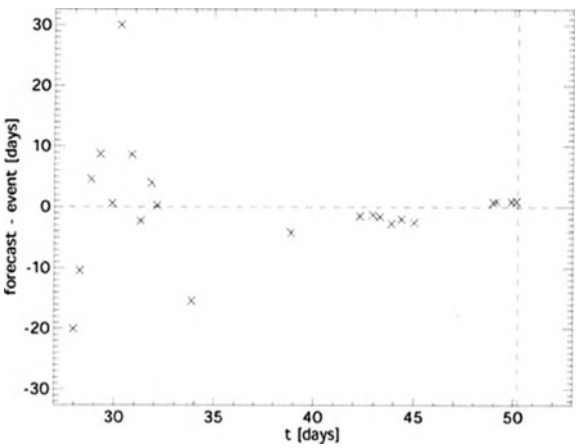


Fig. 1. Measured velocities u on the hanging glacier Weisshorn and hyperbolic function $u(t)$ (after Röthlisberger, 1981)

3 Recent Movement Studies on Hanging Glaciers and Rock Masses

In the following we present two recent cases where the time of breaking off was predicted successfully. The first case concerns a hanging glacier and the second one a rock fall. The breaking off forecast, that means the determination of t_∞, was performed by the integreted form of equation (1) (for $n=-1$):

$$s = s_0 + u_0 t - a\ln(t_\infty - t) \qquad (2)$$

where s is the displacement at time t since the beginning of the instability. Because equation (2) is nonlinear in the parameters, a nonlinear fitting method was used (Householder reflexion and Bevington regression). The advantage of using equation (2) instead of (1) for determining t_∞ is that the measured displacements s_i at time t_i can be directly used for the fitting procedure. This is not the case when equation (1) is used, since the velocity u_j has first to be determined from the s_i measurements. In that case the corresponding time t_j to a velocity u_j is not clearly defined.

3.1 Case Study Eiger

A hanging glacier situated on the west-facing slope of Eiger (Bernese Alps, Switzerland) regularly releases chunks of ice at the glacier front. A large icefall (more than 100 000 m^3) has the potential to impinge on tourist facilities located in the immediate vicinity of the Eigergletscher railway station. It is therefore essential that an icefall event be predicted accurately so that the endangered area can be closed off and, if necessary, evacuated in time. In March 1990 a large crevasse behind the glacier front was observed by the Jungfraujoch railway security personnel. Three stakes with prisms, were installed on the unstable glacier part and regularely surveyed from the station Eigergletscher by electronic distance measurements. On the base of 13 measured positions s the forecasted time for breaking off t_∞ was August 17th ±6 days. On August 20 (1990) 100 000 m^3 of ice broke off and the consecutive avalanche stopped some 200 m south-east from the railway station. This event occured well inside the predicted time interval.

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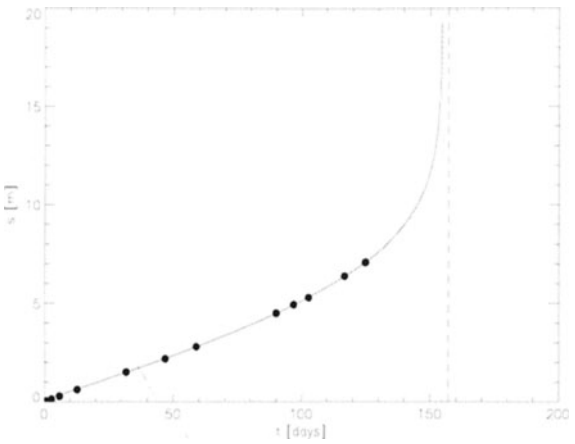


Fig. 2. Eiger ice fall: Measured positions s (circles) and the obtained hyperbolic function. The vertical dotted line shows the calculated t_∞ and the vertical dashed line the observed breaking off time (day 0 corresponds to March 16, 1990)

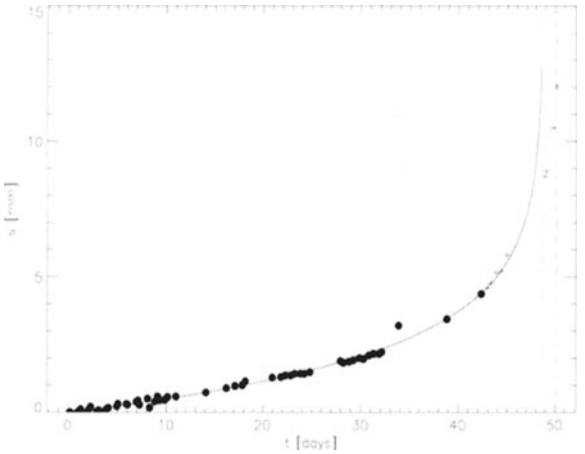


Fig. 3. Jungfraujoch rock fall: Measured displacement (circles, crosses) s as a function of time and calculated hyperbolic function (day 0 corresponds to August 12, 1991). Measurements represented by circles were used for the fitting procedure

In Figure 2 the fitted hyperbolic function and the 13 measured displacements *(s)* between March 16 and July 11 1990 are shown.

3.2 Case Study Jungfraujoch

Jungfraujoch (3500 m asl) can easily be reached by the Jungfrau railway. Up to 10000 people/day enjoy Jungfraujoch and the surrounding tourist facilities. A tunnel allows the visitors to reach the Jungfraufirn glacier from the railway station. The tunnel end at the glacier is exposed to debris and rock falls. In summer 1990, fresh vertical cracks were observed in the rock wall above the tunnel exit. The unstable rock mass was surveyed and joint openings were measured. During the following winter the displacements decreased and in early summer 1991, when melt water intruded the joint system, the displacements increased again.

To survey the unstable body more precisely, two electronic extensometers crossing the dominant crack were installed in July 1991. Clear deformations were measured with one extensometer in the first weeks. As soon as the deformation rate u reached 0.1 mm/day, the exit to the glacier was closed for safety reasons (August 8th 1991). A new tunnel with a save exit to the glacier was constructed to provide safer tourist access. At the end of August 1991 displacement rates above the old exit were still increasing (see Fig. 3) and on October first at

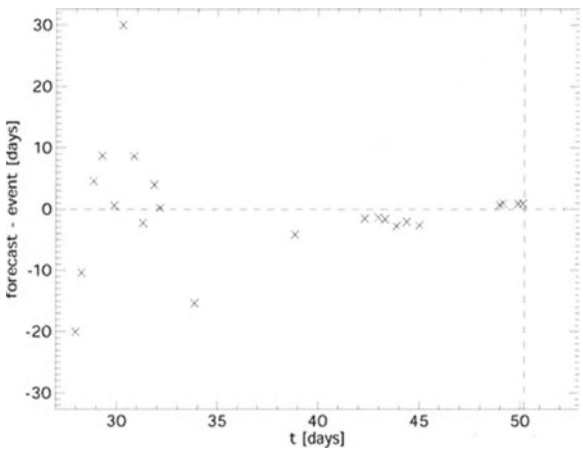


Fig. 4. Time difference between forcasted and observed breaking off as a function of time approaching final breakage (the dashed lines show the observed break off time)

3:30 pm some 3000-5000 m^3 rock material fell on the glacier. Although the displacements were very small, the precise measurements helped to forecast this event and guaranteed the safety of visitors.

In the period 2.5 months prior to the rupture, more than 130 extensometer readings were performed. The final acceleration phase of the unstable rock started at the beginning of August 1991. Starting with the measurement on August 12th (day 0) t_∞ was calculated with equation (2). On September 23th the calculated t_∞ was only 1.5 days before failure occurred (Fig. 3). Figure 4 demonstrates the improve-

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ment of the forecast with the readings approaching the time of breaking off. In the final two weeks preceding the rupture, the forecast was better than ± 4 days. The last reading was taken only two hours before the actual rupture. By that time (Fig. 4) t_∞ was 22 hours after the event. This suggests that the final acceleration phase is not well represented by the proposed hyperbolic function.

4 Conclusions and Perspectives

The limitation of this forecast method lies as much in the short-term irregularities as in the extreme difficulty of obtaining sufficiently accurate data without interruption. The time of breaking off t_∞ in equation (1) or (2) arises when $u \to \infty$· In reality we expect the ice or rock mass to fall for $t < t_\infty$. But there is a lack of experience on the critical velocity and acceleration that is reached immediately before final rupture. The results presented here were obtained by choosing $n = -1$ in equation (2). More experience, especially immediately before final breaking, is necessary to verify this value. A detailed analysis of the velocity-time function from other well documented breaking off events, especially in the final acceleration phase, would give more insight into the open questions. The physical explanation of the proposed hyperbolic law is another open question. Using a finite element computational model for the analysis of stress and flow in a two-dimensional model of an ice mass breaking off from a cliff, Iken (1977) has shown that a stepwise crack extension alternating with viscous flow leads to the observed form of the velocity-time relationship. In the case of rock falls, the process is different. It is therefore possible that another type of law is more appropriate for rock falls.

There are other possibilities of preventive measures. However, none of them are completely satisfactory. The most certain consists of avoiding the danger zone altogether. There is a basic rule applicable especially to important ice falls, that if a particular one has occured once, it will happen again in a similar way. Unfortunately our records do not extend sufficiently far back to allow us to depend very often on this rule.

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Avalanche Warning Switzerland 2000

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Abstract

Avalanche Warning has been a key task of the Swiss Federal Institute for Snow and Avalanche Research in Davos (SLF) since it was established over half a century ago. In the past, the predominant methods used for avalanche forecasting at SLF have been conventional, i.e., snow stability and avalanche hazards were predicted without analytical techniques such as formal numerical and symbolic algorithms. A paradigm shift is currently taking place. Information systems and computer programmes are becoming more and more important, assisting the forecaster in collecting and analysing large amounts of field data. Furthermore, computer models are available which simulate processes in the snow cover and calculate local and regional avalanche hazards, thereby supporting forecasters and decision makers. However, the forecaster with his intuition, experience and local knowledge still plays a decisive role in the forecasting process. While the computer helps to assimilate information, to assess the hazard risks, to support the forecaster in his decision and to distribute forecasts via modern communication channels, it is still the forecasters ultimate responsibility to check and modify the computer's prediction. This new way of avalanche forecasting, which we call 'computer-aided avalanche forecasting', is currently being implemented in Switzerland.

1 Introduction

About 65% (or 26975 km^2) of Switzerland's area is alpine country with about 580 km^2 of controlled ski area and over 1800 transportation facilities, such as cable cars or ski lifts, with an estimated capacity of 450 million pvm/h (person vertical meter or capacity to transport a person one vertical meter per hour). Approximately 1.7 million people (or 25% of the Swiss population) live in alpine regions, and a number of important highways and railways cross the Alps. For example, over 19000 vehicles daily cross the Gotthard Pass, a very important transit route between Italy and Germany (the figures mentioned above are from the Alpenreport 1998). It is therefore no surprise that avalanche mitigation has always played an important role in the life of the people living in the Alps. Over the past 50 years about 1.7 billion Swiss francs have been invested in engineering work for avalanche protection such as snow supporting structures, deflectors or snow sheds. This together with avalanche hazard zoning, has led to a high degree of safety (compared to other hazards) in densely populated areas and on roads with high traffic volumes. Such permanent measures are not cost effective to protect recreational activities such as off-slope skiing and ski-mountaineering, or less frequented roads or sparsely

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populated regions and ski areas. Temporary measures such as evacuation of buildings during hazardous periods, temporary closure of roads or ski runs, artificial release of avalanches and careful route planning are all of low cost and are more flexible. They require, however, an effective avalanche warning service supported by an avalanche awareness programme.

2 The Swiss Approach

Since 1945, the Swiss Federal Institute for Snow and Avalanche Research in Davos (SLF) has been in charge of the national avalanche forecast which covers an area of about 27 000 km^2. Based on daily snowpack observations and avalanche occurrences from a) a network of about 40–75 manned stations, b) information about the current weather c) the weather forecast and d) about 100 snow profiles recorded twice a month, an avalanche bulletin has been compiled two to three times a week, or whenever the situation changed dramatically. Up until 1997, the bulletin has been issued at around 10 a.m. The structure and information content of the bulletin has improved considerably over the years. Furthermore, with the introduction of the European Avalanche Hazard Scale in 1993, a common language to describe the snow cover stability and the probability of an avalanche release has been established which is now being used in all European countries (Meister 1995).

Until the early 1990s, avalanche forecasting at SLF was mainly based on intuition, experience and local knowledge of the forecaster. While these factors still play an important role today, progress in snow and avalanche research, especially in the development of computer models as well as rapid developments in sensor, communication and information technology during the last 5 to 10 years, have opened up new paths in avalanche forecasting[1]. Mathematical analysis of measurements, numerical simulations of weather and snowpack and symbolic and statistical computations of the avalanche hazard are the key elements of modern avalanche forecasting, which can be described as 'computer-aided avalanche forecasting' (CAF). A similar approach is currently being implemented and tested in France (Durand 1997).

It is obvious that this largely office-based forecasting must rely heavily on a mesoscale weather forecasting model which accurately predicts parameters such as precipitation (amount and intensity), temperature and wind. Furthermore, online field data from a dense network of remote snow and weather stations are needed to drive the computer models, as are avalanche observation reports to provide feedback for the verification process. While a fully computer-based forecasting system has difficulty processing incomplete or contradictory data, a computer-aided approach combines the objectivity of a formal procedure with the advantage of combining computed information with the forecaster's intuition, experience, knowledge and personal observation. This is the basic philosophy behind the programme *Avalanche Warning Switzerland 2000,* launched in 1995. The overall aim of this programme is to modernise avalanche warning in Switzerland and to improve temporal and spatial resolution of avalanche forecasting on a national, regional and local level, thereby helping to prevent avalanche accidents. In order to achieve this goal, the following tasks have to be accomplished:

- Building a network of remote snow and weather stations to measure parameters such as precipitation, wind, radiation and temperature near avalanche source zones.
- Establishing an information system to link local, regional and national centres, and to distribute warning information to the general public. This information system should make use of electronic communication channels such as the Internet, telephone, fax as well as radio and TV stations.
- Developing computer programmes to model snowpack factors such as density, settlement, temperature distribution, metamorphism and stability as well as the redistribution of blowing and drifting snow by wind.
- Implementing computer programmes to calculate the avalanche hazard on a local and regional level.
- Providing avalanche forecasts tailored to the needs of the different user groups (e.g. recreational skiers and mountaineers, mountain guides and ski patrollers, safety services). This together with an avalanche

[1] Weather forecasting, which is similar to avalanche forecasting (e.g. physical models, simulation tools or analysis procedures) were through a similar transition about 10 years ago.

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awareness programme, should help to ensure that everybody who travels through avalanche-prone terrain has the necessary information and knows how to use it.

3 Architecture

Figure 1 shows the general architecture containing all major modules and information paths. Shaded boxes denote input sources and white boxes indicate computer models.

3.1 Input Data

Three types of information sources are used as input:

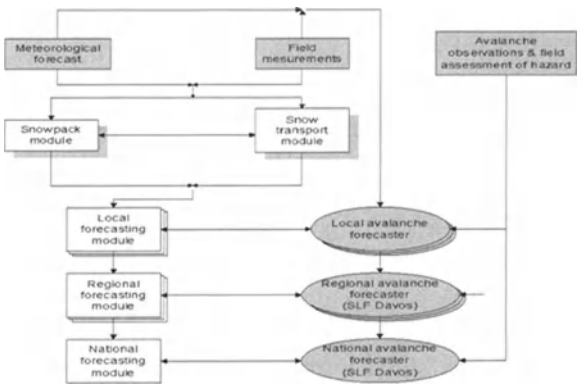


Fig. 1. General architecture

- meteorological forecasts #
- measurements
- avalanche observations and field assessments of the avalanche hazard.

For the meteorological forecast (e.g. precipitation, temperature, cloudiness and wind) the weather prediction model of the Swiss Meteorological Institute (SMI) is used with a grid spacing of 14 km (Majewski 1991).

For field measurements, data from about 65 automatic weather stations of the SMI can be accessed. Furthermore, about 60 automatic snow and weather stations of the SLF, which are located near avalanche sources zones at altitudes between 1600 and 3200 m a.s.l., and 75 manned observation stations of the SLF are available. Figure 2 shows the location of the automatic snow and weather stations together with the manned observation stations. While the automatic stations measure snow and wind parameters every 30 minutes the observers transmit their measurements once or twice a day. The continuous stream of data from the automatic weather stations is used to drive the various computer models such as the snowpack model. Furthermore, about 100 snow profiles are available at fortnightly intervals.

Avalanche observations and subjective judgements regarding local avalanche hazard represent the third information source available. We receive these from our observation stations and

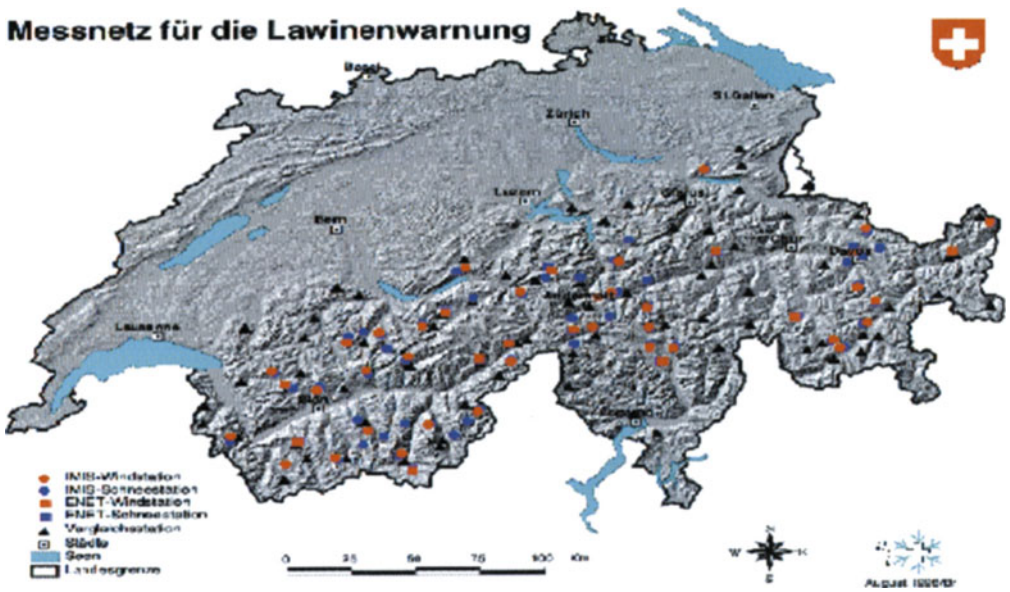


Fig. 2. Locations of the remote snow and weather stations and manned observation stations

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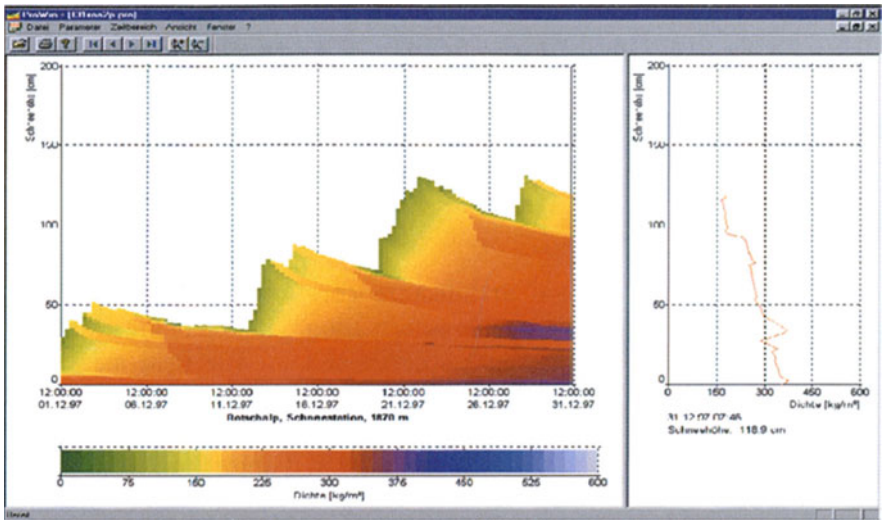


Fig. 3. Example of a density evolution profile at the location of a remote snow station

from guides and ski mountaineers using standardised questionnaires (between 500 to 1000 per winter) (Brabec et al. 1998).

3.2 The Snowpack Module

The formation of avalanches is determined by the mechanical properties of the snowpack and its failure as a result of applied stress. Slab avalanche or a loose-snow avalanche formation requires that the shear stress equals or exceeds the shear strength. In order to assess the mechanical stability of a snowpack, the sheer strength of the snowpack must be known. The calculation of the sheer strength is, however, difficult, and requires a thorough understanding of the physical processes in the snowpack. A one-dimensional snowpack model (see Fig. 3) is being developed at SLF (Lehning et al. 1998 a; Lehning et al. 1998 b). It calculates parameters such as snow height and settling rate, amount of new snow, temperature and density distribution in the snow pack, an index on the formation of surface hoar as well as melting, sublimation and water transport. A metamorphism scheme is under development. Microstructural parameters, such as grain size and coordination number, are used establish a link to mechanical properties such as viscosity. The final aim is to describe weak layers and their mechanical stability.

3.3 The Snow Transport Module

Blowing and drifting snow is a major feature of mountain snowpack, and essential for avalanche forecasting. The task of the snow transport module is to quantify and forecast snow transport by wind. In a first step, a local snowdrift index will be developed using wind speed measurements from the remote snow and weather stations, together with the snowpack model which provides information on snow erodability. This nowcast index will be extended to a short-term forecast index using the output of the SMI's weather forecast model. In a second step, a more regional approach will be pursued to calculate a high resolution assessment and forecast of snow transport by wind (Gauer 1997). In this step, an mesoscale atmospheric flow model with an interface to SMI's forecasting model will be applied.

3.4 Local Forecasting Module

In order to assist local avalanche forecasters, an avalanche prediction system based on the nearest neighbour method (Buser 1983) was developed a number of years ago. Using non-parametric statistics, the programme searches the database for 'similar cases'. For each day, the system stores a set of snow and weather parameters (numerical values) together with the avalanche events. Using a suitable distance measure, the nearest neighbours can be calculated. This approach has been widely used in Switzer-

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Fig. 4. Input and output window of NXD2000, the Swiss local avalanche forecasting system

land and abroad (Buser 1989; Kristensen et al. 1994) for local avalanche forecasting[2]. An improved version of the programme called NXD2000 (see Fig. 4) is available and will be developed further in three respects. Firstly, the system is being connected to the network of automatic stations.

This allows the automatic collection of input parameters such as wind, temperature, new snow, density or radiation from locations near avalanche source zones, rather than taking measurements manually. Since the parameters are measured every 30 minutes, not only single data points but also trends, such as a temperature rise or fall, can be taken into account. Secondly, by coupling the system to the snowpack and the snow transport module, parameters such as density, temperature distribution, surface hoar index as well as stability and drift index can be included. Thirdly, by connecting the local avalanche forecasting systems to the snow and avalanche information network, the local forecast as well as the local avalanche observations are available at the national centre in Davos.

3.5 Regional Forecasting Module

The national avalanche bulletin issued by SLF covers all parts of the Swiss Alps. Since the winter 97/98 it is issued daily at 5 p.m. as a forecast for the following day, with an outlook for the following two days. Its structure and content is synoptic, describing the general snow and weather situation and listing the avalanche hazard levels for every region using the European Avalanche Hazard Scale (see Fig. 7). With the tremendous growth in winter sports, the demand for a more regional forecast[3], i.e. more detailed forecast, has encreased. This forecast must be easy to understand by people with little avalanche education. As part of the programme *Avalanche Warning Switzerland 2000*, regional avalanche forecasts were introduced in 1997. Figure 5 shows an example of a regional forecast of the Grison region, an area of about 5000 km^2. For each sub-area, the hazard level, with corresponding slope aspect and altitude range, is given.

In order to support the forecaster, a computer programme is under development to calculate the regional avalanche risk. This model

[2] The term local (or microscale) avalanche forecasting is used to describe avalanche prediction on a small scale, i.e. for an area of up to 100 km^2.

[3] In our terminology, regional forecasts cover an area between 1000 and 5000 km^2.

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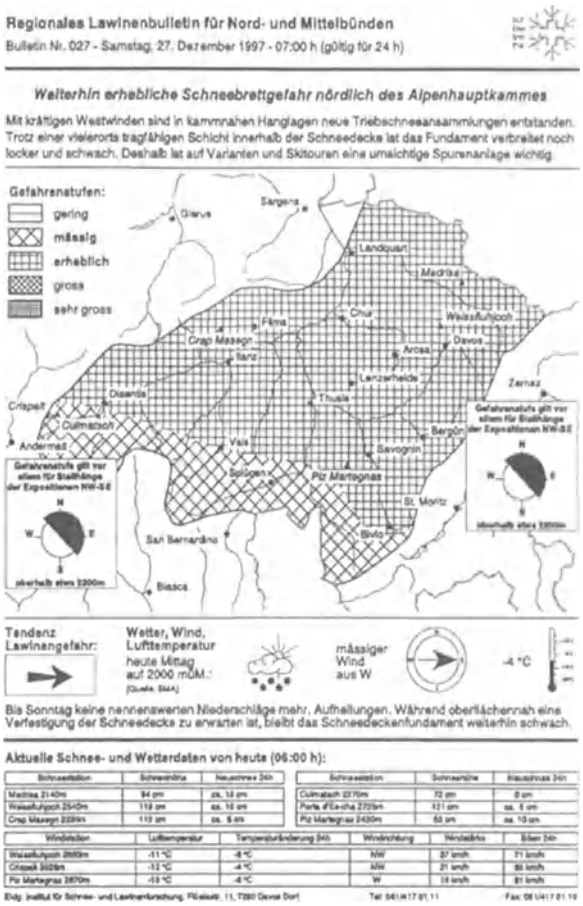


Fig. 5. Example of a regional forecast for the Grison region in Switzerland

employs data from remote snow and weather stations, measurements from manned observation stations, as well as information from snow profiles to generate the hazard level with the corresponding slope aspects and altitude range. The computer model generates a data structure which contains, for each area, the predicted hazard level with the corresponding slope as pect and altitude range. At this stage, the forecaster can manually check and alter the model's prediction. When the editing process is finished, the bulletin is generated fully automatically (for an example, see Fig. 5).

3.6 Role of the Forecaster

With the implementation of the programme *Avalanche Warning Switzerland 2000*, the role of the forecaster is changing. In the past, experience, intuition and local knowledge were the most important skills. In the future, the forecaster additionally needs analytical skills as well the knowledge on how to interpret the output of the models. Having all the information at his fingertips, the difficult task of the forecaster is to quickly survey the information, to judge the different factors and to make decisions based on various pieces of, sometimes contradictory, information. In particular, his task is to analyse the field data and the various predictions of the weather forecasting model. Furthermore, the output of the snowpack model has to be studied and compared to the snow profiles from our field observers. The output of the hazard prediction model has to be checked and compared with the avalanche reports. The forecaster's findings and decisions are discussed at the daily briefing. Moreover, a supervisor has to check the quality of each forecast

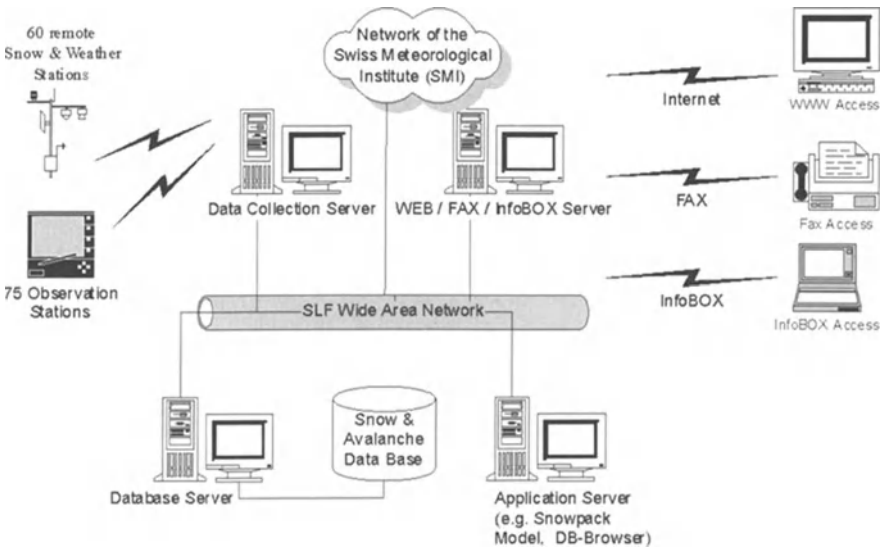


Fig. 6. Snow and avalanche information network

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Fig. 7. Browser with selection panel (left) and selected document, i.e. national forecast (right)

issued. At the moment, we are in the process of establishing a formal procedure and a set of rules which should guarantee the quality and objectivity of each forecast.

4 Avalanche Information System

Figure 6 shows the information system which links the various input sources, the different computer systems, the data base and the distribution channels. A data collection server downloads data from remote snow and weather stations at hourly intervals, and collects the data from manned observation stations once or twice per day. This information is fed into the national data base, a relational database system, which acts as a central data store. Various applications (e.g. snowpack module, regional forecasting module, database browser or GIS-applications), which run on the application server, access this database. A WEB/MAIL/FAX server is used to allow the general public to retrieve the forecasts via the WWW (World Wide Web), or to receive them by mail or fax. An InfoBOX server is used to communicate with local forecasters, ski patrollers and safety experts in the different parts of the country.

4.1 Internet

Over the last few years the Internet has become a very popular way to distribute information. More and more people have access to the Web. During the winter of 96/97, about 65000 requests for information (see Fig. 7 and 8 for an

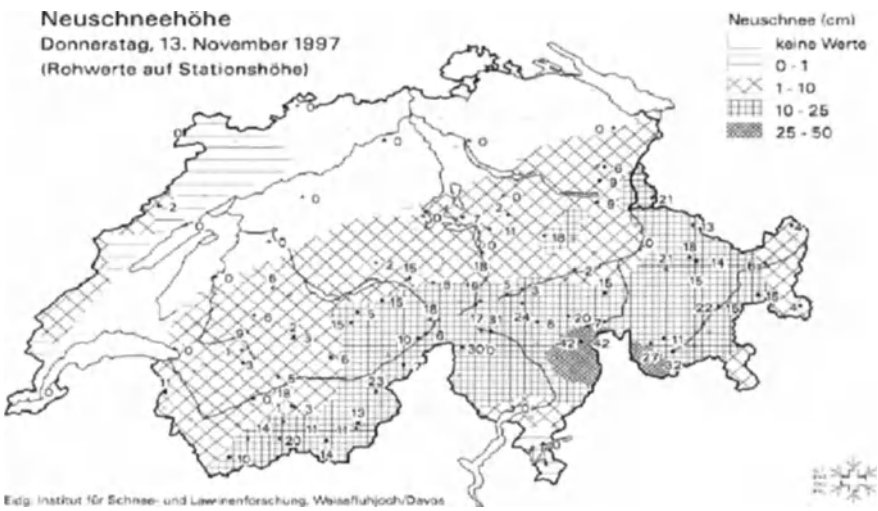


Fig. 8. Map of Switzerland with the amount of fresh snow

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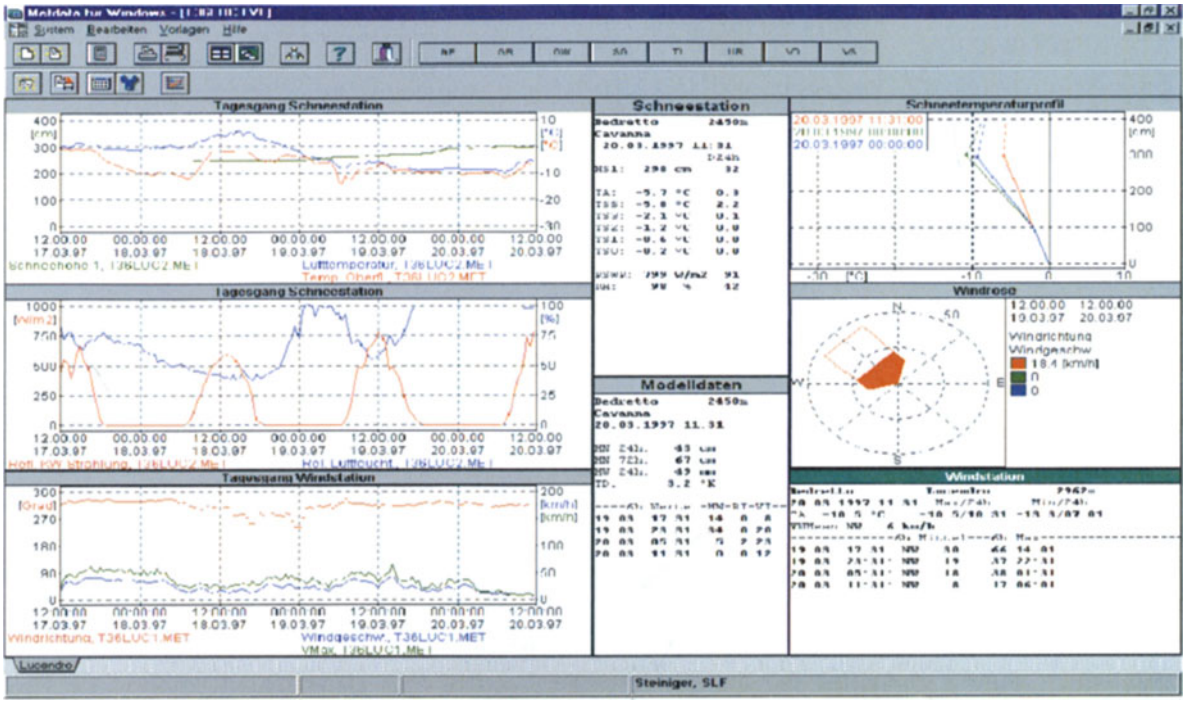


Fig. 9. InfoBOX window showing a 3-day plot from an automatic station

example) over the web were processed. During the winter of 97/98, this number increased to about 350 000 requests.

4.2 InfoBOX

While the web is the main information channel for the general public, a service called InfoBOX was set up three years ago. This service links national, regional and local avalanche specialists in Switzerland. So far, about 140 specialists, i.e. people who are in charge of avalanche safety in villages or towns, in ski areas or on highways, are using the InfoBOX service. Via this service, snow and weather data from automatic stations (see Fig. 9) or weather forecasts can be accessed 24 hours a day.

Furthermore, the output of the different computer simulations, e.g. snowpack data, can be downloaded and displayed (see Fig. 3). The local forecasting programme NXD2000 is also part of the InfoBOX (see Fig. 4). The experience gained over the last three winters have shown that the InfoBOX software package is an extremely useful tool for local forecaster. In order to train the InfoBOX users and to facilitate the exchange of ideas, a workshop is organised annually at the beginning of the winter by SLF.

5 Conclusions and Outlook

In this paper, the programme: *Avalanche Warning Switzerland 2000* has been described. While the overall aim is fairly ambitious, the implementation is pragmatic. Each module of the system is implemented, tested and evaluated independently. Each winter, new components are added and existing components are improved. Because the system is used operationally by local, regional and national forecasters, our research team gets valuable feedback. Over the next two years the main effort will be spent on developing the snow transport module and improving the snowpack module, and the local and regional forecasting module.

While a scientific evaluation of the different modules will be very important, we will also pay close attention to the needs of our forecasters as well the needs of the snow boarders, off-slope skiers or ski mountaineers. From a scientific point of view, our aim is to improve our knowledge about avalanche forecasting. The most important task of the whole programme

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Avalanche Warning Switzerland 2000 is, however, to help prevent avalanche accidents.

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Monitoring the Conditions of Dangerous Lakes in Uzbekistan and Contiguous Territories

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1 Geological and Hydrological Background of Lake Hazards in Uzbekistan

Spontaneous hydrological events in mountainous regions in Uzbekistan and contiguous areas often come as catastrophic flash floods, mud floods or torrents (selej), landslides (opolsnej), and avalanches.

In recent decades, the areas of their occurrence have enlarged as a result of increasing man-made impact on nature, development of areas in mountainous regions and in the alluvial plains and water-meadows of valleys (w pojmach rek), and as a result of the accelerated increase of the population.

The most catastrophic flash floods, with considerable damage, can occur as a result of collapse of unstable embankments (peremytschek) of mountain lakes.

In the mountainous area of Central Asia we have about 3000 lakes of glacial, hydrogenous, tectonic, and "zaval" (sawalnuj) – (a result of landslide) – origin. The lakes are an integral part of the countryside. They have an impact on the water regime of the basins, the water cycle and the regulation of the runoff.

The water resources of the lakes are estimated at 51 km^3. Most of them have very clean water. This makes them very valuable for recreation use and other purposes.

Lakes with a "zaval" or glacial origin are potential sources of catastrophic flash floods which can cause considerable damage in the case of the collapse of natural dams.

Traces and results of embankments collapse of old lakes can frequently be observed in the Tien Shan and Pamir-Alai. N.G. Malitski recorded eight cases of flash floods resulting from a breakthrough of mountainous lakes between 1880 and 1930 in Central Asia. Heavy flash floods and mud slip occurred between 1960 and 1980 after the breakthrough of the dam of the "zaval" lake Yashilkul and other moraine-made and glacial lakes in the river basins of Zeravshan, Pandj, Isfaramsai. They all caused considerable economic damage. The breakthrough of two small lakes in the glacial area of the basin of river Koksu in June 1998 was the reason for a heavy flash flood with a lot of casualties and heavy damage.

Together with the collapse of dams of "zaval" and moraine-made lakes we very often observe in Central Asia floods which are linked with temporal occurrence of groundwater at lateral slopes of valleys, when glaciers pulsate with heavy avalanches and landslides.

2 Observation and Warning

The monitoring of the environment in Central Asia is in the hands of national hydrometeorological services as part of the state administration. Until 1991 there were about 400 meteorological stations in the Aral Sea basin; 475 points observing the runoff and more than 1000 points observing the formation and accumulation of snow in the mountains. Today, about one third of all observation points are not functioning. In particular those points, where the snow cover and the runoff of rivers in high mountain areas of Kyrgyzstan and Tadjikistan were observed, are out of service.

An important part of the monitoring is the unique system of observation, forecasting, and

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warning of dangerous and spontaneous hydrometeorological phenomena, particularly, the forecasting and warning of mud floods, should the embankment of a mountainous lake break through.

The methods of warning of mud floods caused by avalanches are based on forecasting synoptic processes in the atmosphere.

By the end of the 1960s and beginning 1970s the majority of big "zaval" lakes had been investigated by hydrogeologists. The degree of danger of breakthrough of the dams had been determined. Topographical maps of lakes and rubble heaps had been made. Morphometrical characteristics had been compiled. The structure of water balance had been estimated, and the hydrographs of flash floods in the case of breaking dams had been calculated. The zones of the possible overflow had been determined. It has been urgently recommended that the conditions of 22 "zaval" lakes in Uzbekistan, Kyrgyzstan, and Tajikistan be monitored. Floods of these waters would effect the territory of Uzbekistan.

Most of the lakes of glacial origin are found at a height between 3500 and 5000 metres. "Zaval" lakes predominate between 1500 and 4000 metres and are situated in zones of deep folds where tectonic events occurred in recent time. Natural disasters of this sort only occur after the snow-melt in the middle altitudes in May–June. The most cases of breakthrough occurred in July and the beginning of August.

Lakes in high mountainous areas exhibit some special features in their annual and perennial phenomenology. The natural embankments forming the lakes consist of loose moraines, ice, and other permeable materials. In summer we observe extreme variations in the levels of the lake watertables as a result of seasonal melt of snow and glaciers. Lakes can appear and vanish in the course of one year. The breakthrough of moraine-made and rubble heaped embankments as a result of landslides as well as the fall of moraines into a lake basin cause sudden overflow of water and destructive mud floods. The steep slopes of narrow valleys are washed out. The intensity of a mud flood can be even increased by precipitation in spring and summer.

Following special observations, it has been concluded that the main component of the water balance of "zaval" and moraine-made lakes in Central Asia is the melt of seasonal snow, perennial snow and glaciers. Rain plays a minor role only. Therefore the hydrometeorological determination of situations when flash floods can occur is based on the analysis of the available snow in the basin, on measures of the snow depth, on the determination of the height of the seasonal snowline, on the forecast of air temperature and other local and satellite meteorological data.

In case of adverse situations, the lakes are observed from helicopters, and additional hydrometeorological parameters are calculated. The inflow of water into the lakes is calculated with a runoff model which has been developed for small, mountain rivers. In extreme situations, a special temporary hydrometeorological observation network is organised.

Small glacial mud floods as a result of breakthrough of moraine-made and glacial lakes occur each year. The database "Ledniki" (glaciers) contains information on all pulsating glaciers of the region, if they are dangerous from the point of view of forming mud floods. If direct observation of the glacier is absent, the conditions are estimated from the temperature and hydrologic situation of the river at the next observation point downstream. If the runoff strongly decreases and if the temperature simultaneously increases, this indicates a new temporary embankment has been formed upstream and water is gathering behind it, forming a new dangerous situation.

3 The Glavigdromet Scheme of Action

The objective of Glavgidromet is the investigation and the monitoring of the conditions of dangerous lakes by estimating the short-range variations of hydrometeorological factors. The main system of warning of coming dangerous situations consists of:

- synoptic weather forecast,
- observation of the snow condition using satellite data,
- calculation of future runoff with models of water balance of lakes,
- special visual observation of lakes and temporary hydrometric nets.

The estimated variations of hydrological conditions of mountainous lakes and their water resources as a result of possible long-range

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anthropogenic variations of climate point out that the danger of breakthrough of unstable embankments increases mainly because new lakes occur in the zone in front of retreating glaciers as a result of atmospheric warming. The warmer summers allow more small lakes forming at the surface of glaciers, and their breakthrough also can result in mud floods. Increasing air temperature in summer intensifies the snow-melt and the corresponding run-off into lakes. This has an impact on the water balance and the volume of flow through the dams of existing "zaval" lakes. Furthermore increasing precipitation activates the landslide processes on the slopes and in the valleys of rivers and increases the probability of flash floods.

4 Facing a Critical Situation

The hydrometeorological services of the Central Asian countries, in the conditions of transforming economy, suffer from heavy financial difficulties. The hydrometeorological observations have been reduced and continue to be reduced. First to go are those which are very expensive: helicopter and other special observations of snow cover.

Under these conditions, it is of growing importance to improve the monitoring and the early warning system by means of high resolution satellite imagery. It is also necessary to develop a strategy to adapt the water management to possible variations in the conditions of mountain lakes caused by atmospheric warming. There is particularly high concern for waters with unstable embankments.

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VI Early Warning Systems for Fire and Other Environmental Hazards

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CHAPTER 6.1

The Contribution of the Global Fire Monitoring Center (GFMC) for Early Warning and Management of Wildfires

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1 Rationale

In many vegetation types of the globe the application of fire in agriculture and pastoralism and the occurrence of natural wildfires (natural fire regimes) are established (beneficial) elements in traditional land-use systems, in natural ecosystem processes and in biogeochemical cycles. Excessive application of fire due to rapid demographic and land-use changes, however, lead to destruction of productivity, carrying capacity, biodiversity and vegetation cover. Climate variability, such as periodic extreme droughts caused by the ENSO phenomenon, add to the severity of fire impacts. Projected demographic and climate change scenarios suggest that this situation will become more critical during the next decades.

The state of fire science (fundamental fire research, fire ecology) in most vegetation types, and the results of biogeochemical and atmospheric science research of the last decade provide sufficient knowledge for supporting decision making at fire policy and management levels.

It is observed, however, that in many countries the expertise is either not known or is not readily accessible and available for the development of adequate measures in fire policies and management. The fire and smoke episode of 1997–98 in South East Asia was a good example that existing fire information systems or fire management expertise was utilized to a limited extent only. These circumstances led to confusion at national and international decision-making levels and a critical delay in international response to fire and smoke emergencies.

In retrospect this could be explained by the lack of a regional South East Asian or – considering global fire problems – a global fire information system. Consequently, an information and monitoring system was designed which can be utilized by national and international agencies involved in land-use planning, disaster management or in other fire-related tasks for planning and decision making.

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2 The Global Fire Monitoring Center

The Global Fire Monitoring Center (GFMC) was established in 1998 in accordance with

- the objectives of the UN International Decade of Natural Disaster Reduction (IDNDR),
- the recommendations of the International Tropical Timber Organization (ITTO), the World Health Organization (WHO) and various scientific and policy conferences,
- the co-sponsorship of the UNESCO and the World Bank, Disaster Management Facility (DMF),

and was inaugurated on the Internet with the FAO consultation "Public Policies Affecting Forest Fires" in October 1998 (FAO 1998). In its first phase the GMFC is sponsored by the government of Germany (Ministry of Foreign Affairs), as a German contribution to the IDNDR. The fire documentation, information and monitoring system is accessible through: *http://www.uni-freiburg.de/fireglobe.*

The GFMC is established at the Fire Ecology and Biomass Burning Research Group of the Max Planck Institute of Chemistry, Germany. The expertise of the institute is twofold: First, the global scientific research and development work in the field of fire ecology, cultural history and socio-economics of vegetation fires, and science transfer into operational management systems and policy development began at Freiburg University in the mid 1970s. At the same time, the Max Planck Institute for Chemistry took the lead in investigating the role of vegetation fires in global biogeochemical cycles and atmospheric chemistry. The two institutions merged in 1990 and created the first interdisciplinary fire research institute.

In the 1990s the Max Planck Institute has been responsible for designing, coordinating, organizing and partially implementing several international fire research campaigns under the umbrella of the International Geosphere–Biosphere Programme (IGBP). The institute chairs the scientific steering committee of the fire science component within the IGBP (the Biomass Burning Experiment [BIBEX]).

Furthermore since the early 1990s, the Fire Ecology Research Group has taken the lead in the UN system through its role as coordinating unit of the UN-FAO/ECE/ILO Team of Specialists on Forest Fire. The UN team serves the UN agencies and other national and international partners in providing information and links in the field of global fire. Since 1988, the UN Team has been publishing the UN FAO-ECE International Forest Fire News (IFFN) which is distributed to nearly 1000 agencies, institutes, libraries and individuals world-wide. As of October 1998, the IFFN has been available on the GFMC Internet website.

Furthermore, the Fire Ecology Research Group is convener of the IDNDR Early Warning Programme Working Group "Fire and Related Environmental Hazards". The Fire Ecology Research Group has provided scientific and technical assistance to governments and institutions in all continents over the last 20 years. Through international scientific and policy activities the Fire Ecology Research Group has contributed to the formation of several international initiatives on fire issues, including the ITTO and WHO Fire Guidelines (ITTO 1997, WHO 1999).

3 Design and Outputs of the GFMC

Following the principles that were developed for a scientific Global Vegetation Fire Information System in the early 1990s (Crutzen & Goldammer 1993, Malingreau et al. 1993), in 1998 the Global Fire Monitoring Center began to document archived information, and provide real-time or near-real time information related to fire. This includes networking with other national, regional and international information systems.

The products of the GFMC are continuously updated and expanded. As of early 1999, the GFMC provides the following on-line information:

3.1 Near-Real Time Global Fire Data

Under the file "Current and Recent Significant Global Fire Events", sources and products of satellite remote sensing centers are displayed which are either updated daily or provide spaceborne fire information on a regular basis (usually in case of fire events recorded). The GFMC displays full satellite images or maps indicating high-temperature events. These images and maps are then

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- screened for misleading or false information on high-temperature events
- interpreted (mainly as wildfires vs. prescribed or other land-use fires)
- supplied with national or regional meteorological reports and forecasts (including fire weather forecasts and fire danger rating)
- supplemented with other information (e.g. hyperlinks to agencies providing detailed fire reports or summaries)
- explained in terms of ecological and socio-economic background information.

Between August 1998 and January 1999 the following regions were covered:

North America

Main source of remotely sensed fire information was the NOAA AVHRR satellites, made available through NOAA's Operational Significant Event Imagery (OSEI). The most important fire regions covered were:

- Canada (wildfires in the boreal coniferous zone)
- U.S.A. (wildfires throughout the continent; predominantly chaparral and forest wildfires in California and wildfires and prescribed burning activities in the Southeast)
- Mexico (wildfires and land-use fires).

Interlinks to agencies in all three countries are provided in the daily fire updates. In the case of fires in Florida, the GFMC instigated a photo archive with explanatory information on background, objectives and limitations of prescribed burning in forestry and ecosystem management of southern forests and wetland ecosystems.

The global wildland fire photo archive of the GFMC will gradually be made available for all continents and fire regions.

South America

Besides satellite information provided by OSEI, the GFMC also displays the daily fire observations by the National Brazilian Space Institute INPE. INPE covers the South American countries between Venezuela in the North and Argentina in the South. The main fire activities in South America are land-use fires and wildfires in the "Arc of Deforestation" in Brazil.

Explanation and cross-links to Brazilian and World Bank programmes are provided at this site.

Eurasia

The main fire regions of Eurasia (Europe and Central-Eastern North Asia) are in the boreal coniferous forests of Siberia and the Far East of the Russian Federation. The GFMC displayed NOAA AVRR date provided by OSEI and linked to sources in the Russian Federation. At the end of the 1998 fire season (October 1998) statistical fire data from the Russian Aerial Forest Fire Protection Service Avialesookhrana and other background information from the GFMC archive were provided.

South Asia

South Asia is explained in detail under South East Asian Fire Monitoring (see 3.2).

Australia

GFMC produces a daily composite pan-Australian fire map based on the regional geocoded and manually evaluated fire observations by the Satellite Remote Sensing Services Department of Land Administration (DOLA). Recently, GFMC has superimposed the DOLA fire event information on a composite Australian vegetation zone map.

Interlink information is provided by the Australian Bureau of Meteorology and Australian Fire Management Agencies.

3.2 South East Asian Fire Monitoring

The application of fire in land-use systems and wildfires in forests and other vegetation in Indonesia and neighboring countries within the South East Asian region have reached unprecedented levels, and have lead to severe environmental problems and impacts on society. Traditional slash-and-burn systems in the shifting

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agriculture mode are increasingly being replaced by modern large-scale conversion of forest into permanent agricultural systems which are partially maintained by fire, and into forest plantations. Wildfires escaping from land-use fires are becoming more and more common. The impact of land-use fires and wildfires is detrimental to biodiversity and the regional atmospheric chemistry. In Indonesia and within the South East Asian/ASEAN region, a joint concerted approach is needed to cope with the problem of transboundary pollution caused by vegetation burning. However, since fire is an essential tool in land use in the tropics, a response strategy must be developed in which the benefits from fire use are encouraged, and at the same time, the negative impacts of fire are reduced. National and regional fire management plans and policies must take into consideration the complexity and diversity of fire uses in different vegetation types and land-use systems.

Background Information

As an introduction several analyses are presented on this web page which were prepared by the Fire Ecology Research Group, the host of the Global Fire Monitoring Center. The analyses cover fire policies, management, research and basic fire ecological information on the SE Asian region.

Projects and Programmes

As a consequence of the fire and smog episode of 1991 in SE Asia (which was mainly caused by fires burning on the Indonesian archipelago), for the first time the Government of Indonesia called in international cooperation to support national fire management capabilities. In June 1992 an international conference on Long-Term Integrated Forest Fire Management was held in Bandung. All projects and programmes initiated and implemented after 1992 (including the post-1997 projects) are contained in this file. Particular emphasis is placed on analyses of the 1997–98 fire and smoke episode by providing numerous reports on file in the GFMC.

Current Meteorological and Fire Information

This part of the South East Asian Fire Monitoring activity is identical to the first GFMC file "Near-Real Time Global Fire Data" (3.1). It provides daily/regular analyses of the meteorological conditions in South East Asia and displays the ASEAN Fire Weather Information System (ASFWIS) which provides maps describing the current fire weather situation in South East Asia. This system is based on the Canadian Forest Fire Danger Rating System (CFFDRS). After verifying this information with meteorological reports and forecasts by the Indonesian Meteorological Agency and the Meteorological Service of Singapore, fire warnings are issued. Early warnings and extreme fire dangers are explicitly issued in case of changes in fire-weather conditions (blinking red warning signal).

Satellite-derived (NOAA AVHRR) information on active fires are taken or cross-linked to the following receiving stations: Meteorological Service of Singapore, the GTZ (Germany–Indonesian) Integrated Forest Fire Management (IFFM) project in Samarinda (East Kalimantan) and the EU–Indonesian Forest Fire Prevention and Control Project (FFPCP) in Palembang (Sumatera).

3.3 Global Fire Inventories and Models

Global Vegetation Fire Inventory (GFVI)

Assessments of the past, present, and future role of fire in ecosystems, land-use and atmospheric chemistry rely in part on fire inventories, which must be constructed on appropriate spatial and temporal scales. An internationally standardized statistical fire reporting procedure and format is not yet in place.

In the first part of the inventories file, the GVFI produces its continuously updated set of data which is taken from (a) published regional and national statistics (see next paragraph) and (b) reports from agencies provided bilaterally on request by the GFMC (which operates GVFI). GVFI envisages the development of a standardized and globally recognized fire inventory system which is currently under discussion. The proposals – while not yet in agreement with the FAO – are provided in this file.

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The fire data to be collected include wildfires as well as different types of fire application in land-use systems.

Remote Sensing Products

This file provides all links to institutions which have produced case studies or regularly published datasets on active fires or areas burned in various regions or globally. Currently the remotely sensed fire products provide reliable time-space calendars of fire events but are not suitable for burned-area assessments except for case studies.

Fire Statistical Databases

Besides the statistical databases contained in the GVFI files and the more detailed national fire statistics which can be found in national reports or in the country files of International Forest Fire News (IFFN), this section provides the original fire database of the Economic Commission for Europe (UN-ECE) which is published regularly. It includes all Western and Eastern European countries, countries of the former Soviet Union, the U.S.A. and Canada. The last data set covers the period 1994–96 (ECE/FAO 1997). It is envisaged to add in future the Community Information System on Forest Fires of the European Union (under negotiation). The Community Information System on Forest Fires currently covers 319 provinces (departments, states) of Portugal, Spain, France, Italy, Germany and Greece (Lemasson 1997). It contains information on 460 000 fires recorded between 1 January 1985 and 31 December 1995, involving a total of six million hectares.

3.4 International Forest Fire News

The production of International Forest Fire News (IFFN) is one of the core activities of the UN-ECE/FAO/ILO Team of Specialists on Forest Fire. IFFN is produced at the Global Fire Monitoring Center. The printed version has been published biannually by the ECE/FAO Agriculture and Timber Division (now: Timber Section, UN-ECE Trade Division) since 1988.

The last printed issue of IFFN is also available on the Internet homepage of the GFMC. All issues before the latest issue, starting with the 1990 issues, are also available on the GFMC website and are organized as follows:

Country Notes. This is the most important section of the IFFN archive. It contains reports, analyses and statistics from 50 nations. The reports are either authored by government bodies or independent research institutes and individuals.

Specials. A series of "Specials" have been produced in which several reports focused on a nation, region or topic (e.g., South East Asia, the Baltic Region, Russia, Switzerland, Israel, etc.).

Research and Technology News. This section contains all reports and minutes of meeting of research activities, predominantly those which are connected to those the international fire science programmes that are IFFN co-sponsors (IGBP-IGAC-BIBEX, IUFRO, IBFRA; see also paragraph 3.6).

3.5 Other National Fire Reports

General Analyses and Overviews. In this archive national fire general analyses and overviews are presented which are either in preparation for the next issue of IFFN ("near real-time information") or which exceed the size standards or do not meet the newsletter format of the printed version of IFFN.

Research and Development. Reports from national or international research projects are provided in this file. These meet the standards of scientific publications.

3.6 Programmes and Projects

The most important international fire management, policy development and research programmes are described in detail and links are given to reports, publications and websites of these programmes.

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3.6.1 United Nations (UN)

Several UN agencies and programmes became actively involved in regional and global fire issues in 1997–98. Many of these programmes do not yet provide a special fire website. The following information therefore provides (a) a quick overview on fire programmes which may not be complete due to a lack of information, together with (b) a link to the general website of the organization and (c) some important reports or links to reports which are available to the GFMC. The UN agencies and programmes covered are:

International Decade for Natural Disaster Reduction (IDNDR). The complete report of the IDNDR Early Warning Programme Working Group "Fire and Related Environmental Hazards" is given as well as other relevant reports and documents (Goldammer 1997).

Food and Agriculture Organization (FAO). Besides the hyperlink to the FAO website and the special fire section an in-depth report on the FAO Consultation on Public Policies Affecting Forest Fires will be given by mid 1999.

United Nations Educational, Scientific and Cultural Organization (UNESCO). The activities of UNESCO focus on technical and operational aspects related to causes, impacts, prevention and rehabilitation (UNESCO 1998).

World Health Organization (WHO). The core activity of the WHO related to fire and fire-generated smoke pollution is the development of the WHO Health Guidelines on Episodic Vegetation Fire Events. The guidelines are provided in full length (WHO 1999).

World Meteorological Organization (WMO). Reports and analyses of the WMO focus on transboundary smoke haze pollution and related activities in early warning of smoke pollution and relevant research programmes (WMO 1998).

United Nations Environment Programme (UNEP) and the UN Office for the Coordination of Humanitarian Affairs (OCHA). Links are provided to the reports of OCHA in fire disasters (e.g., Indonesia and Russia 1998).

3.6.2 International Tropical Timber Organization (ITTO)

The core of the ITTO file consists of the full text of the ITTO Guidelines on Fire Management in Tropical Forests (ITTO 1997). At international level the ITTO has taken a lead role in assisting tropical countries to cope with the challenges of fire management.

3.6.3 The World Bank

The newly created Disaster Management Facility (DMF) of the World Bank is one of the co-sponsors of the GFMC and is linked to the website. The activities in the field of fire include the Economic Development Institute, Environmental and Natural Resources Division (EDIEN) of the World Bank (World Bank 1998).

3.6.4 International Geosphere–Biosphere Programme (IGBP-IGAC-BIBEX)

The International Geosphere–Biosphere Programme (IGBP) provides an important international research platform for interdisciplinary fire research projects. The main fire science component of the IGBP is organized under the Biomass Burning Experiment (BIBEX) of the IGBP International Global Atmospheric Chemistry (IGAC) project (IGAC 1998). The GFMC hosts the BIBEX secretariat and closely links ongoing and planned research and development activities of both institutions, not only through the website but also by active planning and field implementation.

3.6.5 Other Research Programmes (IUFRO, IBFRA, etc.)

Besides the IGBP programme, two additional organizations provide an umbrella for international collaboration in fire science. Within the International Union of Forestry Research Organizations (IUFRO) the Fire Research Group (S8.05) provides a liaison to all other disciplines in forest science. Fire is one of the research foci within the International Boreal Forest Research Association (IBFRA). The IBFRA Fire Working Group operates in all boreal

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nations. Both fire research groups of IUFRO and IBFRA are co-sponsors of the GFMC and IFFN.

3.6.6 *International Technical Cooperation Projects in Fire Management and Research*

With this file and archive the GFMC emphasizes the need to link fire management and research projects all over the world, particularly in the tropics and subtropics. With this information exchange platform the GFMC encourages technical cooperation projects to make their expertise available to others, thus avoiding the loss of that valuable experience in fire management in grey literature or national archives. GFMC also encourages bi- and multilateral donor organizations and projects to benefit from communication and coordination between fire management projects.

3.7 Fire Meetings and Fire Management Training Courses

This section comprises continuously updated information on upcoming fire meetings (scientific or technical conferences, workshops, symposia) and fire management training courses. Retrospectives (evaluations, reports) of past fire meetings and courses are provided if these have been made available to GFMC. Announcement of university training courses can also be found on this file.

3.8 Fire Literature, Media, Associations

This section facilitates the access to fire literature, media and professional organizations. Most important is the link to the International Association of Wildland Fire (IAWF). IAWF is a non-profit organization whose mission is to facilitate communication in the global wildland fire community. The association has several programs to facilitate this mission by producing or providing:

- Wildfire Magazine (monthly publication)
- Journal of Wildland Fire (a quarterly scientific peer-reviewed scientific journal)
- Current Titles in Wildland Fire (a monthly newsletter that keeps subscribers informed on new publications, dissertations, news reports and governmental reports)
- Library
- Bookstore
- Databases (list of fire researchers and fire managers world-wide; list of 55000 publications on wildland fire)

A preliminary fire bibliography from the GFMC is provided. It contains several hundred literature citations on fire in the tropics, the boreal zone, and nature conservation.

Media coverage of fire events is given under observation of copyrights. An electronic global fire photograph dataset based on the GFMC photo archive is under construction.

3.9 Links

The link section provides links to the most important and regularly maintained websites from Europe, North America, Latin America, South East Asia and Australia–Pacific. Special link sections deal with humanitarian relief and disaster management, remote sensing, and weather and fire-weather forecasts.

4 Outlook

The multiple effects of wildfires and land-use fires on the various vegetation zones of the world and the increased vulnerability of ecosystems and societies to uncontrolled fires have led to an increasing public and political awareness. The design and establishment of a facility with the capability to systematically monitor, archive and distribute information on fire and related impacts on a global scale serves a variety of purposes. These include the demand for information by scientists, land resource managers, the disaster mitigation, prevention and management community, policy makers, and the general public. With the consolidation of global networking between environmental monitoring and early warning systems and the end-users of this information, the future additional information outputs of the Global Fire Monitoring Center will be determined.

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CHAPTER 6.2

Application of Logistic Models to Predict Human-Caused Forest Fires in Siberia

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1 Introduction

Growing concern over global warming has recently focused more attention on the boreal forest zone. Fire caused by lightning is a frequent event in the boreal ecosystem and tree species have adapted to the occurrence of fires to a point where fie is required for natural regeneration (Goldammer & Furyaev 1996). With greater human settlement the number of fires due to the careless handling of fire has increased dramatically. In Russia, approximately 90 percent of forest fires are people-caused (Korovin 1996), creating a dramatic change in the natural fire regime. These fires occur in the more densely populated areas and cause a serious threat to values in timber, property and human lives. A key issue in forest fire management is the quick initial attack time. The faster a fire crew gets to a fire, the higher the changes are that they can control it. By predicting the occurrence of forest fires, fire managers have a powerful decision making tool which enables them to distribute their resources in the most efficient way while optimising pre-suppression planning.

To understand and predict the fire occurrence of people-caused fires, several attempts have been made to describe forest fire occurrent through the aid of probability functions based on historical fire and weather data. This paper endeavours to apply the methods used by Martell and Otukol (1985) in predicting people-caused fire occurrence to the circumstances in the Krasnoyarsk region of Siberia.

2 People-Caused Fire Occurrence Prediction

Cunningham and Martell (1973) showed that fire occurrence is dependent on the ease of fuel ignition and potential ignition sources. Ease of ignition is related to the moisture content of the fuel: the drier the fuel, the easier it is to ignite it. The moistsure contents of different fuel types are described in the Canadian Forest Fire Danger Rating System (CFFDRS), a Fire Daner Rating System developed in the 70s. One parameter of the CFFDRS, the Fine Fuel Moisture Content (FFMC), is of special interest for this study since Martell and Otukol (1985) have shown that the FFMC is the most significant independent variable related to people-caused fire occurrence. This is due to the fact that people-caused fires are mainly ignited by small energy inputs, such as those from sparks or cigarettes, which ignite small fine fuels, lying on the forest floor.

The other factor which influences the probability of people-caused fires is the number of people and their activities in the forest, which are almost impossible to measure, and are therefore considered by most prediction models to be constant. Martell and Otukol (1985) studied human activities in the forest by examining the variation of fire occurrences by cause per weekday. They used 17 years of data, and found no significant difference of fire occurrence per weekday. Following this study it is assumed

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that there is no variation per weekday in the obtained data, although it should be noted that there could be a significant difference in human activity for the forests of Ontario and the Krasnoyarsk region in Siberia. In regards to this aspect further research is necessary.

3 The Data

This study is based on 6 years (1987–1992) of historical forest fire occurrence and weather data from the Angara River region in Krasnoyarsk, Central Siberia, Russia. The Krasnoyarsk fire protection region is subdivided into smaller subdivisions comparable with forest districts in Canada. The provided fire reports contain information for the air subdividions Motigino, Kezhmae and Prospikhino, located approximately 300 km north-easth of Krasnoyarsk along the Angara river. The area is generally hilly, and the landscape is dominated by the Xenisei and Angara Rivers. The range of elevation is from 225 m to 800 m above mean sea level. The area is covered by little rivers and creeks, and large swampy areas. There is however a lack of natural lakes in the area. Pine and larch are the predominant tree species.

The forest fire occurrence records fromt he Krasnoyarsk region indicate that in the six-year period from 1987–1992, 725 fires burned. 1990 was the year of greatest fire activity with a total of 180 fires, while 1988 had the fewest fires of the study period. The annual average of fires over the years is 121, burning a total area of 18368 ha. Of these fires, 263 (36%) were caused by lightning, 290 (40%) were caused by people and 172 (24%) were categorised as cause unknown. In examining the dates of fire occcurrence, the high summer months of July/August correlate to the high season of fires caused by lightning. Human activitiy seems to be the most important factor in the early fire season (May and June) with 59% of human-caused fires occurring during this time, compared with 34% in July/August and 7% in September.

4 The Logistic Regression

The prediction models used for the study area is based on the work by Martell et al. (1985, 1987, 1989). Their studies showed that logistic regression models are useful for fire occurrence prediction systems resulting in a developed model which is currently used in Ontario. Their model has already been applied to Eurasia (Lynham & Stocks 1989) in the Heilongjiang Province, China and was judged to give rather good predictions.

Fire occurrence expressed in terms of a fire day is a binary event, meaning that it only has two outcomes. In this case, if one or more fies occur (1) and if no fires occur (0). The common statistical means by which to model binary events include the linear regression model and the logistic regression model. In this study, a logistic regression model was preferred over a linear regression model for the following reasons: logistic distribution is, from a mathematical point of view, extremely flexible and easy to use, and in the case of modelling fire occurrence, studies have proven that the logistic distribution is applicable to the fire occurrence problem. Stocks (1974) suggested that the probability of a fire-day is an S-shaped function of the FFMC.

Following the work done by Martell this study accepts that the probability of a fireday can be expressed as a logistic function. The following logistic function was used to describe the relationship of P and the fire weather index FFMC.

$$P_{est} = \frac{e^{b_0+b_1 FFMC}}{1 + e^{b_0+b_1 FFMC}}$$

The above-mentioned logistic regression models predict the occurrence of a fire-day. It is predicted that on a specific day one or more fires may or may not occur. Although this is important information, fire managers often require more accurate information, wanting to know what the probability is that one, two or more fires occur on a given day.

Cunningham and Martell (1973) assumed that the occurrence of a forest fire has a Poisson probability distribution. The Poisson distribution can be used to predict the probability of a given number of fires on a specific day.

The Poisson Distribution is computed as follows:

$$P(x) = \frac{\lambda^x e^{-\lambda}}{x!}$$

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P(x) = probability that x fires will occur
λ = expected number of fires per day

The probability that one or more fires will occur is:

$$P[x \geq 1] = 1 - e^{-\lambda}$$

With these assumptions we can incorporate the logistic regression equations to estimate the probability that one or more fire will occur. Solving for λ gives:

$$\lambda_{est} = -\ln(1 - P_{est})$$

Hence it is possible to estimate the expected number of fires per day.

In testing the models the recommendations of Loftsgarden and Andrews (1992) were followed. They recommended grouping the data into 10 groups according to calculated probabilities with as even a distribution as possible. The data was grouped according to the procedures set out by Hosmer and Lemeshow (1989), who recommended splitting ties to ensure that the groups are even. A Chi-square test was performed on the grouped data, which was computed as follows:

$$X^2 = \sum_{i=0}^{1} \sum_{j=1}^{k} [(O_{ij} - E_{ij})^2 / E_{ij}]$$

with O_{ij} = observed probabilities
and E_{ij} = predicted probabilities

A low X^2-Value and a high p-value indicated good fit of the model, the logistic regressions and the results of the Hosmer-Lemeshow Chi-square test are presented in Table 1.

5 Results

The study uses five years of data, which include 740 days of observation and only 60 fire-days. The small sample size caused some limitations to the models. The Chi Square tests ranging from 12.7 to 18.3 with p vales from 0.019 to 0.1281 indicate the general good fit of the data. The model based on the database with the most fire occurrence performed the best in the statistical test. Overall it can be noted that the 5 years of data for the analysis is the absolute minimum for accurate operational prediction systems.

A more detailed look at the Hosmer and Lemeshow (1989) goodness of fit statistic for Model 4 shows the general good performance of the models, and few discrepancies in this grouped data.

6 Field Test and Discussion

To evaluate the performance of the 4 models, they were tested on the 1992 data set, which was not included in the computation of the logistic models. In the 1992 fire season there occurred 8 and 10 fire-days, in air subdivision Motigino (Models 1 and 2 respectively). In the combined air subdivision Kezhmae/Prospikhino there were 24 and 32 fire-days observed for models 1 and 2 respectively. In general, the summer was rather wet with rather moderate fire occurrence in comparison to the other five years of data.

The task of testing fire occurrence models has been a much debated issue in the literature on fire occurrence prediction modelling (Martell 1987; Loftsgarden 1992; Vega Garcia 1995; Mandallaz 1996). After careful consideration, a combined approach was used testing the independent data set with quadratic scoring rules (Winkler & Murphy 1968) and 2×2 classification tables (SAS Institute Inc. 1989).

Table 1. Logistic regression for the Krasnoyarsk region

Model	Air subdivision	Variable in the Model	b_0	b_1	Hosmer-Lemeshow X2	p-value
Model 1	Motigino	FFMC	-28.9728	0.30290	18.28947	0.019
Model 2	Motigino	FFMC	-27.121	0.2847	17.4724	0.0352
Model 3	Kezhmae/Prospikhino	FFMC	-21.581	0.2295	15.20444	0.0411
Model 4	Kezhmae/Prospikhino	FFMC	-18.3586	0.1992	12.707	0.1281

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Table 2. Results for Kezhmae/Prospikhino incorporating the unknown-category (Model 4)

Calculated probabilities	FFMC-class	Days	Fire-days		No-fire-days	
			Observed	Predicted	Observed	Predicted
(0; 0.000124)	1–47	74	0	0.0014	74	73.9985
(0.000124; 0.00445)	47–65	74	0	0.1141	74	73.8859
(0.00543; 0.03174)	66–75	74	2	1.2438	72	72.7562
(0.03174; 0.0815)	75–80	74	8	4.2363	66	69.7637
(0.0815; 0.1645)	80–84	74	6	8.8167	68	65.1833
(0.1645; 0.2268)	84–86	74	17	13.9527	57	60.0473
(0.2268; 0.2636)	86–87	74	10	18.1075	64	55.8925
(0.2636; 0.3478)	87–89	74	20	23.0127	54	50.9873
(0.3478; 0.4426)	89–91	74	33	28.5403	41	45.4597
(0.4426; 0.7241)	91–97	74	40	38.9744	34	35.0256

Degrees of freedom: 8; Chi-square Test: 12.707; p-value: 0.1281

The quadratic scoring test is computed as follows:

$$f(p, e) = 1 - 2(p - e)^2$$

where f(p,e) = score
p = predicted probability that one or more fires occur
e = 1 if one or more fires occur
= 0 if no fire occurs

Table 3. The performance of the prediction models using the quadratic scoring rules

Model	Observed fire-days	Average score	Standard deviation
Model 1	8	0.901	0.31
Model 2	10	0.877	0.356
Model 3	24	0.788	0.347
Model 4	37	0.77	0.366

The performances of all four models are presented in Table 3.

It can be noted that the score is higher in Models 1 and 2 for air subdivision Motigino with a smaller fire occurrence (8 and 10 fire-days) than in air subdivision Kezhmae/Prospikhino with 24 and 37 firedays. This result is consistent with the findings of Martell (1987), who also tested his prediction models for Ontario using the quadratic scoring rule. He noted that the quadratic scoring rule test results performed well for the models during wet fire seasons while in dryer seasons with higher fire occurrence more extensive tests were necessary. Loftsgarden (1992) criticised this test by reasoning that the result of the quadratic scoring rule depends solely on the data set being used. If the fire season is wet with corresponding low fire danger indices the predictions derived from the logistic regression would be near the lower tail of the logistic curve where the probability is near zero. Because most observations are zero, the residual variation is small and the average score is very large. In fire seasons of high fire danger most observations would fall within the middle portion of the logistic curve resulting in a larger residual variation and a smaller average score.

One reason for using the quadratic scoring rule test was to make a comparison between the prediction system developed by Martell 1985; 1987) for Ontario and the prediction system conducted here for Siberia. Martell's use of the quadratic scoring rule test is based upon a peiod of 83 days, from 10 June to 31 August 1984. This period was relatively wet with only six forest fires. His models had scores ranging from 0.475 to 1000, with approximately 70% at 1000. With regards to the longer test period of 150 days for the Siberian models and the existence of a higher fire occurrence, it can be stated that the fire occurrence prediction system developed in this study performed excellently.

To further investigate the problem of testing fire occurrence prediction models another approach was made using the method of 2×2 classification tables of observed and predicted responses (SAS Institute Inc. 1989). Table 4 illustrates the variables included in this classification table. The "False Negative" value indicates the percentage of predicted false fire-days that were observed as true fire-days. The "False Positive" value stands for the percentage of pre-

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Table 4. Classification table of observed and predicted responses

Frequency Table Row Pct.	Predicted no-fire	Predicted fire
Observed no-fire	A Specificity	B False Positive
Observed fire	C False Negative	D Sensitivity

Table 5. Classification table for model Kezhmae/Prospikhino for independent data set 1992 (Model 3)

Frequency Table Row Pct.	Predicted no-fire	Predicted fire
Observed no-fire	91 73.98%	32 62.75%
Observed fire	5 5.2%	19 79.17%

Overall percentage of correctly predicted observations: 74.83%

cut-off point 0.284

Table 6. Classification table for model Kezhmae/Prospikhino for independent data set 1992 including unknown category (Model 4)

Frequency Table Row Pct.	Predicted no-fire	Predicted fire
Observed no-fire	77 70.0%	33 50.77%
Observed fire	5 6.0%	32 86.4%

Overall percentage of correctly predicted observations: 74.15%

cut-off point 0.304

Table 7. Classification table for model Motigino for independent data set 1992 including unknown category (Model 2)

Frequency Table Row Pct.	Predicted no-fire	Predicted fire
Observed no-fire	124 84.93%	22 75.86%
Observed fire	3 2.36%	7 77.78%

Overall percentage of correctly predicted observations: 83.97%

cut-off point 0.186

Table 8. Classification table for model Motigino for independent data set 1992 (Model 1)

Frequency Table Row Pct.	Predicted no-fire	Predicted fire
Observed no-fire	124 84.35%	23 79.93%
Observed fire	2 1.59%	6 75.0%

Overall percentage of correctly predicted observations: 83.87%

cut-off point 0.17

dicted true fire-days that were observed as false fire days. "Specificity" represents the correctly predicted no-fire-days and "Sensitivity" indicates the correctly predicted fire-days. The total percentage correctly predicted is computed as Specificity plus Sensitivity divided by the sum of all four variables.

The computation of this classification usually involves a cut-off point to define when the probability level indicates a fire-day or not. This is usually the midpoint of the logistic distribution 0.5. When the probability is higher than 50% it is assumed to be a "likely event" (true fire-day) and if it is smaller than 50% it is assumed to be an "unlikely event" (false fire-day). This cut-off point can be arbitrarily set depending on the objectives of the study (Jamnick & Beckett 1988; Vega Garcia 1995). This means that every value between 0.0 and 1.0 can be chosen as the cut-off indicating true fire-day and false fire-day. In this study, the concern was to find similar results in predicting both and therefore, for every model, the optimal cut-off point was chosen to best obtain predictive capacities. The results of the field test are presented in Tables 5 to 8.

All four models performed excellently in the field test, although the goodness of fit was considerably low. As in the quadratic scoring rule test, the two weak models performed better than the models Kezhmae/Prospikhino. Model 2 correctly predicted 83.97% of all new observations, 77,78% of the true fire-days and 84.93% of the false fire-days. There were only 2.36% missed fires while 75.86% of the predicted true fire-days were false alarms.

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7 Conclusions

The study was limited due to the small sample size of data. The incorporation of only five years of data in the models it is considered to definitely be the lowest limit for meaningful predictions. Another limitation to the study was the representation of the weather stations. Simard (1972) suggested that one station be representative of fuel moisture over the radius of 80 km. This density of weather stations was however not available in the study area. The maximum distance of a weather station to the furthest location in the study area was 210 km (weather station Yeniseisk). With such a distance, it can be questioned weather the weather data for the region is representative. For the study area only the above mentioned four tested weather stations were available and after consulting local fire managers it was decided that the focus of the study be on the two used weather stations. Problems inherent in developing an early warning system in Siberia are: A lack of weather stations and data, the vastness of the geographical area, and political and logistic problems. Nevertheless, the p-values of the models and the performance of the goodness of fit test indicate that these models are applicable for predicting daily people-caused fire occurrence in Siberia. The FFMC serves as a good independent variable to model fire development. The models may be further improved incorporating more explanatory variables, for example the combination of the BUI and the FFMC could inevitably enhance the performance of the prediction models. The splitting of the fire season into sub-seasons could also enhance the performance of the prediction system although, in this case, due to the small period of available data for this study it was not possible.

The results of the field test of 1992 indicate a good performance of the models, although it would have been more precise to test the models on more then one fire season with 150 days. Interesting is the fact that both the quadratic scoring rule test and the classification table test came to the same result, indicating a superior performance for the region of low fire occurrence (air subdivision Motigino) in 1992, although these models performed worse using the Hosmer-Lemeshow Chi-Square statistic. This contradiction challenges the validity of both tests, indicating that further research in this field is necessary. The approach used by Mandallaz (1996) using skill scores may be an interesting alternative to consider.

The use of the cut-off points in the 2×2 classification table was justified due to the objective of the study to balance the accuracy of the model between specificity and sensitivity. Since these points are arbitrary they can be changed as management objectives change. For example, if suppression resources are scarce, expensive to employ or high protection levels are not critical for values-at-risk, a high cut-off point may be preferable, which would mean less false alarms as well as lower accuracy in predicting fires. Where there are high values of risk, and many mobile suppression resources available, a lower probability value and higher accuracy in predicting fires with more false alarms is better.

The plot of predicted versus actual fire occurrence (Fig. 1) in air subdivision Motigino shows that the models are capable of predicting important trends of fire risk within a fire season. The blue line indicating predicted probabilities rises up to almost every reported fire in the 1992 test season, providing fire managers with a powerful tool to predict trends important for decision making.

The Canadian methods that have been described are applicable for predicting people-caused fire occurrence in the Krasnoyarsk region in Siberia. It is possible to apply the logistic regression models developed by D.L. Martell and S. Otukol (1985), University of Toronto to Eurasia. With further research, prediction systems could be developed for the whole fire protection area to help fire managers cope with the difficult task of fire management in Russia.

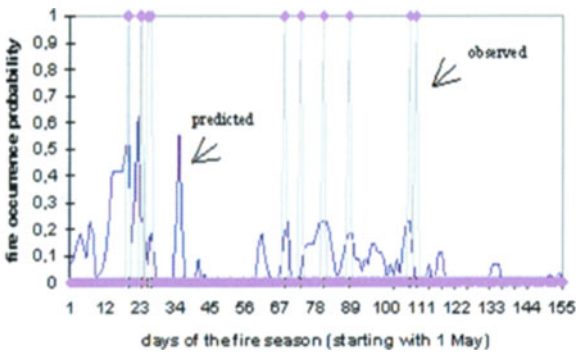


Fig. 1. Plot of predicted versus actual fire occurrence in air subdivision Motigino using Model 3

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CHAPTER 6.3

The Use of Microsatellites in the Fight Against Pest Plagues

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1 The Nature of the Problem

Huge areas covering whole subcontinents, especially in the subtropics, have always been subjects to pest plagues (Fig. 1). Amongst the most important of these migrant pests are swarms of locusts, huge flocks of crop-eating birds, and the African army-worm which causes severe vegetation damage (Bruggers & Elliot 1989; Voss 1986; GTZ 1982).

In recent decades the damaging effects of such plagues have become increasingly serious. The combination of unprecedentedly high levels of population increase in the countries affected, together with much reduced harvests, have fatally undermined the capacity of affected areas to feed their peoples.

Spurred on by the most recent plague of locusts in 1988, there have been urgent and repeated requests to international bodies, such as the FAO, the GTZ, PRIFAS, the European Community and the African Development Bank for remote sensing technology to be supplied and installed, so that potential threats can be located, tracked and combated. Many of these technologies have only become available in the last 10 to 15 years, but it is certain that they will be invaluable in the fight against plagues of migratory pests of all kinds.

The reasons are obvious from the continental scale of the problem alone. The regions affected stretch from west Africa to north-west India in the northern hemisphere and from south-west Africa to east Africa and parts of Australia in the southern hemisphere. They cover altogether

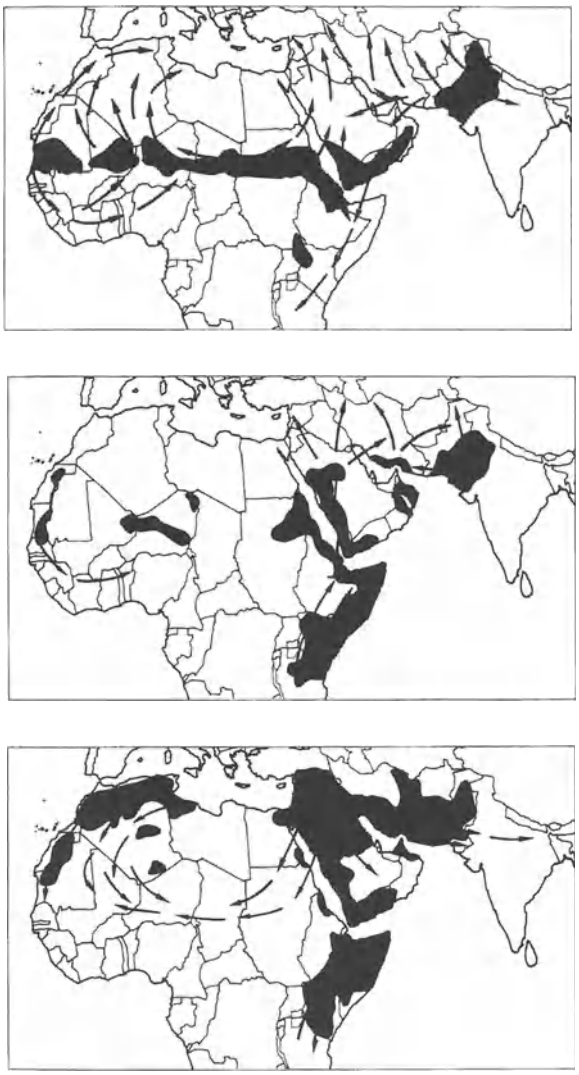


Fig. 1. The occurrence of pest plagues in Africa

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about 25 million km^2, or roughly 20% of the earth's land surface.

Most of the countries in the affected regions have undergone massive population increases in recent decades, leading to an extreme exploitation of all their natural resources and, consequently, to conditions favouring the appearance of massive plagues of swarming insects. For this reason alone, the search has been on to find ways and means of controlling such plagues. The sheer size and continental scale of the problem indicates the arguments for using remote sensing techniques; without which the identification and control of such mass plagues on a large scale will be impossible.

According to the international bodies referred to above, there has previously been no reliable way of obtaining information on the location and extent of swarms of locusts anywhere in continental Africa. A few facts and figures will serve to illustrate the seriousness of the problem. Estimates of the size of the areas affected and requiring protective measures have been known to be up to 50 times greater than the true values, and in Australia only 10% of the outbreak epicentres are ever discovered. One of the main aims of the project described here is to improve the poor state of knowledge briefly outlined above.

For two years now the FAO Remote Sensing Centre in Rome has been using the imagery from a series of permanent satellites to monitor the state of vegetation (undifferentiated) and the distribution of precipitation as part of the Global Food and Feed Security Surveillance Programme. Working with a spatial resolution of between 1.7 and 16 km^2, a joint research project with two major objectives has been set up between the FAO Remote Sensing Centre in Rome and GTZ in Eschborn, in association with research stations in the African countries affected.

Data from the LANDSAT, SPOT and ERS 1 satellites as either 30×30 m or 20×20 m, the smallest possible level of resolution, must all be used in combination to monitor a series of constants derived from naturally occurring geographical parameters to throw more light on the whole issue of pest plagues. The main factors to be taken into account are: topography, morphology, soils, water balance and vegetation. Vegetation should be differentiated on the basis of naturally and culturally determined plant communities, or any other measures conveniently available.

In addition, special characteristics of an ecological nature, such as oases and major clearings in the vegetation, should also be regularly monitored. At the same time, it is also desirable to collect short and long term runs of meteorological data, so as to be able to recognise, for example, impending locust problems. All these parameters relating to the various different biotopes must then be synthesised, turned into maps and combined with other information on settlement and infrastructure, such as airfields, roads and tracks etc. Together they will provide a sound logical basis for the future planning and implementation of pest control programmes. Using these data banks, it should be possible in the future to target chemical spraying in key areas, thus saving both time and money.

Finally, the project is also attempting to find alternative ecological and economic methods of control, which may be used as substitutes for costly, blanket-spraying, campaigns.

In a further development, we hope it will prove possible to identify and map key factors, relevant to the biotopes in question, and then to explain these in terms of variations in vegetation and precipitation. Through cooperation with the new FAO programme on the Global Surveillance of Vegetation and Precipitation there is now a realistic prospect of devising means for forecasting the occurrence of pest plagues of all kinds. However, if the methods used to forecast pest plagues in the future are to be of any real use, then the information provided must be applicable to control programmes that are ecologically acceptable.

The final requirement for a successful coupling of theory and practise is the rapid dissemination of the data being evaluated in the various capital cities to the fighting troops on the ground. For the most part, these data will be in the form of annotated LANDSAT and SPOT images, together with map extracts and written commentaries.

2 Possible Solutions

There are various different methods available for transmitting the information to remote areas. So long as it can be sent in digital form, INMARSAT Standard C, Vitasat and TUBSAT-A, as well as a number of other communication systems, are all possibilities.

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2.1 INMARSAT Standard C

The INMARSAT satellites were originally devised and put in orbit as a maritime communications system, but a parallel world-wide mobile version for use on land, INMARSAT Standard C, has also been developed (TELEKOM 1990; Land Mobile Services of INMARSAT, Bell 1991; Meinzingen 1993). The machines for receiving the data are being designed with vehicles of all kinds in mind, particularly lorries. In the meantime, a number of manufacturers (MAN, TELECOM, HAGENUK, CAL etc.) have terminals available that are compatible with the INMARSAT Standard C system.

The data transmission rate is 600 bits in both directions and the volume of data that can be handled is virtually unlimited. The multi-directional long-wave aerial has no special requirements, for example as far as the vehicle is concerned, but a current of at least 50 watts is needed when transmitting, which is a very high level. The weight of the receiver without the computer for evaluating the data is about 15 kg. It means that the whole system, complete with laptop, can easily be operated from a Land Rover.

INMARSAT Standard C requires a wave length of 5 kHz on the long-wave. Since it depends on slotted ALOHA from geostationary satellites, there can be some transmission delays from time to time. The charge for Standard C terminals depends on the length of time they are used and the country to which the transmission is being made. It is quite feasible to exchange data and text between a wide variety of different systems, such as, for example, Telex, Datex-P and E-mail.

2.2 VITASAT

A world-wide data communication service for development assistance based on the amateur radio satellites (UoSAT, University of Surrey, England) has now been marketed (AIAA 1990). These microsatellites have the same orbit as TUBSAT-A, the sun synchronised, polar, 800 km orbit, typically used by Earth surveillance satellites. The system has been devised primarily for use in developing countries in the far flung corners of the world. Once a ground station has been set up use is so far free.



Fig. 2. The 800 km polar orbit (UoSAT, TUBSAT-A)

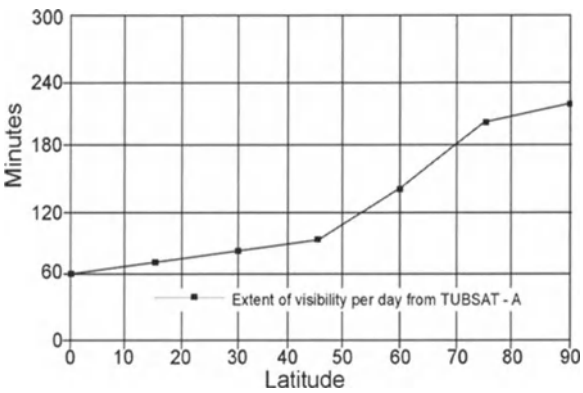


Fig. 3. The visibility span of TUBSAT-A and UoSAT

The ground station itself uses the 2 m and the 70 cm bands for data communication. The data transmission rate is 9600 bauds. The capacity of the VITASAT system is 1 megabyte for all users. Its polar orbit means that the satellite is only visible for a limited period each day, the length of time depending on the latitude of the ground station (Fig. 2).

The maximum communication time per orbit is 12 minutes. If a large number of stations wants to use the satellite all at the same time, there can be communications jams, especially in developing countries in the equatorial regions, because of the limitations of the ALOHA system which governs access (Fig. 3).

The ground station consists of a modified transceiver (Kenwood), a modem, a screen (e.g.

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a PC or a laptop) and a separately-mounted Kreuzyagi aerial. This separately-mounted aerial does not permit mobile usage from a Land Rover, but for a fixed, low-cost, system VITASAT is an attractive option.

2.3 TUBSAT-A

In July 1991 the microsatellite TUBSAT-A was launched, again in a sun synchronised 800 km orbit (Renner 1991). Although it is primarily intended for scientific experiments, the communications technology included alongside the other systems may equally be used to solve any problem relevant to the project.

In this context, special attention has been focussed on the problems associated with the most mobile of communications equipment. Those wishing to communicate can do so either from a car, or from an ultra-mobile ground station, sending and receiving short messages. These minimalist ground stations consist of only a modified YEASU FT23R handheld transmitter, a digital pocket calculator and a simple metal aerial. It is particularly well adapted for use by people on foot and backpacking, because there is so little additional weight to carry.

More sophisticated ground stations substitute a laptop for the pocket calculator and use a cross dipole as an aerial. These additions enable the 32 kilobyte static RAM capacity of TUBSAT-A to be fully utilised. The data transmission rate for both pieces of equipment is 1200 baud in both directions.

There are no access rules as such for TUBSAT-A; every user has the full span of the communication time in the area where it is being used at his or her disposal. At this point it should be emphasised that, because TUBSAT-A has been primarily designed for experimental purposes, it is not really a serious competitor for the other available systems. Rather, it mainly serves to underline, in a general way, that satellite communications systems can help to solve the problem facing developing countries. In this context, a test programme was begun in Kenya in Africa during March 1992 to assess its usefulness in mobile communication systems.

3 The Trial

In order to test the general suitability of microsatellites for these purposes, a test programme was carried out from 3rd to 12th March 1992. At this point a special word of thanks is due to Mr. Wolfgang Meinzingen, the FAO project manager in Nairobi, Kenya without whose generous help these experiments simply could not have been done. As part of this test programme much of which was carried out in some of the remotest areas of Kenya, practical information relating to the control of pest plagues was both sent and received. The means used to relay the information was TUBSAT-A. The information was transmitted during one pass of the satellite and then retrieved. The satellite signal could be picked up within a radius of about 5000 km. Since only one ground station was available, information was sent and received from the same location.

TUBSAT-A weights 35 kg and is in the form of a 38 cm cube. All six sides have solar cells, one being specifically devoted to testing GaAs solar cells. Ten 7 Ah NiCd accumulators provide the necessary energy during the dark phase of its orbit. For its scientific work, TUBSAT-A carries the following experiments:

- star sensor using CCD
- sun sensor using CCD
- transputer experiment (Kayser Threde)
- long wave transponder (Panatec)
- magnetic sensor and air purifier
- digital voice store
- GaAs solar cells.

The following block circuit diagram shows how the experiments are ordered within the satellite. There are two independent systems, each of which is connected to its own type YAESU FT23R transceiver to provide a secure back-up (Fig. 4).

To transmit the necessary information and thus to complete the experiment, all that is required is one microprocessor with a transmitter, the digital voice store, and the 32 kilobyte external RAM.

The information consists mainly of dummy biotope inventories, which are primarily intended to simulate potential pest outbreak epicentres. These inventories are in the form of map and/or processed satellite data. The original map data are very comprehensive, because they are derived from LANDSAT and SPOT

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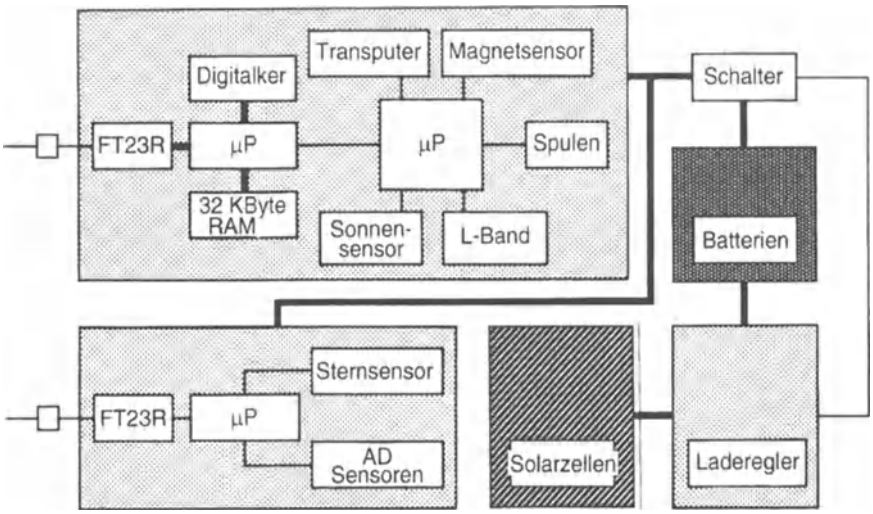


Fig. 4. Block circuit diagram for TUBSAT-A

imagery. These LANDSAT and SPOT data typically contain 24 bits of information for each unit up to 30 m and, as a result, maps of only a few hundred square kilometres considerably exceed the transfer capacity of TUBSAT-A.

Judicious pruning of the data helps to overcome this problem. A further difficulty is that data from the earth observation satellites METEOSAT and NOAA must also be transmitted, though the raw data from these satellites cannot be used directly in the field. At present this data is either processed by the FAO in Rome, or worked on directly in Nairobi later. The information relevant to the control programmes is also initially collected there too, before being sent out to the control zones.

All these data must be transmittable in their entirety, with the help of the microsatellites, to every mobile control team working out in the field. Their precise positioning using GPS (Global Positioning System) is crucial especially in remote areas. This makes deciding what to include much easier and helps to reduce the volume of information required. The amount of morphological and landscape information, all of which uses up vital memory, can be kept to a minimum.

The biotope map extract used in the trials covered an area of 144 km^2. By using specially designed data compression software, the volume of the data was reduced by a factor of 10 and the relevant information confined to possible locust breeding areas. At the same time, synchronisation information was added, so that should bit errors occur the picture could still be reconstructed.

The city of Tokar in the Sudan can easily be identified on satellite images by means of the characteristic airstrip at the regional airport in the south of the center. The LANDSAT data have already been reworked and additional geographical information added. The areas where locust breeding is likely to be concentrated appear dark on the map. One of these is the large area to the south-east of the town.

The edited map retains only the information required by field observation teams. This always includes the locust biotopes and typical geographical features, as well as, for example the map grid.

The reduction technique used is extremely simple. The original map had 256 possible different grades of shading, requiring a memory capacity of one byte per point on the picture. The first step is to reduce the number of grades of shading to 4, thus reducing the memory required per point to 2 bits. The remaining 6 bits in each byte are left unused. The second step is to merge adjoining pixels with the same shading level into a single byte. The two MSBits (most significant bits) contain the number of bits. Up to 64 pixels can be combined together in a single byte. The beginning of the group of lines is indicated by a '0'-byte. If bit errors occur, the programme used to draw the map always readjusts using the beginning of the group of lines as a marker.

The map transmitted required a capacity of 13 kilobytes (Fig. 5). With a data transmission rate of 1200 baud, roughly 90 seconds were needed for the actual transmission. The signal strength of the satellite amounted to 2 watt RF

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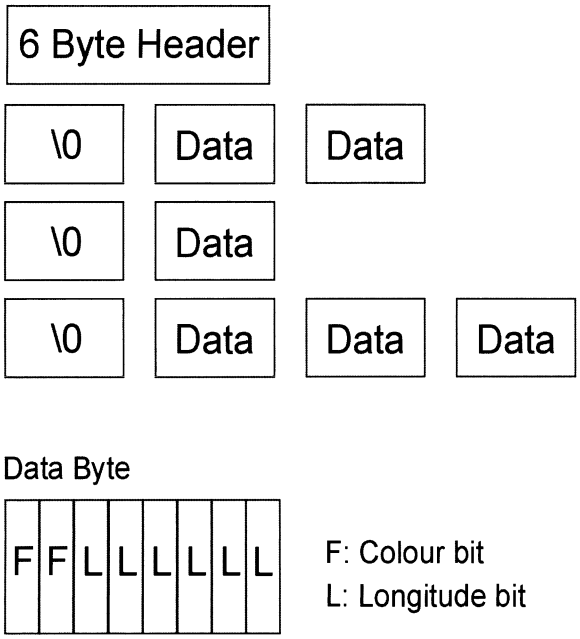


Fig. 5. A sample of the storage system for a simplified map

output, that of the ground station to 5 watts. If one was in an area with a lot of infrastructure, such us for example central Europe, it might be sensible to increase the strength of the uplink signal, so as to avoid interference from other terrestrial transmitters.

The TUBSAT-A ground station in Kenya used to transmit the map consisted of an IBM compatible 286 laptop, a cross dipole aerial mounted on a car roof, and a modified YAESU FT23R transceiver to as the satellite receiver. The information was sent to the satellite in the course of one pass and then retrieved. The satellite signal could be picked up within a radius of about 5000 km. As there was only one ground station available the information was sent and received from the same place.

The transmission frequency used was in the 2 m band at 143.075 MHz. The receiver requires a power supply of 12 volts. This voltage can be provided either by 10 NiCd cells, or alternatively by a car battery. The amount of current needed for receiving is under 130 mA, but when transmitting the total required by the whole apparatus is 2 A.

In this trail both text and speech transmission were tested. TUBSAT-A has a digital voice store developed by the Institute for Long Distance Communications Technology (Institut für Fernmeldetechnik) at the TU Berlin. It enables up to two minutes of speech to be stored and then retransmitted. Through some clever programming of this basic unit, a kind of transponder exchange can also be built in. Amongst other things, this application can be used for radio transmissions. Shortly after the tests in Africa had been completed the speech transmission facility was used during the search for a missing polar explorer.

4 Conclusions

After many years of research into the use of remote sensing in the whole area of environmental inventories, mobile communications systems linked to microsatellites now seem to be opening up a whole new range of possibilities, most of which would have been in the realm of fantasy only a few years ago. There is now real hope that these new techniques will be able to help in the fight against the recurrent pest plagues in Africa.

Inventories of the key geographical parameters for given biotopes, collected using data from LANDSAT, SPOT and ERS-1, can now be linked via GIS (Geographical Information Systems) to information on the distribution of vegetation types and precipitation, making the use of the following evaluation techniques a realistic possibility:

- The synoptic regional monitoring of a range of geographical information on a world scale.
- Locally targeted forecasting of potential occurrences of pest plagues.

The decisive last link needed to set up a successful and flexible field control system depends upon the introduction of a mobile and portable communications system, which can be used to send considered advice and information from headquarters directly to the observation teams in the field. TUBSAT-A has demonstrated that microsatellites can make a valuable contribution in this area by overcoming some of the communications problems. VITASAT has already made a most notable contribution in this same area. However, what is really needed now is a microsatellite designed specifically for this purpose.

Hopefully, this project will help to improve the lot of those people in developing countries, faced with such suffering as a result of the diffi-

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culties they are now encountering in feeding themselves and will continue to encounter in the future.

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CHAPTER 6.4

ECPC's Global to Regional Fire Weather Forecast System

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Abstract

Experimental global to regional and daily to seasonal atmospheric forecasts of fire weather variables are being developed at the Scripps Experimental Climate Prediction Center (ECPC). At the largest space and time scales, ECPC's forecasting system uses the National Centers for Environmental Prediction's (NCEP's) global spectral model (GSM). The GSM is initialized from NCEP's operational global analysis. A higher-resolution regional spectral model (RSM) is nested within this global model. An even higher resolution mesoscale spectral model (MSM) can be nested within the RSM or the GSM itself. Global to regional and daily to seasonal forecasts of a fire weather index (FWI), 2 m temperature, 2 m relative humidity, and 10 m wind as well as precipitation and soil moisture are currently displayed on the ECPC web site *http://ecpc.ucsd.edu/*. Skill evaluations of these forecasts are just beginning.

1 Background

Accurate fire weather forecasts would be useful at a variety of time and space scales. At large space and time scales, fire weather forecasts could help to allocate scarce resources. At intermediate time and space scales accurate fire weather forecasts could help to alert, plan, and stage the deployment of fire crews and equipment. At the smallest time and space scales, accurate fire weather forecasts could help to formulate optimal methods for fighting fires as well as for determining optimal periods for setting prescribed silvicultural fires (Fosberg & Fujioka 1987).

Right now, official US fire weather forecasts are prepared mostly from short-range intermediate scale weather forecasts (1–2 days) by the National Center's for Environmental Prediction (NCEP's) Eta model (80 km resolution). Current observations at remote weather stations are also heavily used. However, various experimental forecast extensions to these official efforts are being attempted. For example, Roads et al. (1991) discussed the experimental application of alternative medium range forecasts (2–10 days at 250 km) of near surface fire weather elements such as temperature, relative humidity, wind and a derived fire weather index (FWI; Appendix 1).

The Scripps Experimental Climate Prediction Center (ECPC) has attempted to further extend these medium-range dynamical forecasts spatially and temporally and is also disseminating near real time forecasts via the WWW (Roads et al. 1997a, b). The purpose of this talk is to describe this experimental global to regional and daily to seasonal forecast system.

2 Forecast System

ECPC's atmospheric forecast system consists of three models. At the largest space and time scales, the modeling system uses NCEP's medium range forecast (MRF) model or global spectral model (GSM; Kalnay et al. 1996). A high

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resolution regional spectral model (RSM; Juang & Kanamitsu 1994, Chen et al. 1998; Anderson et al. 1998), is nested within the global model by first integrating the GSM, which provides initial and low spatial resolution model parameters as well as lateral boundary conditions for the RSM. The RSM then predicts regional variations influenced more by the higher resolution orography and other land distributions within a limited but high-resolution domain. A mesoscale spectral model (Juang 1998), which uses the nonhydrostatic equations, can then be nested within the RSM or can be initialized and bounded by the global model. All models use the same 28 terrain following sigma layers and the same comprehensive set of physical parameterization modular packages, which include land surface parameters (e.g. soil wetness, soil temperature, etc.), sensible and latent heat fluxes, radiation fluxes, cloudiness, various three dimensional heating and moisture distributions, max/min temperatures, etc.

The forecast procedure is as follows. First, NCEP makes the global forecasts and posts the analysis and 4×daily 72-hour forecasts on their ftp site. Due to bandwidth limitations of the Internet, only the complete initial (operational analysis) and 72-hour forecasts 4 times daily (00, 06, 12, 18 UTC) for the global model are transferred. From these global initial conditions, which are then immediately copied to MHPCC for the Hawaii runs, experimental global forecasts are made. The GSM provides the basic data (200 km resolution) for global and focused spatial regions, which include the Pacific Basin and the U.S. The global model is first integrated for 7 days, every day, and 90 days, every weekend. Initial SST anomalies are persisted throughout the integration. Tests are underway to evaluate whether forecast SST anomalies would be more useful than the current persisted SST anomalies. Tests are also underway to evaluate ensemble forecasts (90 day forecasts made every day).

After the first 7 global forecast days are completed (about 5 hours 275 MHz DEC Alpha cpu time), three regional domains, which use the forecast global fields as initial and boundary conditions, are integrated for 7 days (about 24 hours 433 MHz DEC Alpha cpu time for each regional model). The global forecasts are then continued out to 12 weeks plus every day. These extended runs are then combined for the same validation time to provide an ensemble forecast. Due to lack of computer time, seasonal regional forecasts can not yet be done on a regular basis since forecast start times and duration are dictated by available computer time at night and on weekends (individual workstations). A beginning collaborative effort (Hawaii Ohana, which is based at the Maui High Performance Computer Center) is developing an even finer scale operational mesoscale modeling effort for the Hawaii Islands. All of the islands are being modeled with a corresponding nonhydrostatic mesoscale model at 10-km resolution and individual island complexes are being modeled at 2–4 km resolution with a total forecast duration of 24 hours, although this could be extended during emergency situations. The purpose of these regional simulations is to provide a regional climatology for the Hawaii Islands. Similar RSM runs are being developed for the US, southwest, and California regions. The MSM has also been applied to various case studies and could be used to further downscale the regional predictions.

3 WWW Display

Several products from our global to regional and daily to seasonal forecasts are currently displayed on our Experimental Climate Prediction Center's worldwide website *http://ecpc.ucsd.edu/*. Our major table (Table 1), introduces output from the ECPC global (200 km), Pacific (200 km) regions, US (200 and 50 km), US Southwest (25 km), California (25 km). Products include the FWI and associated variables such as 2 m temperature, relative humidity and 10 m windspeed as well as precipitation and soil moisture for several regions. Separate displays of weather (up to 7 days) and climate forecasts (Table 2) are then developed. The climate forecasts are displayed as weekly means for the first four weeks and then monthly means thereafter. For both the weather and climate forecasts, combinations (2×daily for the weather forecasts and weekly for the 12 week forecasts) of all the latest forecasts can be seen in a virtual VCR, which can step through the forecasts one by one forwards or backwards or which can animate the forecasts. The VCR display effectively summarizes twice daily and weekly forecast variations. Exam-

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Table 1. Entry to weekly products (FWI, T, RH, W, SMC, P) and regions (global, Pac., US, SW, CA)

		Global	Pacific	US	US SW	California
FWI	Total	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
	Anomaly	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
WSP	Total	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
	Anomaly	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
T2M	Total	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
	Anomaly	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
R2M	Total	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
	Anomaly	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z	00Z 12Z
PRECIP	Total	DLY	DLY	DLY	DLY	DLY
	Anomaly	DLY	DLY	DLY	DLY	DLY
SMC	Total	DLY	DLY	DLY	DLY	DLY
	Anomaly	DLY	DLY	DLY	DLY	DLY

Table 2. Table entry to weekly to 3 monthly FWI forecasts for the global domain

Weekly Averaged Fire Weather Index at 00Z (16:00 PST)
GLB 00Z FWI FCST Last Update on Aug 12, 11:51 California Time

Initial date[a] (6 wks animation) ~248 Kb	Valid. wk[b]								
	Jul 18–Jul 25[d]	Jul 25–Aug 1[d]	Aug 1–Aug 8[d]	Aug 8–Aug 15[e]	Aug 15–Aug 22[f]	Aug 22–Aug 29[f]	Aug 29–Sep 5[f]	Sep 5–Oct 3[g]	Oct 3–Oct 31[g]
Aug 8, 1998/ [anim. gif][c]			obs	wk1	wk2	wk3	wk4	wk5–8	wk9–12
Aug 1, 1998/ [anim. gif]		obs	wk1	wk2	wk3	wk4	wk5	wk6–9	wk10–13
Jul 25, 1998/ [anim. gif]	obs	wk1	wk2	wk3	wk4	wk5	wk6	wk7–10	
Jul 18, 1998/ [anim. gif]	wk1	wk2	wk3	wk4	wk5	wk6	wk7	wk8–11	wk12–15
Jul 11, 1998/ [anim. gif]	wk2	wk3	wk4	wk5	wk6	wk7	wk8	wk9-12	
Jul 4, 1998/ [anim. gif]	wk3	wk4	wk5	wk6	wk7	wk8	wk9		
Jun 27, 1998/ [anim. gif]	wk4	wk5	wk6	wk7	wk8	wk9	wk10		
Jun 20, 1998/ [anim. gif]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

obs observation for validation week, *wk* week
[a] Initial date od 1 week forecast and 4 weeks forecasts
[b] Validation week for forecasts
[c] Animation of 6 week forecast from this initial date
[d] Forecasts for previous weeks
[e] Forecast for current week
[f] Forecasts for future weeks
[g] Future 4 weeks forecast

ples of current forecasts will be displayed at the meeting.

As an example of the current displays, Fig. 1 shows the anomalous FWI forecast for the US for the period Aug. 29–Sept. 26 and Sept. 26–Oct. 24, 1998. Note that red indicates above normal potential and blue indicates below normal potential. For the forecasts shown here, most of the country has less fire weather potential than normal. Increased potential is found over Canada and Mexico. This reduced potential over the US is due to reduced wind speed and relative humidity; temperature effects have less influence on variations in this parameter.

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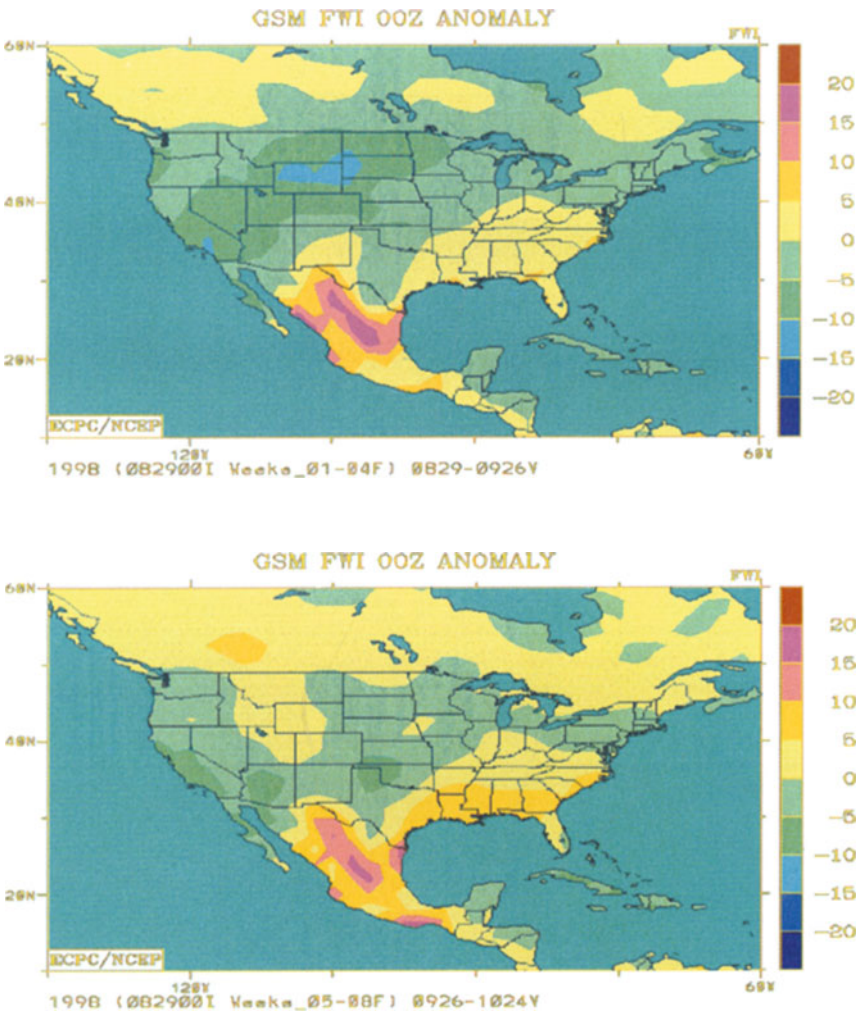


Fig. 1. Monthly FWI anomaly forecast for the US region for Aug. 29–Sept. 26, 1998 and Sept. 26–Oct. 24, 1998. Red indicates above normal fire potential and blue indicates below normal fire potential

The anomalies are calculated here with respect to the NCEP reanalysis anomalies (Kalnay et al. 1996) and could thus contain some influence of systematic forecast model bias. Eventually, the forecast bias of the model will be removed, which will provide a better forecast of anomalous values.

4 Future Developments

New features are under development. Right now, the regional models (US, US SW, CA, HI) are reinitialized every day with the new global analysis. Eventually the regional models will be run continuously and only the horizontal boundary conditions and large-scale variables will be reinitialized. This continuous regional simulation will allow the surface boundary conditions to evolve toward a true regional equilibrium. Provision of additional land surface variables such as snow, soil and vegetation moisture, evaporation are also being developed. These additional variables will be need to transform fire weather indices into fire danger indices which measure soil and vegetation as well as weather parameters, although further research is needed to optimally combine model and observed surface parameters.

Atmospheric surface forcing parameters such as sensible and latent heating, short and longwave heating, surface wind stress and precipitation minus evaporation will soon be provided as part of this new land surface as well as a related ocean forecasting effort. Many sea surface temperature experiments are also under development in order to understand the influence of the SST on the 1–12 week forecasts. Besides the persistent SSTs, which are currently used to forecast the atmospheric models, observed SSTs, climatological SSTs, and forecast SSTs will also be used to force the models. We are also

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testing the influence of the initial state by doing similar experiments in which the observed initial state is replaced by a model initial state. This forecast is similar to what is currently being used by many groups to make seasonal forecasts and positive results will suggest that the optimal way to make a seasonal forecast is to first make a weather forecast as well as a forecast of the anomalous sea surface temperatures.

Skill evaluations are just beginning (Roads et al. 1998). There are systematic biases in all the fields with the temperature and relative humidity biases being most noticeable. Separating out the systematic bias as well as evaluating the true forecast skill from a limited number of forecasts is dangerous and we have to be patient in developing a true evaluation from a still limited number of forecasts. Nonetheless, the forecast skill is consistent with current medium range forecast model skill. The greatest skill occurs initially and then decays toward zero at long forecast ranges. However, daily or weekly or monthly forecast skill does not ever reach absolute zero and the residual weekly forecast skill when averaged into monthly and seasonal averages shows skill levels that may be significant and comparable to other long range forecast methodologies.

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Appendix 1: Fire Weather Index

The physical aspects of wildland fire can be quantified in a variety of ways, e.g. rate of spread, rate of thermal energy production, fireline intensity, etc. Similarly, fire danger can be described by a variety of measures; in the United States, the most common measure in the US is the US National Fire Danger Rating System (NFDRS; Deeming et al. 1977). From this national fire danger rating system, Fosberg (1978) derived a simplified fire weather index (FWI) based upon equilibrium moisture content a, which is a function of temperature, T (Fahrenheit) and relative humidity, R (percent), and wind speed, W, (statute mph). As might be expected times of potential fire danger (as described by the simplified FWI) are during windy, relatively dry, and to a lesser extent, warm conditions. The FWI is computed from the following expression given in Roads et al. (1991):

$$\mathrm{FWI} = (1+\mathrm{W2}\ )1/2(1-2a+1.5a2-0.5a3)/0.3002$$

$$a = \mathrm{m}/30$$

$$\mathrm{m} = 0.03229+0.281073\mathrm{R}-0.000578\mathrm{RT}, \quad \mathrm{R}<10$$

$$\mathrm{m} = 2.22749+0.160107\mathrm{R}-0.014784\mathrm{T}, \quad 11<\mathrm{R}<50$$

$$\mathrm{m} = 21.0606+0.005565\mathrm{R2}-0.00035\mathrm{RT}-0.483199\mathrm{R}, \quad \mathrm{R}>50$$

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CHAPTER 6.5

Overview of Lightning Detectors: Their Role in Risk Management of the Lightning Hazard

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Abstract

An essential element of lightning safety is early detection of the approaching or developing threat. Lightning warning systems employ several types of sensing technologies for advanced indication of the danger.

Many government and private sector groups utilize lightning warning equipment. For example, forestry managers commonly employ lightning detectors. By knowing characteristics and location of lightning flashes to ground, woodlands fire response officials can dispatch investigation and suppression crews earlier in time, thus reducing costs and damages.

1 Introduction

Lightning accounts for an estimated USD 5–6 billion in annual USA damage (Appendix 1). Some 10 000 annual forest fires are lightning-caused. A recent forest fire in the Boise, Idaho USA National Forest, was contained only after 45 days with fire crews of 245 people at a cost of USD 65 million.

Lightning detectors provide advanced hazard notice for safety of people and for structures. Some detectors can be coupled to automated start/stop switches connected in turn to AC power devices. This can reduce the likelihood of electrical upsets from lightning-energized electric power lines. Detectors vary in complexity, cost and size from large dedicated equipment packages to desktop size to small hand-held portable units. Available technologies of present-day detectors include:

- Radio Frequency (RF) Detectors. These devices acquire lightning's atmospheric discharge (electromagnetic radio) or return stroke signal.
- Optical Detectors. These devices measure lightning's light flash emissions.
- Electric Field Detectors. These devices measure changing atmospheric voltage (potential gradient) as a precursor to lightning discharges.
- Hybrid technologies, employing a combination of measuring techniques.

Networked or multi-station systems, while expensive, provide considerable information. A successful USA network is the National Lightning Detection Network (NLDN). This approach, consisting of some 106 linked ground-based sensors, recognizes lightning's unique return stroke (RF) signal. Direction, range, amplitude and polarity can be measured and archived for later study. The NLDN design also operates, in whole or in part, in Canada, France, Germany, Italy, Netherlands, Norway, Sweden, Spain, Austria, Colombia, Brazil, Indonesia, S. Korea, Japan, Thailand, and Malaysia (Ref. 1).

Space-based lightning detection is an emerging technology with potential for higher levels of accuracy. Several in-orbit detectors are providing sophisticated lightning information. One such instrument processes some 5000 images per second. Comparisons with ground-based detectors are favorable (Ref. 2).

None of the foregoing instruments detect all lightning strikes all of the time. Users should

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avoid a false sense of total confidence in the instrumentation, since false alarms are possible. Detectors do not provide predictions as to "first strike" time or location. An important part of lightning detection is a written safety plan describing: a) when to suspend activities; b) where to seek shelter, and; c) when to resume activities (Ref. 3).

2 Case Study in Western Canada

For some years, the Alberta, Canada Forest Protection Division has employed the networked lightning detection system described above. It consists of multiple direction-finder sites, a position analyzer, and a display output. The location of lightning flashes can be recorded and studied.

Bearing data from at least two direction finders is required. Lightning's unique waveform displays an extremely rapid rise to peak energy. Raw data is detected by both a flat plate electric field antenna and a vertical orthogonal loop antenna. Processors indicate location accuracy to some 600 m, incident time, number of return strokes, intensity (measured in kiloamperes), and polarity (negative or positive). With this real-time information, fire managers are able to monitor cloud-to-ground lightning. They can dispatch area patrols as required (Ref. 4).

3 Conclusion

Safety from natural hazards requires advanced notice of high risk situations and the ability to adopt a low risk defensive posture. Lightning detectors contribute a useful element in the risk management process.

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3. National Lightning Safety Institute WWW site at: *http://www.lightningsafety.com*
4. Alberta Canada Forest Protection Division WWW site at: *http://www.gov.ab.ca/env/forests/fpd/wx/ltg_sys.html*

Appendix 1: Annual USA Lightning Costs and Losses

Compiled by the National Lightning Safety Institute, 1998.

The National Weather Service reports lightning damage at some USD 35 million annually. Instead, we suggest that lightning losses may reach USD 5–6 billion per year. They include:

App. 1.1 Forest Fires

Half the wildfires in the western USA are lightning-caused. In total there are about 10 000 such fires costing about USD 100 million annually.
- Dale Vance, BLM, US Dept. Interior.

In 1996 the National Park Service had 517 lightning-caused fires, costing USD 19 567 128.
- Gary Hasty, National Park Service, US Dept. Interior.

App. 1.2 Residential Fires

Lightning causes 26 500 house fires amounting to USD 147.3 million in losses annually.
- Association of US Fire Chiefs, 1995 Report.

App. 1.3 Insurance Claims in the Homeowner Sector

Lightning losses approach one billion dollars, representing 5% of all residential claims.
- Insurance Information Institute, NY, 1998.

On average, lightning results in one insurance claim for every fifty-seven lightning strikes.
- Holle, Lopez, Arnold & Endres, 1995 IAGCLSE Proc.

In 1995, there were 22.3 million lightning flashes to the USA.
- Orville and Wilbur, 1997.

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App. 1.4 Storage and Processing Activities

Looking specifically at storage and processing activities lightning accounts for 61% of the accidents initiated by natural eventsmany of the North American accidents were a lightning striking storage tanks containing petroleum products...
- Journal Of Hazardous Materials 40 (1995) 43–54.

App. 1.5 Aircraft Mishaps and Upsets

More than 50% of military aircraft weather-related mishaps are caused by lightning.
- Major P.B. Corn, Air Force Flight Dynamics Lab.

Each lightning incident to commercial aircraft costs about USD 100 000. Commercial aircraft are struck, on average, about once per year.
- Mr. Andy Anderson, Vaisala USA.

Lightning costs about USD 2 billion annually in airline operating costs and passenger delays.
- NOAA Report No. 18, MIT, 13 Feb. 1998.

App. 1.6 USA Electric Power Industry

Some thirty percent of all power outages are lightning-related on annual average, with total costs approaching one billion dollars.
- Ralph Bernstein, EPRI ; Diels, et al. (1997).

App. 1.7 Sensitive Electronic Components

Lightning-caused insults include explosions, fires, burn marks and mechanical distortion. Data corruption and slow degradation of circuit boards are serious hidden problems caused by lightning. No one knows the dollar cost or the magnitude of damage here.
- Richard Hasbrouck, LLNL (retired).

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Meteorology and Desert Locust: Experience and Implementation of a Monitoring System

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Abstract

The permanent threat of the locust invasion and the immense damages caused to agriculture and the ecological system by the last generalised plague during the period 1987/1989 has caused the National Meteorological Office of Algeria, in close coordination with the National Institute for Plant Protection and the Commission for Control Locust. In the North West Africa of the Food and Agriculture Organisation (F.A.O), to establish a specific program to contribute to a better management of the locust control system.

This program is structured as follows: a) establishment of a national climatic network (automatic stations) to complement the network in Central Sahara, and b) establishment of a specialised Centre (Tamanrasset) to complement the permanent locust watch (monitoring) system to improve the aerial assessment of the rainfall and of air corridors for the development and progression of the desert locust (vegetation index).

The implementation of this program, during recession periods as well as during plague periods has led to a better management of the control system.

1 Introduction

The Desert Locust, Schistocerca gregaria (Forskal), is one of about a dozen species of short-horned grasshoppers (Acridoidea) that can form dense, mobile swarms (of adults) or hopper bands (of nymphs). The Desert Locust is one of the most important locust species because of its:

- great mobility – up to 1000 km a week,
- vast invasion area,
- ability to build up to prodigious numbers,
- ability to eat its own weight of fresh food daily,
- damage to a wide variety of crops can be sudden and severe.

The life cycle has three stages:

- *egg*: laid by females or clusters (*pods*) in the ground.
- *hopper*: wingless *nymphs* or *larva*, separated by moults into 5 or 6 sub-stages (*instars*).
- *adult*: the winged stage (or *imago*) – a large insect with a wing span of 10–15 cm, and a weight of 1.5–3.0 g.

When there are many bands and swarms over large areas there is a plague, and crop damage can be disastrous. Between any two plagues there is a recession – where there is only a small number of locust and crop damage is small. During plagues, swarms may spread over an enormous invasion area of some 29 million km^2, and extending over or into 57 countries. During recessions, locusts occur in a smaller recession area of some 16 million km^2 in the semi-arid or arid interior of the invasion area, and extending over into parts of 30 countries (Fig. 1).

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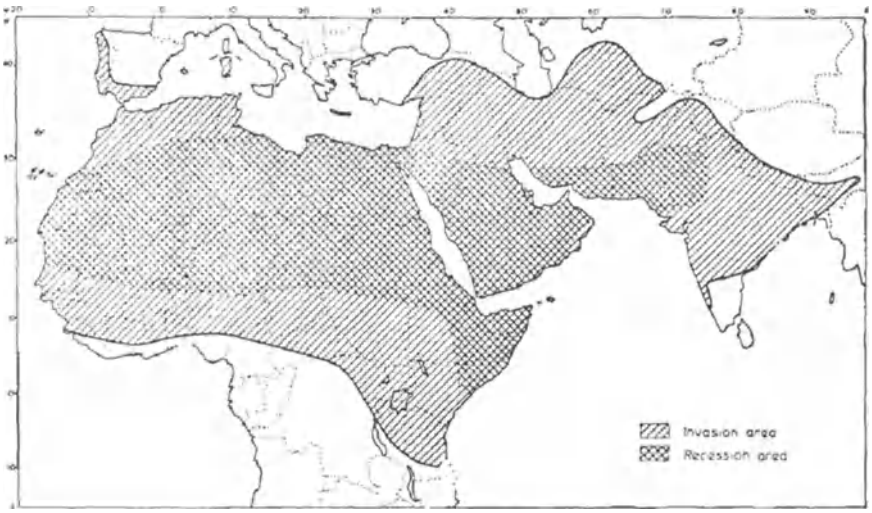


Fig. 1. Invasion and recession areas of the Desert Locust (updated from Waloff 1976)

The invasion area has been divided into four major regions: Western, North Central, South Central, and Eastern. Each region contains complementary seasonal breeding areas connected by seasonal migration circuits, but it is important to bear in mind that these circuits are not always closed – both swarms and low density populations often move from one region to another (Locust Handbook 1988).

2 Seasonal Breeding and Movements of Swarms During Plagues

The invasion area of swarms of the desert locust is very large (Fig. 1) extending over 113 degrees of longitude, from the Canary Islands off West Africa to Assam (from 18 °W to 95 °E), and 51 degrees of latitude, from Turkey to Tanzania (41 °N to 10 °S). It covers about 29 million km^2, and comprise the whole or parts of 57 countries as well as a considerable range of climatic regimes.

In addition, swarms, groups and isolated locusts have all been seen at sea, both flying and in the water, as far as 2400 km from land (Waloff 1963) and recently, during the last plague (Nov. 88) have been seen crossing the Atlantic and reaching the Caribbean Islands.

Most of the climates in the desert locust area have, however, a common characteristic in that they are dry, with low average rainfall that falls either sporadically or, more commonly, is restricted to limited seasons. Desert locusts need moist soil for egg laying and incubation, and fresh vegetation for hopper development, and in their generally arid environment they can reproduce only during periods of rainfall.

Two major seasonal belts in which rains fall and in which locusts breed (the northern hemisphere summer and spring, respectively) run from west to east through the Desert Locust invasion area. Between the two belts, and partly overlapping with each, lies a third belts, of winter breeding, which is particularly important on the Somali Peninsula and around the Red Sea. Within these seasonal belts, the distribution and extent of breeding varies from year to year.

Young swarms as a rule leave their source areas at the end of the rains, and the greater parts of the seasonal breeding belts become free of swarms during their dry seasons. The emigrating swarms move downwind to the next or next-but-one breeding belt, and these migrations usually result in seasonal translocation of entire swarming populations between complementary seasonal areas, often thousands of kilometres apart.

3 Migrations of Summer Swarms to North West Africa

Soon after young swarms appear in the summer breeding belt they begin to leave their source areas and migrate towards the countries in which they will breed in winter or spring, or both.

The initial emigrations are often to the north and north-west or west-north-west, with swarms moving down the advancing southerlies

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during northward surges of the ITCZ, or more commonly with the south-easterlies associated with the approach of depressions moving in from Atlantic and eastward over the Sahara. Such movements result in the spread of swarms into the Algerian Sahara, northern Mauritania and Western Sahara, all of which may be invaded from September, though more frequently from October and even from November. Morocco may be first reached between late September and November, though most frequently during October, while Algeria north of 32 °N may be invaded between October and December. All the countries of north-western Africa may experience repeated invasions by successive waves of swarms moving in from between south-west and south-east as atmospheric disturbances move from west to east across the region.

South-western Libya may be first reached in October or November, with swarms moving north and north-east either directly from Chad and Niger, or after crossing the Algerian Sahara. An eastward to north-eastward trend may appear in all the invaded areas, with swarms moving on the west or south-west winds around the southern side of eastward-moving cyclones; this trend may lead to movement of swarms from Mauritania into the Algerian Sahara, and from Algeria into Tunisia and north-western Libya, both of which may be invaded either from the south or from the west (Locust Handbook 1988).

4 Implementation of a Monitory System

Because of its importance and suddenness, the Desert Locust plague of 1987–1989, which occurred in West and Northwest Africa, forced Algeria and Marocco into an unprecedented campaign covering more than 5 million ha and requiring more than USD 100 million. Algeria has responded to the 1987–1989 locust invasion on more than 2 million ha representing more than 30% of the treated area in the Maghreb (7 500 000 ha).

The dangerous evolution of the locust situation from October 1987 onwards had led the Algerian government to adopt exceptional procedures to face this plague so that minimum damage to agricultural production and the environment would result. Subsequently, the National Meteorological Office, in close coordination with specialised organisations, has established a specific program to contribute to a better management of the locust control system taking account of the different phases.

The investigations, which have been going on intensively for two years, have proven that meteorological data available at the local level have contributed significantly to the organisation of the desert locust prevention and control effort.

The meteorological phenomena at the synoptic scale proved to be the major factors in the Desert Locust tragedy. The quick availability of these meteorological products (particularly the forecast from the European Centre for Medium-Range Weather Forecasts ECMWF) by fax transmission from the European Meteorological Centre (Reading/UK) to the national meteorological centre and then to the local control centres has been decisive in that a wind map is more expressive than a long telex. This technique of meteorological dissemination helped with real time data and enabled specification of relations between the meteorological conditions and movement of the swarms.

However, some shortcomings have been detected concerning mainly the meteorological conditions, which affect the locust reproduction in the Sahara regions, and the effect of mesoscale meteorological phenomena on the aerial spraying of locust swarms. In view of these deficiencies, the need for a desert locust strategy was discussed with different structures concerned by the problem (I.N.P.V.), and it was decided to develop a permanent integrated meteorological and desert locust monitoring system to provide the necessary assistance for plant protection survey teams.

Therefore, since 1993 a specific program for watching climatic condition and growth of vegetation has been in operation and structured as follows:

- A regional meteorological centre for the Saharan area built on the strategic site of Tamanrasset (22 °47N/05 °31E) which is the heart of the desert locust breeding area common to Algeria, Niger and Mali.
- A National Climatic network in central Sahara; limited in the north by the Saharan Atlas, and which will help to improve the aerial assessment of the rainfall and of air corridors necessary for the development and progression of the desert locust.

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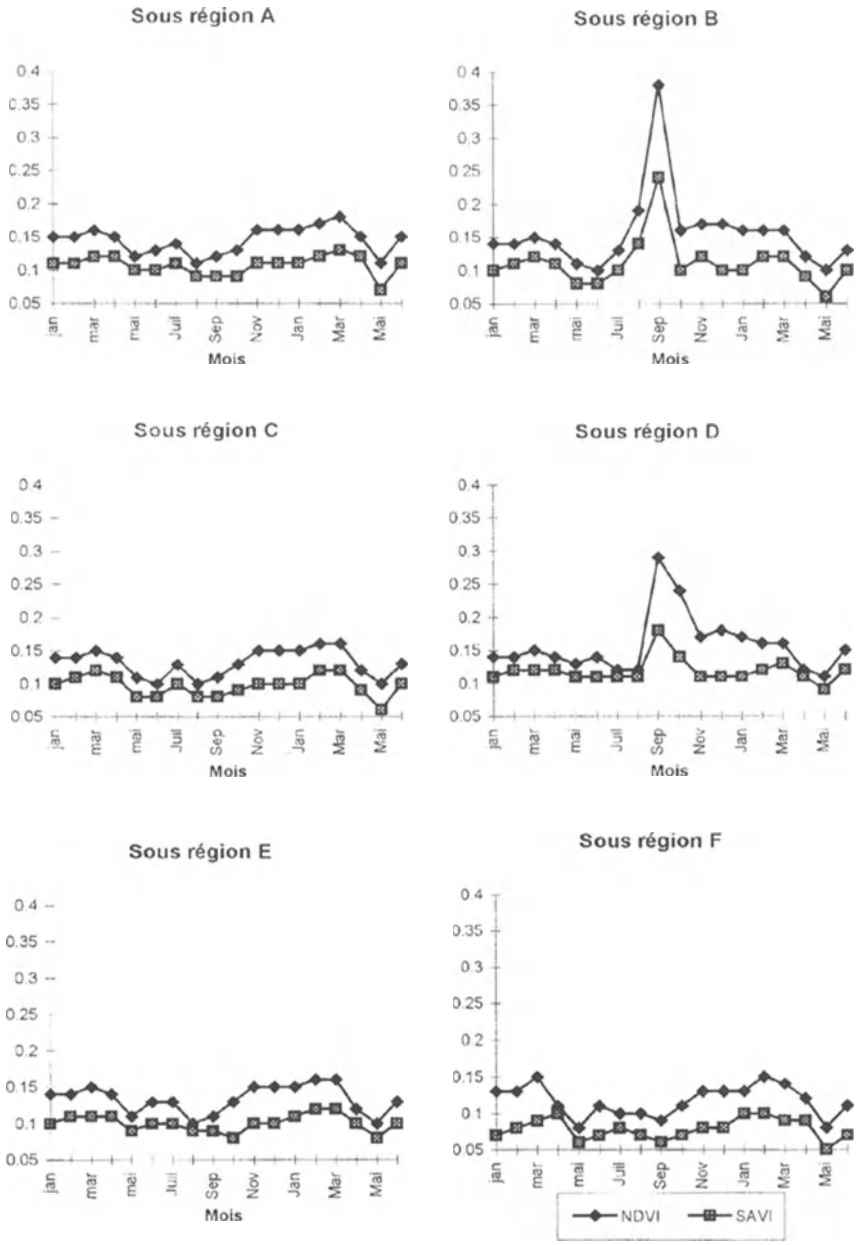


Fig. 2. Index of vegetation on different areas during the last months (since January 1997)

- Synoptic network consisting of 20 automatic weather stations fitted with data collection platforms (D.C.P.) for transmission via Meteosat and covering the sensitive area of desert locust activity from the central Sahara.
- Elaboration of a vegetation index map (N.V.D.I.) on sensitive breeding areas situated in the extreme south of Algeria and north Niger and Mali (Fig. 2). For this work, two systems of satellite reception (Meteosat and NOAA14) were installed at Tamanrasset with the collaboration of TAMSAT-PROGRAM from the University of Reading and "Natural Resources Institute" (UK).

The aim of the system is to determine as early as possible those populations of pests which will increase to significant proportions. Locating such populations is the major problem in operational crop protection against migrant pest.

As has been known for a long time, water equivalent to about 20 mm of rainfall must be present in the typical, sandy soils of the relevant regions, to induce female Desert Locust to lay their eggs, and then for these to absorb sufficient moisture for hatching to take place. The rate of development of the eggs decreases quite rapidly with temperature, but so does the rate of evaporation, and the initial quantity of water

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required in the soil to lead to successful hatching may not vary greatly. The other water requirement before a population can expand is for the growth of vegetation to sustain the emergent hoppers.

Where no substantial vegetation is present at the time of laying, a minimum available soil moisture of ca. 20 mm of rainfall represents the threshold level at which vegetation development may be sufficient to introduce the risk of population expansion.

This national meteorological monitoring network will rely on and also strengthen the integrated system of World Weather Watch. Parallel, the desert locust control plan should allow for the following actions:

- Establishment of a permanent locust watch (monitoring) system as a main component of the plan of action to strengthen and reorganise the preventive control of the desert locust plague at the national scale. As a matter of fact, the desert locust research base of Tamanrasset could well present an important focal point because of its strategic position in the main Sahara breeding zone.
- Continued maintenance of the prospection teams in the field, to allow them, supported by the past, present and forecast meteorological information, to go through all the potential breeding areas where the ecological condition might be favourable to desert locust development.

To conclude, and keeping in mind the recent field experience of the 1987/1988 desert locust plague, it is extremely urgent to consolidate and perpetuate the monitoring system for locusts and meteorology, knowing that the desert locust is a permanent calamity and constant threat over a long time. This integrated system should allow a minimal use of pesticide, which used in large quantities represents another threat to the environment.

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Early Warning Systems for Asteroid Impacts

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Abstract

Asteroids and comets are small members of our solar system, some of them having orbits bringing them close to the Earth, and thus increasing the possibility of a collision. These objects are called NEOs (Near-Earth Objects). The probability of large (>1 km) NEOs impacting the Earth is relatively low but the resulting damages would be catastrophic. However, even smaller NEOs may also have disastrous consequences. On June 30th 1908, a 60 meter sized stony asteroid entered the Earth's atmosphere at Tunguska, Siberia. Due to its velocity of about 15 km/s, the NEO exploded some 9 km over ground, releasing energy equivalent to 10 megatons of TNT. The shock wave devastated an area larger than 2200 km^2, the size of a major city such as Berlin. Due to the remote location of the impact site only two men were reported killed. Such impacts are statistically expected once every 100 to 300 years, but the next large impact can only be predicted if the NEO is discovered in advance. This paper presents the current NEO detection efforts, and discusses the possibility of preventing future impact catastrophes.

1 Introduction

Our solar system was formed about 4.6 billion years ago. In addition to the Sun and the planets, innumerable small celestial bodies, namely comets and asteroids, were formed. Because of their small masses relative to the planets they are susceptible to orbit disturbances. Therefore, it can happen that some of them change their orbit and approach the Sun. In this case they can intersect the Earth's orbit thus making a collision possible. These objects are called near-Earth objects (NEOs). NEOs approaching Earth closer than 5 million km are called potentially hazardous objects (PHOs). Although NEO impacts are rare events they can occur at any time. Due to the low NEO detection completeness of only a few percent, a sudden unpredicted impact is the most probable scenario for the next impact event. A prediction of a future NEO impact can only be made by an extrapolation of the observed NEO orbits into the future. Therefore, the search for NEOs has to be intensified. The next step is to explore typical NEOs in order to select future deflection systems, which then have to be tested. The efforts required for a successful deflection mission in the (near?) future would be of the order of a large space programme, but the potential benefits, e.g. millions of people saved from death and the prevention of widespread destruction, are invaluable.

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2 Relevance of the Impact Hazard

2.1 Recorded Impact Events

The smallest particles (dust) are captured by the Earth without any observable interaction, while meteors (shooting stars) produced by mm to cm sized objects represent the smallest impact events. The latter are visible to the naked eye when entering Earth's atmosphere and burning up at velocities ranging from 11.2 km/s to some 73 km/s. There are 3 large camera networks in Europe, Canada, and USA for the registration and analysis of meteors (Oberst et al. 1998).

Large meteors known as fireballs which are caused by metre-sized NEOs have also been detected by optical and infrared sensors onboard U.S. military DSP satellites (Defence Support Program). These DSP satellites are intended to control the nuclear test ban treaties but their sensors detect about 15 to 25 explosions with an energy release of up to 10 kilotons of TNT in the upper atmosphere each year. These data are now being made available by the military to the scientific community. Depending on the impact angle, velocity, NEO density and strength, and other parameters, the impacting object may not burn up completely and meteorites can fall to the ground. Some historical reports about people being killed by meteorites have been found, and one report (Yau et al. 1994) gives a number of over 10000 people struck to death when a meteorite shower hit a city in China in 1490. It is questionable weather this number is correct but such meteorite showers have also occurred in the current century. These meteorite showers are caused by NEOs with a size of several metres which are disrupted in the lower atmosphere and can produce thousands of fragments with masses of up to several tens of kilograms. However, the main hazard to Earth's biosphere and mankind is posed by larger objects as discussed below.

On July 30, 1908, an explosion of a stony asteroid with an energy release of about 10 megatons of TNT devastated a region called Tunguska, Siberia, an area of 2200 km^2; which is the size of a major city such as Berlin or Rome. Due to the remote location of the impact area only two people and several reindeer herds were reported killed in this event. Two comparable atmospheric explosions on the megaton scale with ground damage happened in Brazil on August 13, 1930, and in British Guyana on December 11, 1935. These events have only recently been identified and are not yet completely researched.

The largest explosions ever observed in our solar system occurred in the summer of 1994, when the fragments of comet Shoemaker-Levy-9 impacted onto Jupiter. The largest fragment, about 3 km in size, entered Jupiter's atmosphere at 60 km/s and produced a fireball the size of the entire Earth. The cumulative energy release of all fragments was about 300 gigatons of TNT which is comparable to the energy of about 18 million Hiroshima bombs.

In addition to these impact records there is a growing number of observations of close NEO fly-bys in recent years which indicates that the statistical impact frequencies are correct. The largest NEO passing Earth within the distance of the Moon was the asteroid "1996 JA1" with a diameter of about 150 m in 1996. The 300 m asteroid "1989 FC" passed Earth at 690000 km on March 23, 1989. The comparably large asteroid 4179 Toutatis (dimensions along its main axes are 1.92, 2.4, 4.6 km) is trapped in an orbit resonance with Earth and Jupiter and therefore nears Earth every 4 years. On its next very close approach on Sept. 29, 2004, it will miss Earth by 0.0104 AU (Astronomical Unit = 1.495 * 108 km) which equals 4 lunar distances. Due to its close approaches, Toutatis is defined as a potentially hazardous asteroid (PHA).

2.2 Impact Probabilities

NEO impact probabilities are mainly derived from crater statistics (Neukum & Ivanov 1994). About 140 impact craters ranging from a few meters to more than 250 km have been identified on Earth. Cratering statistics derived from measurements of craters on Earth and on the Moon show certain average time intervals between NEO impacts depending on their diameters. Tunguska-like events (NEO diameter about 60 m) are expected every 300 years or even more frequently. The impact of a 150 m NEO is expected once every 5000 years, a 1 km NEO once every 300000 years, a 5 km NEO impact every 6 million years, and a 10 km NEO impact about every 30 million years within a factor of

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about 2 (Morrison ed. 1992). This means that there is a 1 in 3000 chance that our planet will be hit by a 1 km NEO within the next century, which would cause a global catastrophe.

However, impact statistics cannot give any information about a forthcoming impact event. A prediction of a future NEO impact can only be made by an extrapolation of the observed NEO orbit into the future. Taking into account current observation and simulation inaccuracies, an impact can only be predicted about two or three decades in advance. If radar measurements can be performed and combined with optical observation data, which may be the case for a NEO fly-by within a few lunar distances, the prediction time could be extended up to one century. Today only about 500 NEOs (mostly asteroids) ranging from some meters to about 10 km, are known with more or less accurate orbital parameters. The total number of near-Earth asteroids larger than 100 meters has been estimated to be around 320 000 with an uncertainty factor of 2 (Morrison ed. 1994). These assumptions are mainly based on crater statistics and NEO population models. The few largest objects are known due to their relatively good visibility, but only a few percent of the 1 km sized NEOs have been detected so far and the detection rate is very modest. A subgroup of the NEAs is defined as the PHAs (Potentially Hazardous Asteroids) which come closer to the Earth than 5 million km (about 13 lunar distances) and are therefore candidates for a future collision with the Earth. Out of the above mentioned 500 NEAs, 125 PHAs have been identified as of July 20, 1998 (see MPC homepage).

Comets, which make up some 20 to 40% of all impacting objects, pose a problem in that they are only detectable in the inner part of the solar system. The orbits of short-period comets (SPC) can be extrapolated, and an impact can be predicted in the same way as for asteroids. The long-period comets (LPC) are expected to originate directly in the Oort cloud at the outskirts of the solar system. This means that LPCs have high velocities when close to the Earth. LPCs on retrograde orbits may collide with the Earth at velocities of up to 73 km/s. It is possible that LPCs approach the Sun and Earth only once, if on a parabolic or hyperbolic orbit. LPCs can be detected on average only about 1 or 2 years in advance using current detection technology. This would probably be too little time for a successful deflection mission. SPCs and LPCs can also have larger diameters than near-Earth asteroids, e.g. the nucleus of comet Hale-Bopp was about 40 km in diameter. This clearly shows that NEO search, follow-up programmes and mitigation analyses need further support.

2.3 Effects of Impacts

Impact effects depend mainly on the mass, density, impact angle, and velocity of the impacting object. While NEOs below 100 m may explode in the atmosphere producing damage due to shock waves, larger NEOs produce craters on the ground or Tsunami at sea and on coastlines. If the comet Shoemaker-Levy-9 (the largest fragment had some 3 km in diameter) had impacted onto Earth instead of Jupiter in 1994 about 1/4 of the world population would have died and the aftermath for the survivors would be beyond description. In Table 1, the expected impact effects for NEOs of certain sizes (and certain explosive yields) are listed. These values apply for a typical impact velocity of 20 km/s.

Figure 1 is a schematic indication of the fatality rate (deaths per year) from transportation accidents, natural disasters, and impacts as a function of the number of deaths per event. However, only impacts are capable of killing more than 100 million people per event.

3 Early Warning Systems for Asteroids and Comets

There are, or have been, some NEO search activities world-wide, of which the most important are: the Planet-Crossing Asteroid Survey PCAS (1973–1994), the Palomar Asteroid and Comet Survey PACS (1982–1994), the Spacewatch Survey (since 1981), the Near-Earth Asteroid Tracking NEAT (since 1995), the Anglo-Australian Near-Earth Asteroid Survey AANEAS (1990–1997), the Lowell Observatory Near-Earth Object Survey LONEOS (since 1996), the Observatoire de la Côte d'Azur/DLR Asteroid Survey ODAS (since 1996), and the Lincoln Near-Earth Asteroid Research LINEAR (since 1996). Other observatories and even amateur astronomers contribute to NEO observations.

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Table 1. Effects of NEO impacts on Earth (Morrison et al. 1994)

Explosive yield [MT]	NEO dia. [km]	Crater dia. [km]	Effects
<10	<0.075	<1.5 (if iron)	Explosions of comets and stony asteroids in the atmosphere, only iron asteroids penetrate to ground and produce craters.
10–102	0.075	1.5	Iron asteroids cause craters (Meteor Crater), others explode in the air (Tunguska). Impacts on land destroy areas the size of large cities such as Berlin, Rome, or Washington.
102–103	0.16	3	Iron and stony asteroids cause craters, comets explosions in the atmosphere. Land impacts destroy large urban areas such as New York or Tokyo. Tsunami occur at the coast.
103–104	0.35	6	Land impacts by asteroids and comets devastate areas twice the size of Luxembourg, Tsunami higher than 20 m can occur in the case of sea impacts.
104–105	0.7	12	Land impacts destroy areas the size of Taiwan. Tsunami can destroy larger areas.
105–106	1.7	30	Climate change due to dust raised into the upper atmosphere by the impact. An area the size of France is destroyed. Destruction by Tsunami reaches global dimensions. World-wide destruction of the ozone layer.
106–107	3.0	60	A global climate change will occur. Re-entering impact debris causes forest fires world-wide. A region the size of India will be destroyed directly.
107–108	7.0	125	Large scale climate changes and possibly mass extinctions are expected. Direct destruction of areas the size of the USA or Australia.
108–109	16.0	250	Large scale mass extinctions (such as the K/T-event) expected.
>109	>16.0	>250	Threat to all higher life forms. Very few near-Earth asteroids of this size observed, but comets can reach this size, e.g. the nucleus of comet Hale-Bopp was about 40 km in diameter.

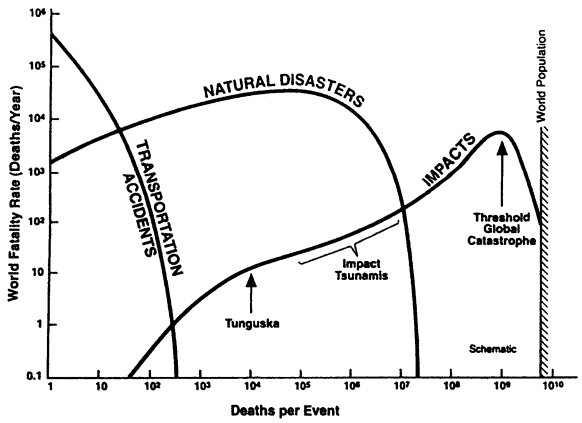


Fig. 1. The fatality rate from transportation accidents, natural disasters, and impacts (Morrison et al. 1994)

Japan announced on April 20, 1998, that they will spend about USD 15 million on building of a radar station to track space debris and a 1-m telescope to search for space debris and NEOs. This telescope will have a field of view of 3 degrees and will be equipped with 12 to 14 CCD sensors each of 2000x4000 pixels. Construction will begin in the second half of 1998 and will last 3 years.

Continuing at the current NEO detection rate will lead to only about 20% of the NEOs larger than 1 km being discovered by the year 2020. Therefore, in 1992 the Spaceguard Survey program was proposed by Morrison et al. (1994). This program consists of 6 new telescopes dedicated to NEO discovery, of which 3 will be located in the northern hemisphere and 3 in the southern hemisphere in order to provide a continuous search. These identical telescopes will have apertures of 2.5 meters and be equipped with CCD sensors. Data analysis will be performed automatically by computer programs. For each telescope a staff of 11 is foreseen. A Spaceguard Survey Operations Centre is proposed to provide coordination of the international observational and follow-up efforts. The total investment cost is about USD 50 million, with annual operating costs of USD 10 to 15 million. A less costly alternative would be to update existing telescopes by equipping them with new high quality CCD sensors. NEO searching in general needs only relatively small telescopes (aperture > 1 m) with a large field of view (about 2–3°). Therefore, increased finan-

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cial support for the already existing NEO search activities would be very helpful. Due to the relatively low cost more than the minimum of 6 telescopes could be operated. This could compensate for observational problems due to bad weather. The accuracy of orbital parameters of the NEOs could be enhanced by observing them simultaneously from several sites.

In the Report of the Near-Earth Object Working Group (Shoemaker et al. 1995) such an alternative NEO search program was proposed to NASA. In order to proceed promptly a maximum use of existing telescopes was recommended via a co-operation with the U.S. Air Force and the international community. It was estimated that a completeness of 90% for the 1 km NEOs within 10 years could be achieved. The costs for NASA (excluding the costs for the US Air Force) for an update of existing telescopes, for a new 2-meter telescope, and the operations are estimated at ECU 36 million for the first 10 years. In general further financial support for the research groups currently involved in NEO searches is strongly recommended due to serious funding problems, e.g. the Anglo-Australian Near-Earth Asteroid Survey AANEAS was closed by the Australian government on January 1, 1997. Recently, NASA announced its NEO budget will increase to USD 3 million in 1998, which will improve NASA's detection capabilities – at least in this year. It is astonishing that there are large amounts of money to produce movies on this subject (costs for "Deep Impact" were USD 75 million and for "Armageddon" >USD 100 million) but there is only slight support for science.

Space-based NEO detection systems could significantly support the ground-based search activities. On the ground there are many constraints, for example observations can only be performed during night time, clouds, light pollution by cities and the phases of the Moon, which restrict the observation campaigns. Space-based NEO detection systems can also discover NEOs approaching from the Sun, i.e. after reaching their perihelion. It is not necessary to establish a very large (and expensive) telescope such as the Hubble Space Telescope (HST) in space for a NEO search program, although the HST has already incidentally made some NEO observations and could be used for follow-up studies.

When a NEO passes Earth within a few lunar distances (depending on the NEO diameter) radar observations can be performed. Radar data combined with optical data can enhance the accuracy of orbital parameters by a factor of 100 or more. Collection, evaluation, and distribution of the NEO observation data is performed by the Minor Planet Centre (MPC). The Homepage of the MPC (see Internet Resources) includes information of close NEO fly-bys and PHOs.

4 Options for Hazard Mitigation

4.1 Neo Exploration

Follow-up observations and studies are needed to provide data such as an object's orbital parameters, surface composition, spin vector, size, mass, etc., which are important to develop and to realise a successful deflection mission in case of an emergency. In-situ exploration of NEOs is very important to obtain more information on their mass distribution, shape, internal structure, surface gravitation, centre of gravity, chemical composition, etc. There are already some asteroid and comet (including NEO) exploration missions on the way or in preparation. These exploration missions will greatly improve our knowledge of asteroids and comets, including NEOs. The research goals of current and future exploration missions should be extended with regard to the preparation of future test and deflection missions.

4.2 Test of Deflection Systems

Tests on deflection systems need to be performed in order to select optimal systems for certain scenarios. These scenarios depend on the target material (stone, iron, ice), the available time for the deflection mission, the payload capacity of the launchers etc. These fundamental tests should be performed well in advance, as in case of an emergency, there will be no time left for further studies and tests. Deflection systems with impulse delivery via an explosive event (nuclear explosions or impactors) suffer from the problem that they could destroy the NEO, depending on its internal structure and strength, or their impulse could

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be buffered by a porous object (Asphaug et al. 1998). Therefore these simulation results have to be verified by real tests. Testing of nuclear deflection systems poses technical, legal, and environmental problems that have to be considered carefully (Harris et al. 1994). Tests with nuclear devices could be avoided if simulation data can be combined with the test results of high speed impactors (as proposed for Clementine-2) which would show how impact craters form under low-g conditions typical for NEOs. These data can be only roughly extrapolated from 1g data gathered in experiments on Earth. A first attempt towards such fundamental tests was the USAF/NASA mission Clementine-2, which was to release high speed penetrators to impact on several asteroids. Although further funding has been recently stopped by a veto from President Bill Clinton, there is still hope that he could reverse his veto.

4.3 Operation of Deflection Systems

Basically there are two mitigation strategies:
- to destroy the NEO, and
- to change the NEO orbit.

In the case of the first strategy there is no guarantee that the resulting fragments will be very small and therefore harmless. Due to existing fractures inside the NEO it is possible that some of the resulting fragments could be large enough to cause even more damage on Earth than a single object because of the larger area affected. Therefore, this strategy should apply only for NEOs smaller than about 100 meters because our atmosphere protects us against NEOs up to some 20 to 30 meters. Changing the NEO orbit seems to be the only practicable way to prevent an impact of a NEO larger than about 100 m. Depending on the time remaining between detection and impact, the velocity change needed could be very small.

Conventional liquid propulsion systems are available, but are not very effective because the propellant has to be transported to the NEO. Current space transportion capabilities seriously limit the deliverable impulse to the NEO from liquid propulsion systems. A more effective method of NEO orbit alteration is to use an impactor. The impactor with a relative velocity of some 10 to 30 km/s explodes upon hitting the NEO forming a crater, and ejects NEO material at velocities higher than the escape velocity of the NEO which is only some cm/s. Therefore, the velocity vector of the NEO will be changed. The specific energy of the deflection system can be greatly enhanced by applying a nuclear explosive device. After approaching the NEO the nuclear yield would explode at an optimal distance. The radiation will heat up surface material which will abruptly expand and therefore spall away (Ahrens & Harris 1992). To perform a more efficient surface (or sub-surface) explosion, a lander (and a drilling or penetrator device) would be needed. However, nuclear explosives used in a deflection system pose some serious problems. Nuclear devices have to be guarded prior to and during, a mission in order to avoid their misuse.

A detailed analysis and comparison of possible deflection systems based on current and future technology has been performed by the author (Gritzner 1997). The result of the study showed that nuclear explosives are the most effective method of impulse delivery due to their low specific system mass. Other deflection systems can be applied if a long warning time (years or decades) is available or if the NEO is relatively small (below about 1 km, depending mainly on payload capacity). A deflection system ready for launch upon detection of NEO on collision course needs to be continuously maintained thus resulting in high costs. Furthermore the deflection system has to be guarded in order to prevent a misuse. This could be excluded by producing a deflection system only after detection of a NEO on collision course with Earth. The disadvantage is that the production of such a system needs several months or years. However, the current development and production time even for small satellites is more than 2 years. The flight time additionally consumes some weeks or months depending on the orbit constellation. A compromise could be to develop and test one or more complete deflection systems. Later, these systems would be dismantled and stored at separate locations. In the case of an emergency, the parts could be assembled and supplied with propellants, batteries etc., and could be launched within short time.

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5 Summary

Collisions of large asteroids and comets with our planet are rare events but have catastrophic effects on Earth's biosphere. The 1994 impact of comet Shoemaker-Levy-9 onto Jupiter demonstrated the catastrophic effects of large impacts, and that impacts still occur in the solar system. However, impacts of asteroids and comets onto the Earth have to be avoided. Due to the global consequences of large impacts and the problems related to the development and operation of NEO deflection systems, international cooperation in solving this problem is mandatory. This paper divides the activities to prevent future NEO impacts into 4 phases as follows:

Phase 1:
Because only a precalculation of the NEO orbital data can predict a future impact the discovery and analysis of all relevant NEOs has highest priority. Up to now there are only about 500 NEOs known, combined with the estimated number of 320000 near-Earth asteroids (NEAs) larger than 100 m, the number of comets is unknown. With the current detection rate it will last about one century to find 90% of all NEAs larger than 1 km. This clearly shows that we have to intensify our efforts in NEO detection which are still at a low level. The cost for an extended worldwide NEO detection programme is about USD 5 to 10 million per year.

Phase 2:
In-situ exploration of NEOs is very important in order to obtain more information on their mass distribution, shape, internal structure etc. There are already some asteroid and comet (including NEO) exploration missions underway or in preparation. The research goals of current and future exploration missions should be extended with regard to the preparation of future test and deflection missions. Typical costs for small current asteroid and comet missions are about USD 100 million.

Phase 3:
Tests of deflection systems need to be performed in order to select optimal systems for certain scenarios. These scenarios depend on the target material (stone, iron, ice), the available time for the deflection mission and the payload capacity of the launchers etc. These fundamental tests should be performed well in advance because in the case of an emergency there will be no time left for further studies and tests. Depending on the deflection technologies to be tested the costs for such missions are comparable to the costs of NEO exploration missions.

Phase 4:
Basically there are two mitigation strategies: to destroy the NEO, or to change its orbit. With current technology sufficient orbit changes of NEOs could be achieved only by either conventional propulsion systems or impactors or nuclear explosives, depending on the NEO mass, available time for deflection, etc. However, further studies have to be performed to prepare and optimise the establishment of a NEO deflection system.

The general priority of the NEO hazard mitigation activities is *high* because we have to date only recognised the NEO impact hazard, but we have too little information on most of these objects to predict a possible future impact. This complies with the Resolution on the Detection of Asteroids and Comets Potentially Dangerous to Humankind passed by the Council of Europe in 1996 (see Spaceguard Foundation homepage). NEO search and research, follow-up programs, and NEO deflection studies should be extensively supported – the costs for these initial activities are comparably low. Mankind has the knowledge and the skills to protect planet Earth against catastrophic impacts of asteroids and comets. The next large impact will occur – the question is not *if* but *when*!

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Internet Resources

Asteroid and Comet Impact Hazard homepage: *http://impact.arc.nasa.gov/index.html*

MPC-Minor Planet Centre – The NEO Page: *http://cfa-www.harvard.edu/cfa/ps/NEO/TheNEO-Page.html*

Spaceguard Foundation homepage: *http://www.mi.astro.it/SGF/*

E.A.R.N. – European Asteriod Research Network homepage: *http://pentium.pe.ba.dlr.de/*

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Space-Borne Autonomous On-Board Recognition of High Temperature Events

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1 Introduction

Satellite fire detection and monitoring observations are currently in an experimental or pre-operational phase and directed to the development and testing of fire detection and analysis algorithms.

The Mid Infra-Red (MIR) spectral range at 3–5 μm is commonly recognised as the optimal spectral range for satellite fire detection (e.g., Robinson 1991), because:

- the MIR is near to the spectral maximum of fire emission, and
- both, reflected solar radiation and background thermal emission are relatively low in the MIR.

As a result, the maximal fire/background contrast is achieved in the MIR. In the Thermal Infra-Red (TIR) spectral range at 8–12 μm the contrast is lower due to lower fire radiance and to higher background emission. In the Short Wave Infra-Red (SWIR) at 2–2.5 μm, where the fire radiance is also high, a serious problem for daytime hot spot observations are sun light reflections.

The main problems facing reliable fire detection and analysis in satellite data are:

- strong temporal and spatial variability within the fire,
- a big dynamic range is required to avoid saturation,
- obscuration by smoke,
- variable background,
- false alarms.

Administrative users of high temperature event information such as fire departments, local authorities/environmental agencies, management of forests and national parks need near real-time transmission of hot event parameters including coordinates at a possibly earliest stage of their development. The same is valid for potential commercial users like the management of coal mines or insurance companies.

The principal reason preventing an operational utilisation of the currently available satellite data for fire detection and monitoring is the absence of:

- satellite sensors which are optimised for this task (with optimal spectral bands, spatial resolution and dynamic range),
- satellite platforms with required small revisit times, and
- near-time data processing and information delivery capability.

Data from general purpose operational satellite sensor systems such as the Advanced Very High Resolution Radiometer (AVHRR) on NOAA weather satellites and the Along Track Scanning Radiometer (ATSR) on the ERS 1 and 2 satellites are used mainly to derive "Fire products" (fire distribution maps and fire seasonality at country, continent and global level) at the moment.

In previous studies and investigations (see a review in FIRES, 1994), it was found that the

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Advanced Very High Resolution Radiometer (AVHRR) 1-km resolution data are suitable for monitoring of big fires and their relationship to the vegetation status on a regional scale. On the other hand, the AVHRR data are not suitable for a reliable fire classification and high temperature event parameter extraction due to low-temperature saturation of its MIR channel as well as for early fire detection due to its low resolution and insufficient revisit time. The same is true for the ATSR data.

Most of the known "spaceborne" fire detection algorithms have been developed based on experience during processing of the AVHRR data. They include the following typical procedures (e.g., Kaufman et al. 1990; Kennedy et al. 1994; Franca et al. 1995; Arino & Melinotte 1997):

- thresholding of MIR radiant temperature T_{MIR} to retrieve potential hot spots,
- using the difference of the MIR and TIR radiant temperatures T_{MIR}-T_{TIR} to filter out warm surfaces,
- thresholding of the TIR radiant temperature T_{TIR} to filter out clouds,
- using VIS/NIR channels to filter out high-reflection surfaces.

However, the MIR threshold values used for the MIR channel data of the AVHRR and ATSR sensors are "fixed" to figures corresponding to the saturation limit of these sensors. This is the only way to proceed, but it is far from the optimum!

Optimised hot spot detection algorithms must be implemented and validated as soon as new spaceborne sensor data are available which does not suffer from the saturation of their MIR channel.

2 New Spaceborne Hot Event Recognition Sensors

A modified medium resolution multispectral conical scanner MSU-SK/mod. was launched on the Russian satellite Resurs 04 in July 1998. The MSU-SK/mod. is equipped with a new, additional MIR channel. This channel has two switchable saturation levels: 50°C and 230°C. The on-ground pixel size (sampling step) of this channel and of the thermal channel is 520 m, the on-ground pixel size of the visible and near IR channels is 130 m.

The Moderate Resolution Imaging Spectrometer (MODIS) with a MIR channel which will be saturated at 450 K was launched on board the EOS satellite AM1 in 1999. The on-ground pixel size of this channel and of most of the other MODIS channels at nadir will be 1 km.

The MSU-SK/mod. and the MODIS are mechanical scanning sensors. Both are not dedicated hot spot detection sensors, but they may allow the testing of new and optimised hot spot detection algorithms.

Starting from the FIRES Study, the DLR is developing a new approach to the design of a small satellite mission for BI-spectral IR Detection (BIRD) which is dedicated to hot spot detection and evaluation. The BIRD project is running in phase C since September 1997. The BIRD sensor system consists of:

- a push-broom Hot Spot Recognition Sensor (HSRS) with adaptive saturation levels in the MIR and TIR channels (Lorenz et al. 1997) and
- a Wide-Angle Optoelectronic Stereo Scanner (WAOSS), originally developed for the Mars '96 Mission.

The main BIRD sensor parameters are given in Table 1.

The airborne model of the BIRD sensors has been flown successfully since 1997. Figure 1 shows the MIR camera of the BIRD airborne model. The BIRD launch target is the mid of 2001.

In 1997 DLR submitted a proposal to ESA for a High Temperature Environmental Disaster Recognition System Prototype FOCUS to be flown as an Externally mounted Payload during the Early Utilisation Phase of the International Space Station. One of the main goals of this experiment is the realisation and validation of the autonomous on-board recognition of high temperature events. The Intelligent Infrared Sensor System FOCUS was peer review evaluated and selected by ESA as the European Earth Observation payload grouping for the early utilisation phase of the Space Station. The nine month FOCUS Phase-A Study was completed in July 1999.

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Table 1. Sensor parameters of the BIRD mission

Sensor parameter	WAOSS	MIR	TIR
Wavelength	(forward) 600–670 nm (nadir, back) 840–890 nm	3.4–4.2 µm	8.5–9.3 µm
Focal length	21.65 mm	46.39 mm	46.39 mm
Field of view (FOV)	50°	19°	19°
F# number	2.8	2.0	2.0
Detector element number	2884	512×2 staggered	512×2 staggered
Detector element size	7×7 µm	30×30 µm	30×30 µm
Ground pixel size (altitude 572 km)	180 m	360 m	360 m
Swath width (altitude 572 km)	530 km	185 km	185 km
Quantisation	11 Bit	14 Bit	14 Bit
Date rate	597 kbps compressed	420 kpbs	420 kpbs

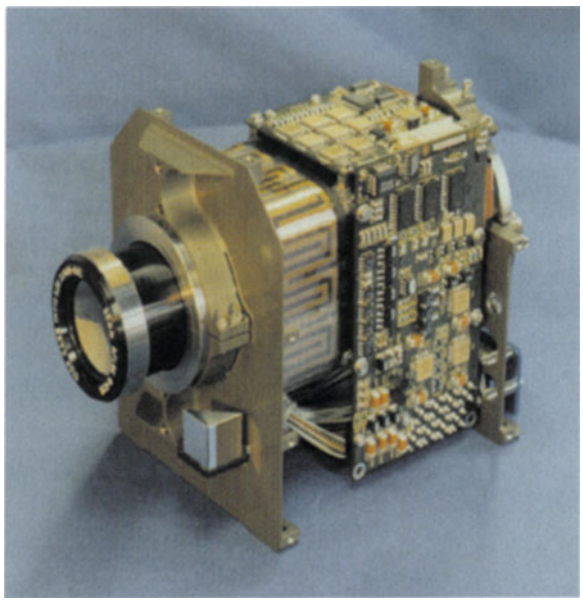


Fig. 1. MIR camera of the BIRD mission

3 The Hot Spot Detection Development Chain

Starting from the FIRES Study (1995) – together with the German industry partner Orbital&Hydro-technology Bremen-System GmbH (OHB-System) – and considering the BIRD project running (since 1996) the following Hot Spot Detection (HSD) development chain has been considered and partly realised by DLR:

1. Modelling of the detection and analysis of HTE for the BI-spectral IR Detection (BIRD) mission by:
   - airborne remote sensing of artificial fires and natural hot spots (Etna),
   - development of new hot spot detection algorithms,
   - testing of the new algorithms with different airborne sensor data.
2. Application of the new hot spot detection algorithms to data obtained by satellite sensors not suffering from possible saturation of the MIR channel such as the mechanical scanning systems:
   - MSU-SK/mod. on the Russian satellite Resurs 04,
   - MODIS on the US satellite EOS AM-1.

   If possible, dedicated "active field experiments" with on-ground, airborne and spaceborne data takes over vegetation fires and volcano events should be conducted for the validation of the new algorithms and for a comparison to the currently used detection algorithms (applied to the new non-saturated satellite data sets).
3. Development and test of new hot spot detection and analysis algorithms for spaceborne autonomous on-board recognition of HTE using:
   - airborne HTE data sets,
   - data obtained by satellite sensors not suffering from possible saturation of the MIR channel such as MSU-SK/mod. and MODIS.
4. Conduction of the BIRD mission, including:
   - remote sensing of HTEs,

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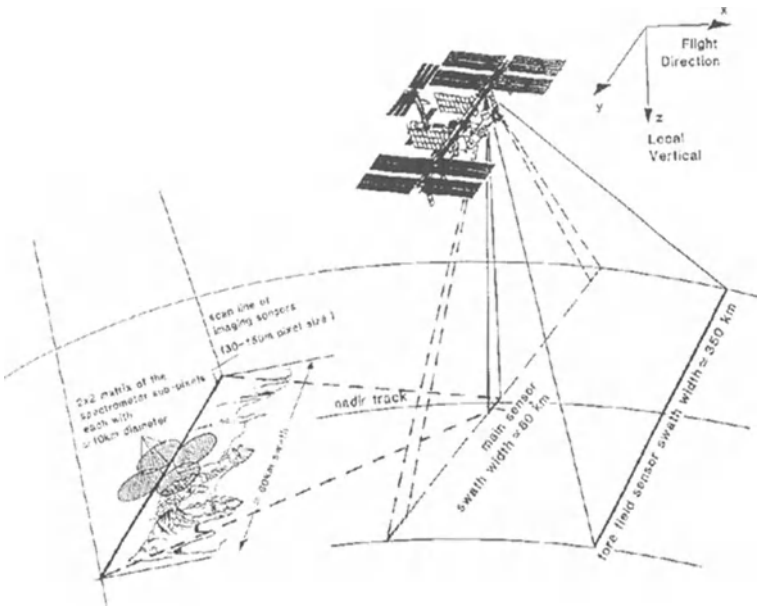


Fig. 2. FOCUS Viewing Geometry

- application of the new hot spot detection algorithms to the BIRD push broom data sets (off line, no on-board detection),
- on-ground simulation of the FOCUS Autonomous Detection Sensor.

5. Realisation of the FOCUS Experiment on the International Space Station with autonomous on-board hot spot recognition.

The BIRD data will play a key role for FOCUS and for the preparation of the first generation of dedicated operational High Temperature Environmental Disaster Recognition Systems such as FUEGO or the first instrument equipment of a Forest Fire Earth Watch (FFEW) mission, both considered now in Europe, but not targeting on an autonomous on-board detection of the HTE and the direct down link of the event messages from space to ground (as foreseen for FOCUS).

The FUEGO system intends to provide detection and monitoring of forest fires in designated risk areas with primary emphasis in the Mediterranean region and with a high revisit rate. The instrument discussed so far uses infrared sensors directed to nadir or off-nadir across the flight path to sites of already known wild fires or forest fires in designated risk areas for close inspection.

The Intelligent Infrared Sensor System FOCUS on the Space Station will be a prototype experiment of a future world-wide operating satellite system for global detection and parameter determination of both unknown and locally known wildfires as well as of other not predictable high temperature events such as volcano eruptions and coal mine burning.

For the autonomous detection of hot events and its detailed analysis by FOCUS, a sophisticated sensor payload, consisting of several multispectral imaging IR sensors and a spectrometric IR-sensor, is required. Its main characteristics are:

- infrared fore-field sensors within a broad swath to detect and identify also hitherto unknown hot spots,
- 30 seconds later the main imaging sensor, directed by the above hot spot information towards the heat emitting source, performs a close investigation and analysis of the selected high temperature event,
- in addition the gas and smoke exhaust from that source are analysed by the spectrally high resolution IR-spectrometer of the FOCUS main sensor.

FUEGO should be considered as the first generation and FOCUS as the prototype of the second generation of a High Temperature Environmental Disaster Recognition System.

Figure 2 shows the FOCUS viewing geometry and Figure 3 shows a sketch of a possible accommodation of FOCUS on the Pallet Adapter of the International Space Station.

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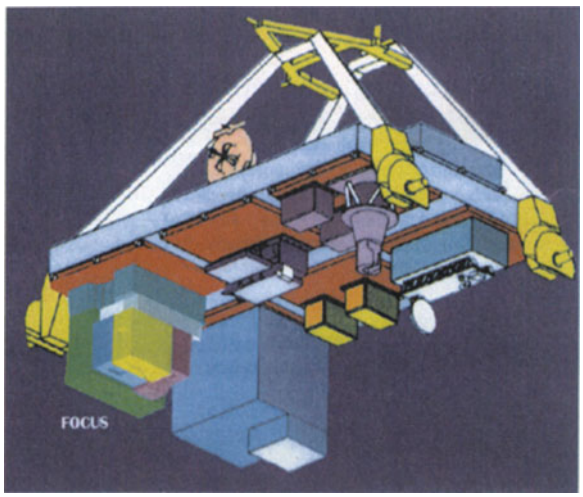


Fig. 3. Possible accommodation of FOCUS on the Pallet Adapter of the International Space Station

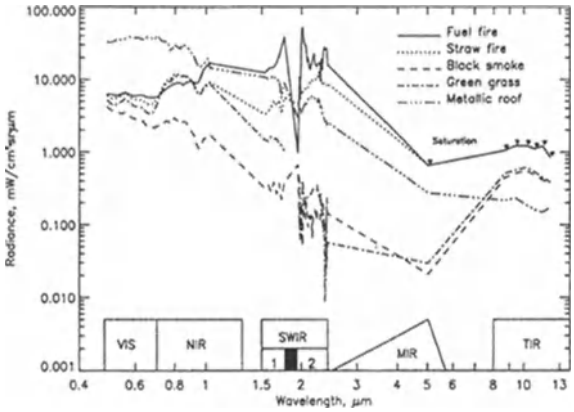


Fig. 5. Spectra of various objects as measured by DAIS-7915 on 29 May, 1996

4 Airborne Hot Spot Experiments and Simulation Results

In 1996 DLR conducted airborne imaging experiments with artificial fires using the imaging spectrometer DAIS-7915 on board a Do-228 aircraft. Imaging was performed with the resolution of ~10 m from a height of 3 km in 79 spectral bands of the 0.4–14 μm spectral range, including 1 MIR and 6 TIR bands. In 1997 the DAIS-7915 as well as the airborne prototype of the BIRD sensor system were used to image a hot calibration target from a height of 2 to 3 km.

The BIRD images of the hot calibration target are shown in Figure 4. The alibration target had the size of 1 m^2 and was heated by a gas burner to a temperature of up to 300 °C. It is clearly recognisable in the MIR and TIR images but not in the NIR image. Generally, the quality of the images obtained using a new MIR/TIR linear detector array technology was good.

Figure 5 shows the spectra of the fuel and straw fires, of the black smoke from the fuel fire, of green grass, and of a metallic roof with sun glitter obtained by DAIS-7915.

The fuel and the straw fires are the brightest objects in the SWIR, MIR and TIR spectral ranges (at wavelengths longer than 1 μm). The higher-temperature fuel fire is significantly brighter than the straw fire in the SWIR. It should be also brighter in the MIR and TIR, however, in this spectral ranges they could not be differentiated due to sensor saturation. The black smoke from the fuel fire is well pronounced by its low radiance in the NIR, due to sensor channel saturation, as well as in the SWIR until 1.5 μm. At longer wavelengths its spectral signature may be confused with grass.

The sun glitter from the metallic roof is nearly an order of magnitude brighter than all



Fig. 4. NIR: 0.84–0.89 μm, MIR: 3.4–4.2 μm, TIR: 8.5–9.3 μm. Images of a hot calibration target (indicated with the arrows) obtained by the airborne prototype of the BIRD sensor system

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the other objects in the VIS/NIR. In the SWIR/MIR it is darker than the fires, but is still brighter than the other objects. In the TIR it is the darkest object due to a low emissivitity of the metallic roof.

The DAIS-7915 images of the artificial fires were also used to simulate fire images in the spectral bands of the BIRD sensors. Based on the results of processing these images, a HTE detection and analysis algorithm has been proposed which includes the following principal steps:

4.1 Geographical False Alarm Rejection

This step excludes from processing the areas, where the HTEs can not be expected (e.g. large water bodies), as well as the known industrial hot spots. It requires an accurate data geo-referencing.

4.2 Bright Spot Detection

This step allows to select bright spots in the MIR images by an adaptive MIR thresholding (FIRES, 1994).

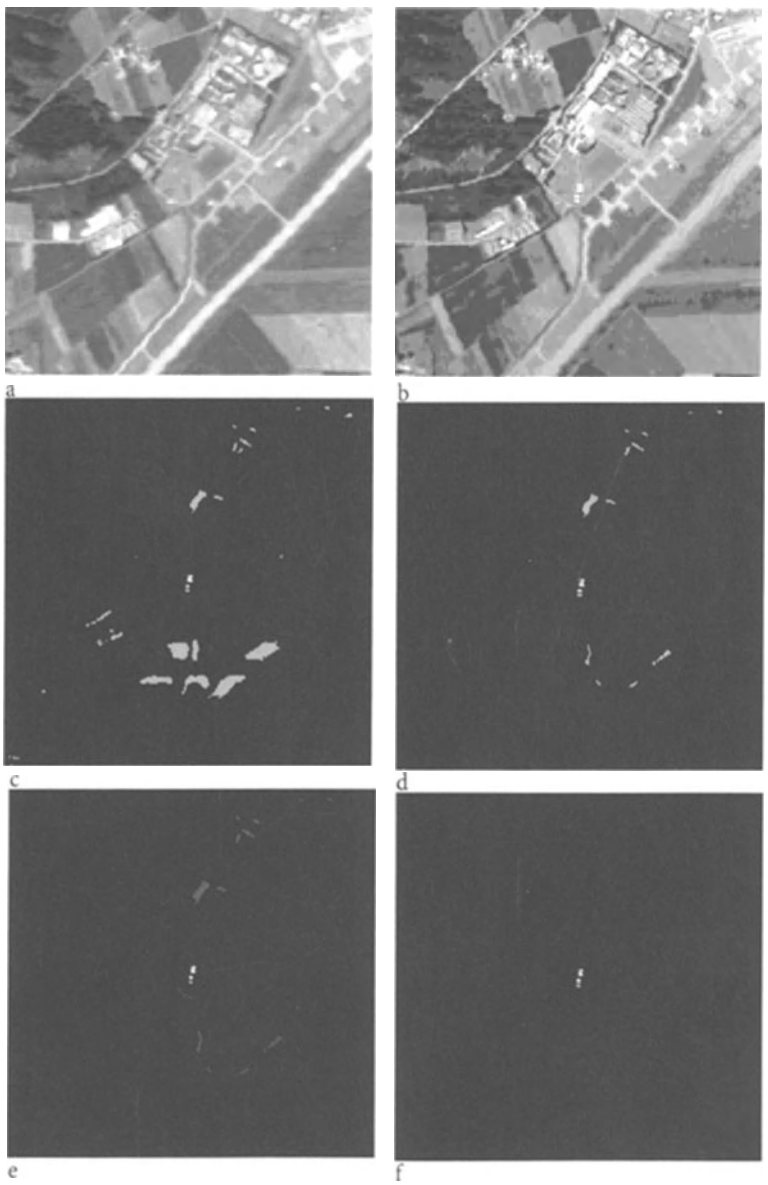


Fig. 6. Application of the HTE detection-and-analysis algorithm to a DAIS-7915 straw fire scene: a – VIS image; b – MIR image; c – detected bright spots; d – bright spots after the preliminary false alarm rejection; e – sub-pixel target temperatures retrieved by the Bi-channel technique; f – detected fires after the final false alarm rejection

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4.3 Preliminary Rejection of False Alarms

This step includes the following three tests to reject most of the false alarms:

- *Absolute TIR Thresholding to Reject Clouds*
  Since clouds have a low temperature, a rather low TIR threshold may be sufficient for this purpose.

- *Thresholding of the MIR/VIS Radiance Ratio*
  This test allows to reject high reflecting surfaces. The MIR/VIS ratio threshold value of thresh MIR/VIS = 0.01 was found to be optimal for the investigated scenes.

- *Adaptive TIR Thresholding*
  The adaptive TIR thresholding allows to select among the MIR bright spots only those pixels, which have the TIR radiance value higher than for the background. A rather small TIR threshold, corresponding to ~ 1 K above the median value, can be recommended to be used for this purpose in order not to limit the detectability of small HTE's.

4.4 Application of the Bi-channel Technique (Dozier 1981)

The Bi-channel Technique is applied to the MIR and TIR signals of the pixels, which have been selected after the preliminary false alarm rejection, to retrieve the apparent target temperature and the apparent target area.

4.5 Final Rejection of False Alarms by Temperature Thresholding (optional)

Only the pixels with the target temperature in the HTE temperature range of 500 to 1500 K are selected as hot spots. The other pixels are considered as false alarms and rejected.

Figure 6 illustrates the application of this algorithm to detect artificial straw fires in an airborne data scene obtained with the DAIS-7915 sensor.

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Dedicated Earth Monitoring and Disaster Warning Applications by Asia Pacific Advanced Network (APAN)

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Abstract

The Asia and Pacific region is subjected to a wide range of natural disasters, such as volcanic eruptions, earthquakes, torrential rains and flooding which trigger devastating impacts and losses to local economy, human lives and ecosystems. Wild fires in the region, predominantly caused by human activities, are also a global-environmental threat causing a further emulation of CO_2 after fossil fuel combustion.

To improve methods for taking prompt action against those natural and human-caused disasters, a high performance (in speed and security) data transmission is essential in any early warning system for disasters.

The Earth Monitoring and Disaster Warning Working Group was established in July 1998, within the Asia Pacific Advanced Network Consortium (APAN, 1997). The working group aims for earth monitoring and real time disaster data dissemination by advanced networking applications and services within APAN.

This paper, based upon the Charter of the Earth Monitoring and Disaster Warning Working Group of the APAN (Elvidge, 1998), is prepared and further tuned to cover a wider range of disasters and to elaborate capabilities of the advanced network as requested by the organiser of the conference.

1 Environmental and Disaster Threats in Asia Pacific

The Asia Pacific region contains 60% of the planet's population. The region is correspondingly rich in marine and terrestrial biotic resources, many of which are increasingly impacted by anthropogenic activities.

There are a number of pressing environmental issues in the region, including deforestation, coral reef degradation, and pollution of air and water resources. In addition, there are major questions regarding the sustainability of fishery resources, which have supplied the region's people with protein for millennia, but are now being heavily exploited with an array of technologies.

The region is subjected to a wide range of natural disasters. The region is a part of the circumpacific "ring of fire", with hundreds of potentially active volcanoes and a significant history of earthquakes and derived disasters of landslides, mud and pyroclastic flows, and tsunami. Monsoons bring torrential rains and flooding to the region. When monsoons falter, due to events such as El Nino, drought and devastating fires can prevail.

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2 Need for High Performance and Dedicated Networks for Early Warning Systems

Satellite remote sensing technologies have proven to be capable of environmental monitoring and disaster warning. However, the full value and benefit of current sensor systems is seldom realised due to limited distribution of the data and derived products, which are constrained, in part, by the data communication capacities in volume and speed.

For emergency disasters such as earthquakes, volcanic eruptions and tsunamis, demands fast and secured (fast and "back-upped") communication systems which convey the real time detection and alerts of the events, can only be fulfilled by a dedicated communication network.

The recent advances in high performance networking technologies open up new opportunities for wider access and utilisation of remotely sensed data, and for more reliable communication of emergency information.

Tile monitoring WG will utilise the APAN to distribute remote sensing data and derived information products, and detected alerts of events to new sets of data users which will be developed through the APAN nodes. The monitoring WG will seek to democratise the decision making impact of the distributed data through local media outlets, universities, government laboratories, and non-governmental organizations (NO Os).

3 Tile Mission

The mission of the monitoring WG is to implement remote sensing applications and data dissemination within APAN, to promote sustainable economic development, preservation of the region's biotic resources, and early identification of events or conditions which may lead to disasters.

4 WG's Policy and Membership

The monitoring WG has established a Set of implementation objectives, tapping into capabilities available at monitoring WG member institutions. In the longer term, the monitoring WG will seek out collaborations with a broader range of remote sensing data and product providers and disaster warning missions, to serve as a regional hub for the distribution of earth observations and disaster warning into the Asian Pacific region.

It is also essential to monitor the feedback from data users to respond through the changes and adjustment in the products and delivery patterns to better serve the objectives of the end users.

The intended users of remote sensing and disaster data should be registered through national WG committees which arc the national nodes of the Earth monitoring WG of APAN.

5 Implementation on Wildfires

Fire is used to clear land, as a tool of agriculture and forestry. Other burning may be of religious or cultural origin. However, during drought years it is difficult to control. Fire is closely associated with deforestation, land cover change, land degradation, and losses in species diversity. Smoke from fires can become a regional health and navigation issue. Anthropogenic fires are the second largest source of greenhouse gas emissions, exceeded only by fossil fuel combustion.

Because of their distinct spectral emissions, fires can be directly observed in data from certain meteorological satellite sensors such as the DMSP-OLS, ERS2-ATSR and locally receivable NOAA-AVHRR. Smoke can be spectrally distinguished from clouds in data from Japan's geostationary Meteorological Satellite (GMS) and NOAA-AVHRR. The GMS data was used successfully to monitor smoke sources and smoke movement during the 1997 fires of Indonesia.

It is proposed to develop a multisource program to monitor fires and smoke in Southeast Asia. Initially this will be based on the near real-time distribution of DMSP-OLS fire products (processed by NOAA-NGDC) and digitally enhanced GMS data for monitoring of smoke sources, extent and movement. The APAN nodes for data delivery and distribution will be the Asian Institute of Technology (AIT), Bangkok, Thailand, the Institute of Technology, Bandung (ITB), Indonesia, University of Sains Malaysia, Malaysia and Australian departments.

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6 Implementation on Fisheries

Fisheries provide a major source of protein for the people of Asia Pacific countries. The cumulative impacts of overfishing using advanced technologies could lead to a major loss in food security for the region.

Monitoring of fishing effort, in terms of the number of fishing vessels which arc active, when combined with total catch, can be used to regulate the population of the fished species.

As a proof of concept it is proposed to implement a monitoring program for the region's squid fishing activities. Squid fishing vessels use large banks of high intensity lights to attract squid to the ocean surface for netting. The squid fishing boats can be detected using night time data from the DMSP-OLS. It is also proposed to generate and distribute nightly georeferenced visible and thermal band OLS products (at NOAA-NODC) of squid fishing areas in the Sea of Japan. If successful, this effort will later be expanded to the Philippines and Gulf of Thailand.

7 Implementation on Torrential Rains

Torrential rains can be observed directly using data from the DMSP Special Sensor Microwave Imager (SSMI) and with data from the yet to be launched Tropical Rainfall Measuring Mission (TRMM). The TRMM provides 3-dimensional rainfall structure data and quantitative rainfall measurement. We propose to distribute SSMI or TRMM data and data products in near real-time using the APAN. By rapidly distributing these products the monitoring WG intends to enhance the available information on powerful storm systems prior to landfall and flood.

8 Milestones

- September 1998: Test APAN distribution of DMSP-OLS products of Sea of Japan
- October 1998: Begin daily distribution of Sea of Japan DMSP-OLS products
- January 1999: Begin distribution of daily DMSP-OLS fire products, Indo-china Peninsula
- February 1999: APAN and WG Meeting, Osaka
- March 1999: Begin daily distribution of Philippine and Gulf of Thailand DMSP-OLS products
- July 1999: Begin daily distribution of Malaysian/Indonesian DMSP-OLS fire products
- Late 1999: DMSP-SSMI and TRMM data transmission
- Mid 2000: Evaluation of WG achievement and reporting.

9 Network Resource Allocation Required

Beginning in October 1998 it is anticipated the distribution of approximately 15 MB of data per day to Japan and Korea is required. It is also anticipated that this amount will increase to approximately 20 MB in January 1999 and 40 MB per day in March, 1999.

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The Finnish Forest Fire Index Calculation System

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Abstract

Since the summer of 1996, the forest fire index calculation in Finland has been based on surface moisture estimation. The calculation is done on a 10×10 km grid. Air temperature, air humidity, wind speed, solar radiation and precipitation measurements made at observing stations are interpolated onto the grid with an objective interpolation method known as 'kriging'. Potential evaporation is calculated for each grid-square based on the interpolated meteorological data using the Penman-Monteith equation. The moisture of a 60 mm thick surface layer is estimated using potential evaporation and precipitation data and, finally, the surface moisture is scaled to forest-fire index values (1–6) which are distributed to the fire authorities through the Internet. In the future, the inclusion of weather radar and satellite information in the spatial analysing system will further improve spatial analyses of precipitation and solar radiation.

1 Introduction

Finland, located in northern Europe between latitudes 60°N and 70°N, is a forest-covered country; boreal forests cover nearly 78% of the total land area, i.e. about 26 mill. ha (e.g. Aarne 1993). During most of the year there is no risk of forest fires, as during winter the ground is usually snow-covered and during autumn the evaporation is low and the precipitation keeps surface moisture high enough to make forest fires extremely unlikely. However, during the spring and the summer, from May until August, there are periods every year when the forest fire risk is high, leading to restrictions, for example on lighting open fires in or near the forests. During these periods, the level of preparedness of the fire authorities is raised, and includes the initiation of forest fire survey flights. To avoid extra costs the raised level of preparedness should be maintained during the risk period only. On the other hand, when the forest fire risk is high, the fire authorities as well as the general public should be made aware of the increased risk immediately. To be able to estimate the forest fire risk, special fire risk indexes, are usually based on weather information, have been developed.

Until very recently, the forest fire risk in Finland as calculated by the Finnish Meteorological Institute was based on a statistical relationship between a number of weather variables and the occurrence of fires. A number of problems with the old index, such as the difficulty in verifying the index values using direct measurements and the discontinuous nature of the index, led to the development of a new method for the estimation of the forest fire risk. This new method is based on the estimation of soil surface moisture, calculated with the help of potential evaporation and precipitation data. It is physically realistic and simple enough for public use. The method is explained by Heikinheimo et al. (1998), and a brief description is also given in this article.

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2 Theory

In a forested landscape the highest fire risk can be found in forest clearings where trees have been recently harvested, and where there are plenty of dried tree branches and twigs on the ground. In a clearing, solar radiation can fall directly on the ground and furthermore, the wind speed is higher in a clearing than within a dense forest. These two factors lead to higher potential evaporation values in a clearing than in a forest. The moisture of the topsoil layer in a forest clearing can thus be assumed to give a good indication of the fire risk in a forested landscape. According to field measurements (Heikinheimo et al. 1998), the best correspondence with soil surface moisture and the occurrence of forest fires was reached when the moisture of a 60 mm thick surface layer was used as the indicator of fire risk.

The moisture of the surface soil depends mainly on evaporation and the storage of rainwater in the layer, which, in turn, depends on rainfall and percolation. The ratio of actual water loss to potential evaporation (atmospheric demand), i.e. the drying efficiency, has been related to the instantaneous volumetric moisture of the surface layer based on experimental data. Similarly, the relationship between the stored rainwater and precipitation was defined with the help of experimental data (Fig. 1).

The amount of rainfall can be obtained from measurements made at weather observing stations. The calculation of potential evaporation in the current application is made using the so-called Penman-Monteith equation (e.g. Monteith 1981).

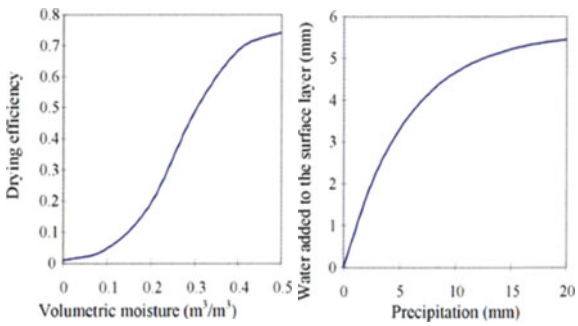


Fig. 1. Drying efficiency (the ratio of actual evaporation and potential evaporation) as a function of surface volumetric moisture (left) and the amount of water added into the surface layer as a function of precipitation (right). The curves are for a 60 mm thick layer of organic soil and residue and obtained based on measurements made on three forest clearing areas in southern Finland

3 The Operational System

The follow-up of soil surface moisture starts immediately after the snow has melted and the soil is wet and near the field capacity, and the volumetric moisture of a 60 mm thick surface layer can be assumed to be 50% (Heikinheimo et al. 1998). The surface moisture is increased by precipitation and reduced due to evaporation (Fig. 1).

The potential evaporation is calculated using the Penman-Monteith equation, for which, air temperature, air humidity, wind speed and surface net radiation data are needed. There are different kinds of meteorological observing stations; some stations record only daily precipitation, some stations record air temperature and air humidity, wind speed and cloudiness, and then there are stations that measure precipitation, air temperature and air humidity, wind speed and solar radiation. To be able to utilise the maximum amount of data, the values measured at observing station locations are first interpolated onto a 10×10 km grid and all the calculations are made on this grid. The interpolation onto the grid is performed using a method know as kriging (e.g. Henttonen 1991, Bigg 1991, Hudson & Wackernagel, 1994).

In Finland, about 200 stations send their precipitation measurements to the climatological database daily. Calculations are made using 3-hourly values of meteorological data, and the 3-hourly precipitation values are interpreted from daily values with the help of synoptic weather observations made at the nearest available synoptic station. Air temperature, air humidity and wind speed observations are available from about 160 stations. Solar radiation measurements are made at about 15 stations. An indirect estimate of solar radiation can be obtained from stations making cloud observations (Venäläinen & Heikinheimo 1997) and the number of stations undertaking the needed cloud observations is about 40 at the moment. The interpolation of solar radiation onto the grid is thus performed based on measurements from about 55 stations.

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The volumetric moisture in a 60 mm thick surface layer is scaled to forest-fire index values. The index values are between 1 and 6. A forest fire warning is given if the index reaches 4, which corresponds to a volumetric moisture of 20%. The information is distributed to the fire authorities twice a day, at 6 GMT and 18 GMT, using the Internet. Forest fire warnings to the general public are distributed via radio and TV news broadcasts.

4 Discussion

The amount of rainfall is a crucial factor when estimating soil surface moisture. The spatial variation of rainfall can be large, even inside a relatively small area, and the spatial analyses of rainfall based solely on rain-gauge measurements can, in some cases, be inaccurate. The accuracy of these analyses will be improved by the use of weather radar data as a source of information.

Based on meteorological data obtained from HIRLAM, a numerical weather forecast model and 12- and 24-hour forecasts for the development of soil moisture were calculated during the summer of 1998. According to the preliminary results, the forecasted soil moisture values were good for the case where the surface was drying. Predicted by the HIRLAM model were, however, a little too high, and thus in case of rainy weather, the predicted soil moisture values were too high. However, the first results were so good that the prediction of forest fire indexes based on the numerical model output seems to be justified.

5 Conclusions

The use of the forest fire index calculation system based on the estimation of soil surface moisture in the most inflammable conditions in the forest, i.e. in a forest clearing with a lot of dry, dead material, small branches and twigs on the ground, was found to give a realistic view of the fire risk in the boreal forests in Finland. Meteorological data needed to calculate the index were first interpolated onto a 10×10 km grid, and all the calculations were made on the grid. The use of the grid-based calculation system made it possible to use a maximum number of observing stations for the calculations. For example, the spatial analysis of rainfall is based on about 200 observing stations, whereas solar radiation analysis is based on about 55 stations. According to the first results, forecasts of the forest fire index of up to 24 hours can successfully be made using data obtained from the numerical weather forecast models.

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Satellite Based Forest Fire Detection and Automatic Alert System – Pilot Experiment

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1 Abstract

A fully automatic system has been developed to detect forest fires using data from the meteorological NOAA satellites. The system has been tested in four pilot experiments in 1994–1998 in Finland and its neighbouring countries Estonia, Latvia, Russian Carelia, Sweden and Norway. For each detected fire, a telefax including data on the location of the fire, the observation time and a map showing the location, is sent directly to the local fire authorities. The area of the smallest forest fires detected was 0.1 ha. The time delay between receiving the NOAA scene and the sending of the fire alert was 31 min in average. Nearly all detected fires were forest fires or prescribed burnings. In the pilot experiment of the summer 1997 363 fires were observed and alerted. The verification showed that 83% of the given alerts concerned real fires. According to the authorities, none of the real significant forest fires in Finland remained undetected. The good verification results show that satellite-based detection system of forest fires is reliable, fast and cost effective, and it has potential in sparsely populated areas if continuous supply of middle-infrared satellite data can be guaranteed in the future. Because of the ecological and human necessity, fire monitoring and alert system on a global scale should be established urgently. For this purpose dedicated fire detection instruments and satellites should be developed.

2 Introduction

Every year about 1 billion ha of forest is burnt down. These fires have an important impact on the destruction of vegetation, on atmospheric pollution (greenhouse effect), and directly on human lives. Satellite based wild fire detection has proven a viable tool in collecting statistical information on the emission of greenhouse gases in the past (e.g. Setzer and Pereira 1991, K. Briess et al. 1995, Y. Rauste 1996). The characteristics of the NOAA series of meteorological satellites also make it possible to collect near real-time information in support of fire control activities (Häme and Rauste 1995, Y. Rauste 1997).

Wild fires are an essential threat to forest resources and human population in large areas of the world. Very often, the cities or villages do not get an early warning of the approaching forest or bush fires. In addition, in many cases the authorities do not have telecommunications equipment e.g. telefax machines or even paper for that machine to send/receive the warning messages. Therefore, the alerts to the population and to the rescue forces often come too late.

For such occurrences as forest and vegetation fires, volcanic activity or burning oil spills and coal seam dedicated space instrumentation does not exist. The existing spaceborne instruments and the missions are not designed for fire detection, e.g. time coverage for the fire management is not satisfactory. Therefore, the fire management is only a by-product of the

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current remote sensing missions. New dedicated instruments, procedures and missions are needed.

3 Fire Detection Methodology

A prototype software (Fig. 1) has been developed by VTT Automation for automatic detection of forest fires using NOAA AVHRR (Advanced Very High Resolution Radiometer) data. Fire detection is based on middle-infrared data channel 3 of AVHRR, 3.7 μm. Image data are received from an existing receiving station operated by the Finnish Meteorological Institute. The system automatically chooses a sub-scene from each received scene, which optimally covers the experimental area, approximately 1150 km by 1150 km.

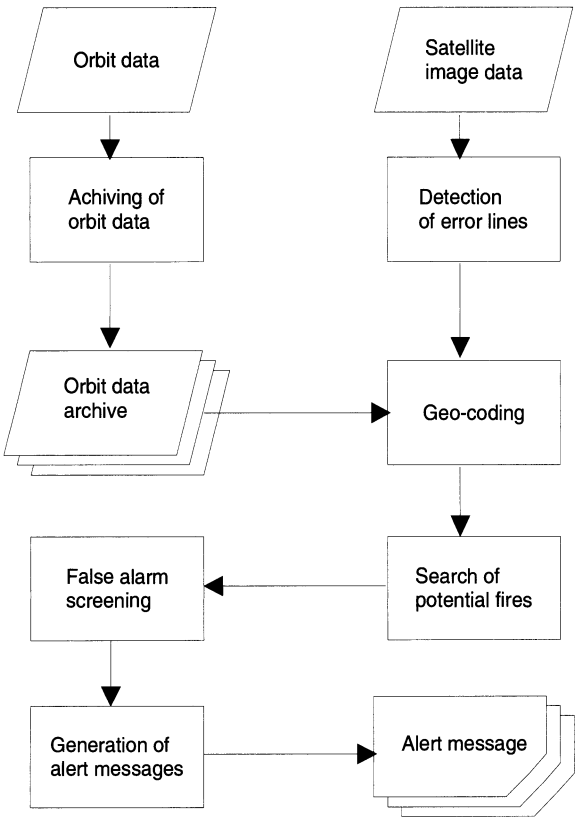


Fig. 1. Software system in the pilot projects

In the detection algorithm Channels 2 (near infrared 0.7–1.1 μm), 3 (middle IR 3.6–3.9 μm), and 4 (thermal IR 10.5–11.3 μm) of the AVHRR sensor are used. Channel 2 is in the visible and near-infrared part of the electromagnetic spectrum where all radiation is reflected sunlight. Channel 4 is in the thermal infrared part of the spectrum where all radiation is emitted by the earth surface according to its temperature and emissivity. Channel 3 is in the middle-infrared part of the spectrum where both reflected sunlight and emitted radiation have significant contributions to the total radiation measured by the sensor. The processing includes: detection and marking of image lines affected by reception errors, image rectification, detection of hot areas, elimination of false alarms, and generation of alert messages by e-mail and telefax.

The spectral distribution of radiation of the forest fire, and the solar radiation reflected from the Earth surface can be estimated using the Planck radiation law (Driscoll 1978). Radiation intensities from the Earth surface in the temperature 300 K, from the forest fire in the temperature 800 K, and from the solar radiation reflected from the Earth surface can be compared in the Table 1.

It has been assumed in these figures, that a large forest fire is big enough to cover the whole pixel (1 km×1 km or 100 ha), when a small forest fire (1 ha) causes radiation flux density to the satellite sensor which is only 1% of that of large fire. Reflectance coefficient of the Earth surface for visible and near IR is as-

Table 1. Spectral radiant exitance $W\,m^{-2}\,(\mu m)^{-1}$

Wavelength/μm	T = 300 K (M_{earth})	T = 800 K (M_{fire}) large fire 100 ha	T = 800 K (M_{fire}) small fire 1 ha	T = 6000 K (M_{sun}) [1] r=30%, [2] 3%	S/N large fire	S/N small fire
1 (Ch 2)	1.4×10^{-12}	9.2	0.09	220[1]	0.04	0.0004
3.7 (Ch 3)	1.6	4100	41	0.17[2]	2300	23
11 (Ch 4)	29.3	580	5.8	0.001[2]	20	0.2

$S/N = M_{fire}/(Msun + M_{earth})$ is the signal-noise ratio, where
M_{fire} is the radiation intensity on the Earth surface caused by forest fire,
M_{sun} is the intensity of the solar radiation reflected (reflectance 3% for thermal)
Wavelengths, 30% for visible and near IR) from the Earth surface in day time
M_{earth} is the spectral radiant exitance from the normal Earth surface (emissivity 1)

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sumed to be r = 30%, and for middle and thermal IR r = 3%, and emissivity 1. Furthermore, it has been assumed that the effect of atmosphere (scattering, absorption on the specific wavelengths) is not remarkable (Driscoll 1978). It is easily seen from the figures in the Table 1, that radiation intensity on the channel 3 from the large and small forest fires is clearly higher than the normal thermal radiation of the Earth and also much higher than the solar reflection. On the other hand the intensity of the solar reflection on the channel 2 is much higher than the radiation caused by the forest fires.

In practice, small forest fires down to 0.1 ha in area can be detected. In these cases the signal-noise ratio is about 20 on the channel 3, high enough to detect fires. On the channels 2 and 4 the signal-noise ratio is less than 1, and makes it impossible at all to detect small forest fires. Because of strong thermal radiation of Earth the thermal infrared data is of little value in detection of small forest fires even in Boreal forests. A typical small forest fire (area 1 ha) that can be detected using middle-infrared data does not affect remarkably on the thermal infrared data (11 μm) in channel 4.

A limitation of the AVHRR sensor for fire characterisation is the low radiation intensity at which channel 3 saturates (Kennedy et al. 1994). The thermal radiation of the Earth surface at temperature 48 °C (321 K) is high enough to cause the saturation. However, in the Boreal forest zone, the problem of the sun-heated bare soil areas, mountains, or sand deserts is practically non-existent, and the Earth surface does not reach such high levels as in tropics and the Mediterranean areas.

Accordingly, detection of fires is based on the use of channel 3 middle infrared data, assuming that all pixels with high radiation intensity in channel 3 contain fires. Each patch of connected high radiation "hot" pixels is considered as a potential fire. To avoid false alerts the "fires" where the imaging geometry is close to the case of solar specular reflection (from clouds, lakes and from highly reflecting bare soils) are eliminated. Four additional constraints are also applied: 1) Strong solar reflection from clouds can cause saturation on channel 3. Therefore, a threshold is needed on near infrared channel 2 data to reveal cloud reflections in day-time scenes, 2) Thermal radiation of real fire on channel 4 is high, while thermal radiation of clouds is low. Therefore, a threshold on thermal infrared channel 4 data reveals false hot spots due to cloud reflections in daytime and night-time scenes, 3) a threshold on the number of pixels in a fire patch, and 4) a threshold on the distance to known steel factories.

4 Demonstration Experiments 1995–1996

The prototype system was tested in an experiment phase during the summers 1994–1996. The prototype fire detection system was run in the computer facilities of the Finnish Meteorological Institute. 205 AVHRR scenes were processed between 4 July 1995 and 8 September 1995. The system detected over 14000 potential fires (high radiation intensities), but only 85 of the potential fires were classified as fires by the automatic system. A preliminary verification was done immediately for fires located in Finland. For each detected fire, the system sent a telefax message to the City of Helsinki Rescue Department. The fire was located on a map and the telefax (equipped with a request for prompt verification of the detected fire) was further sent to the right local rescue department. Of the 16 fires detected in Finland 11 were prescribed burnings, one case was a forest fire, three cases were a steel factory, and in one case the reason of the detected fire is not known so far.

In summer 1996, the system ran from 24 June to 16 September. After the elimination of false alarms 272 fires were detected. In 30 cases elimination was caused by the location of a known steel factory. For 79 fires real-time telefax message was sent fully automatically. Most of the detected fires were prescribed burnings. In other cases, the fires were outside of the experimental area.

5 Pilot Experiment in 1997

In summer 1997 the system was tested in cooperation with VTT Automation, the Finnish Meteorological Institute and the Finnish Ministry of the Interior. Also, local correspondents were available in the neighbouring countries. For summer 1997 the experimental area was enlarged from the original to cover the whole

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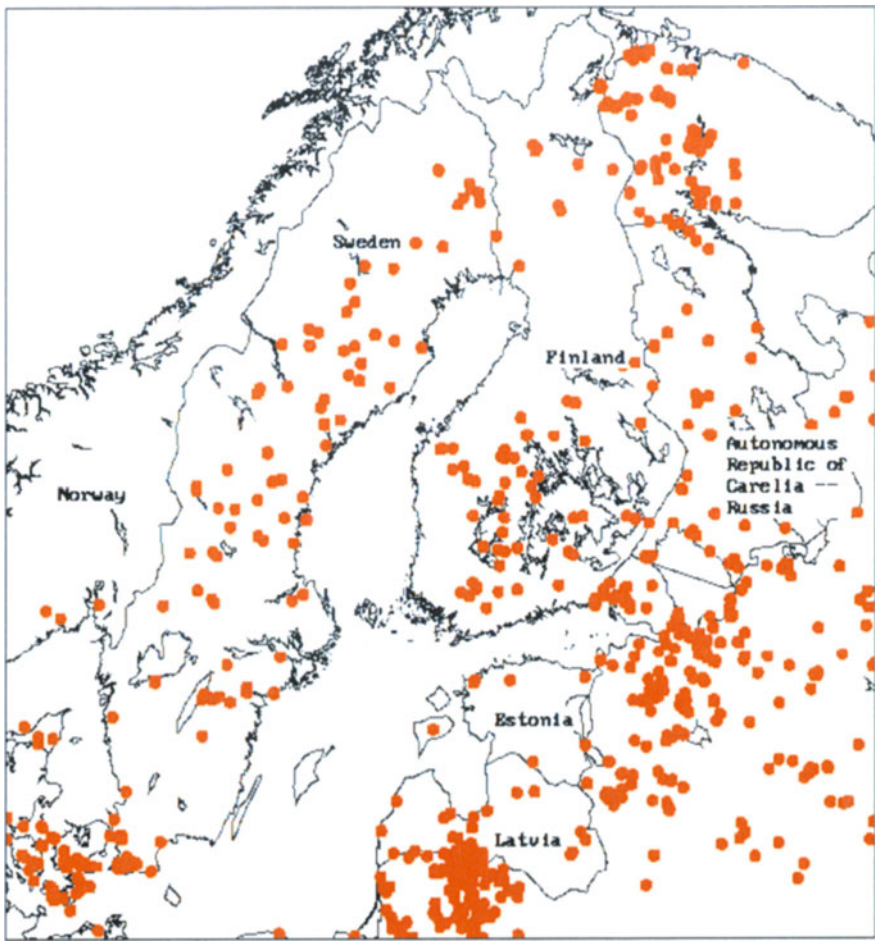


Fig. 2. Detected fires in the experiment period May 5–September 15, 1997

Table 2. Verified fires in 1997

Country	Pre-scribed Forest burning	Forest fire	Building fire	Other Pre-scribed burning	Other fire	Peatland fire	False-alarm*	Total
Finland	27	23	5	1			8	64
Sweden	13+9**	25		3+19**	3		2+16	90
Norway		2					1	3
Estonia		4				1		5
Total	40+9**	54	5	4+19**	3	1	27	162

* = Includes fires which are classified unknown
** = Fires which are probably that type

area of Norway, Sweden, Finland, Estonia, Latvia, and Russian Carelia, approximately 1690 km by 1690 km. In summer 1997, the system ran from 5 May until 15 September. During that time 1013 hot areas were detected most of them in Russia and in Lithuania outside of the project area, Figure 2. 363 fires were located in the area of Norway (20), Sweden (116), Finland (96), Estonia (12), Latvia (49), and Russian Carelia (70). The corresponding alerts were sent automatically. In 17 cases the fires were close to the border between Norway and Russia and the alerts were sent to Norway.

Verifications were received from local authorities in 162 cases, Table 2. 83% of the alerts were real fires, most of them forest fires. Amount of detected building fires was 5. 17% of the alerts were false alerts or unknown fires. According to the reports from the local authorities, none of the real forest fires in Finland remained undetected. The area of the smallest forest fire detected was 0.1 ha.

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6 Processing Performance

During the summer 1997 in average 5 NOAA images were processed daily, the number of processed NOAA scenes varied from two to eight. The average delay between receiving of the NOAA scene to sending the fire alert was 31 minutes varying from 14 minutes to 291 minutes. The system ran almost without interruptions. Longest interruption was ten hours. Interruptions were due to computer hardware problems and hardware and software updating.

7 Conclusions

The screening of false alarms is an essential technique in fire detection if the results are to be used in fire control. Effective screening enables fully automatic detection of forest fires, especially if known sources of error like steel factories are eliminated based on their location. In the experiment in 1994–1997, most of the detected fires were real fires. Only 17% of the sent alerts were false alerts. According to the Finnish authorities, none of the real forest fires in Finland is known to be undetected by the system. This shows that satellite based detection of forest fires is reliable, fast and has potential for fire control purposes. Because of the ecological and human necessity, fire monitoring and fire alert systems on a global scale should be established urgently. This can be only done by remote sensing from space, as other systems are not suitable for global applications.

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VII Early Warning Systems for Rapid Damage Assessment and the Mitigation of Technological Hazards

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CHAPTER 7.1

Technological Hazards

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1 Introduction

Technological hazards are an increasing source of risk to people and their environment. This is an effect of the globalization of production, an increase in industrialization and a certain level of risk of accidents connected with production, processes, transportation and waste management. These risks are associated with the release of dangerous substances in the case of an accident, substances which could affect human health or the environment by contamination and their effects on animals and plants.

Severe accidents have happened which afflicted thousands of people. These have found expression in the public demand to provide technical and organizational tools for the prevention, mitigation and relief of disasters. Special international attention has focussed attention on incidents of Bhopal, Mexico City, Basel, Seveso, the "Exxon Valdez", "Erika" and Chernobyl. Expert groups, institutions, organizations, authorities and institutes work on the problems of prevention and relief on local, regional, national and even global basis.

Each of these accidents have been of a different kind, due to different reasons and substances involved and therefore also the consequences were of different nature. The Chernobyl accident led directly to the International Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. The release of chemicals into the Rhine River was a starting point for bi- and multinational agreements concerning early warning systems for accidental releases of hazardous materials into rivers.

In regions with high density of industrialization, where a risk of this kind of accident is evident, guidelines, regulations and legislation have been developed and adopted. The Convention on the Transboundary Effects of Industrial Accidents of the United Nations Economic Commission for Europe provides an example of agreed measures for the prevention, preparedness and response to industrial accidents capable of causing transboundary effects. They also provide exemplary experience about the feasibility of fostering international cooperation in this field.

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There are guidelines, regulations, and specific directives for substances whose handling, processing, transportation or production is related to risks for human beings and the environment. There are practical procedures on the presentation of measurements, information, modelling and risk assessment. Data which is necessary for technical emergency response exists, as do several different material description systems, logistics concepts etc. The extent of this existing information, operational procedures, and communication systems constitute the basis of numerous existing infrastructures. In such cases of an abundance of capabilities distributed over many implementing areas of responsibility, it may be necessary to reconsider, or at least rationalize, these systems where transboundary risks may be anticipated.

Obviously technical, legislative and institutional methods already exist to deal with technological hazards. With few exceptions, technological hazards are not ordinarily of global dimensions. Transboundary effects, may however, become a consequence of an accident. Considering the amount and distribution of facilities using hazardous materials throughout the world, the risks posed by them to societies and the environment it has to be considered as an increasing global problem. This situation is likely to be expanded further as the consequences of human activities and technological processes on phenomena such as global warming, and ozone depletion becomes better understood. International terrorism is also being cited more as a potential source of other forms of chemical or biological contamination of crucial elements of a society.

There is a certain probability that the expanding genetic technology (gentechnology) will pose more problems of this kind in future. Substances in which self-reproduction is possible will need special global considerations. Another form of related threat is evident today by the transfer of biologically-active substances or species to places where they can destroy the natural established equilibrium. Special precautions will be necessary to avoid contaminations with unpredictable effects to the environment.

Taking into consideration other possible effects of an accidental release of hazardous materials, including their progressive accumulation in plants, animals, fish or entire ecosystems, they can now more easily be distributed to very different regions of the world. Hence, the emergence of increasing risks of technological hazards has to be seen on a global dimension. A global threat of technological hazards can also be seen in the fact that facilities which may not comply with the safety standards enforced in industrialized countries can readily be transferred to poor, or non-industrialized, countries. It should be possible to overcome such problems when using special environmentally designed facilities or "cleaner technologies", (e.g. Best Available Technology, or B.A.T.).

With this future outlook, it is therefore necessary to globalize the efforts for the reduction of technological hazards. This can be done by considering some principles and technical guidelines for the implementation of adequate preparedness and prevention measures. The strong emphasis which is being given to this subject now by so many countries, shows that there is the understanding on the national basis of the importance of these issues. There are many bilateral and multilateral agreements concerning the involvement of more than one country in such a problem, however, a growing density of industrial activities demands far more risk reduction than is presently evident. Major accidents can have long-lasting consequences, with many of them that extend beyond frontiers of an individual country. The ecological and economic cost of an accident is borne not only by the establishment affected but also by the States concerned. It must become an objective to keep the risk level as low as possible, taking into consideration the probable character of increasingly complex, and potentially more severe, technological incidents. It therefore becomes necessary to take measures that can ensure a high level of protection.

It is anticipated that there may be a recognized value in considering a global agreement to address international problems arising from technological hazards. The aim would be to harmonize, standardize information and methods, where a response action from more than one country is necessary and where international aid can be expected. This should also be understood as a contribution to overall global risk reduction in a consistent and efficient manner. This should in fact go beyond harmonization, but actively address collective measures which are necessary to realize a more ef-

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fective system for preventing major accidents and limiting their consequences.

It is necessary to consider what could become the activating mechanism for such an early warning system. Again, global warning will at the moment be limited to few technological activities. A globally-oriented warning system could be understood in the sense of encouraging the widespread and common usage of recognized information systems, and data provision systems. In this context technological hazards can be seen in connection with major threats of the following types:

- accidents and releases where radionuclides or radiation are involved,
- a release of chemical substances in accidental conditions to the environment, or
- activities which could lead to a release of biological substances, or organisms
- the accumulation effects of substances affecting environmental conditions.

Based on the Yokohama Message and as a result of the World Conference on Natural Disaster Reduction in 1994 it is considered that technological hazards need to be addressed in all aspects of disaster management capabilities, *viz.* disaster prevention, mitigation, preparedness and relief. In terms of early warning, however, the main emphasis should be directed toward disaster prevention, mitigation and preparedness to achieve the goals and the objectives of the International Decade for Natural Disaster Reduction. Disaster response should only be considered as applying measures in cases where all prevention measures have failed. Regrettably, it yields only temporary results at a very high cost. In the case of technological disasters this would be of very limited use, as it must be considered that regions affected by technological accidents can be of reduced utility by societies or for human habitation for a very long time, due to the long-lasting effects of many technological contaminants.

Based on this understanding early warning for technological hazards must be seen on different levels and with different concepts and tools. Early warning concerns an immediate risk as it is in the case of accidental release of toxic substances which could be transported via air and water. It must address risks which will become manifest in form of damages into the future, such as for example the use of materials, chemicals, but also an accumulation of substances released by the production, or the post-consumer phase of products. Therefore, the long term problems associated with slowly emerging effects, or other consequential manifestations, of technological hazards have to be specifically discussed. In some circumstances, the longer term influence could be even more important to the wellbeing of a society or to the future generations of its present inhabitants, than the more evident, short term consequences addressed on a more immediate, and temporary time scale. Therefore, the significant risk of technological hazards, in fact, demands concentration on the prevention of their occurrence, an opportunity that can be enhanced when one appreciates that they are, by definition, a function of human creation.

1.1 Nature of an Early Warning System for Technological Hazards

Most of the releases of substances into the environment are due to accidental situations. As early warning detection systems can act through measurement equipment which can indicate dangerous situations of processes (e.g. temperature, pressure) these measurements can act as indicators for onsite alert systems. By contrast, the situation becomes significantly more complex as one considers external effects of technological hazards where warning systems must additional relate to:

- measurements, data acquisition, sampling,
- data transfer for processing (risk estimation, decisions, alarm, assistance),
- information dissemination to public and authorities, decisions about information levels, local, regional, national, international exposure, and
- reaction for widely ranging relief measures.

Both on-site and off-site contexts require that early warning possibilities be utilized mainly to optimize reactions and to make sure that the necessary personnel and equipment to reduce the effects is available. In the case of technological hazards, early warnings need to be based on the anticipation of risks and a certain predictability of accidents which can be established by using known techniques for risk and consequence analysis. Such assessments will be

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used primarily to avoid, or at least to minimize, the risk of situations with a technological hazard. This can be done by appropriate safety measures embodied in established disaster prevention programs.

Risk is the likelihood of a specific effect occurring within a specified period or in specified circumstances. The risk as a quantity is defined as the product of the probability of an accident leading to a release of substance and the potential of damage due to a defined specific situation.

To establish reasonable risk hierarchies, special tools such as Risk Analysis, Life Cycle Analysis (LCA) and comparable methods should be used, and where necessary, developed. Data bases for these tools should be provided, and where necessary, such data should be evaluated.

1.2 Indicative List of Technological Hazards

The following list indicates the type of actions which can constitute technological hazards:

- release of chemicals to the atmosphere by explosion, fire
- release of chemicals into water (groundwater, rivers etc.) by tank rupture, pipeline rupture, chemicals dissolved in water (fire)
- oil spills in marine environment
- satellite crash (radionuclides)
- radioactive sources in metallurgical processes
- other sources of releases of radionuclides to the environment
- contamination by waste management activities
- soil contamination
- accidents with groundwater contamination (road, rail)
- groundwater contamination by waste dumps (slowly moving contamination)
- aircraft accidents
- releases and contaminations as a consequence of military actions (e.g. depleted uranium), or destruction of facilities
- releases as consequence of the industrial use of biological material (e.g. viruses, bacteria, fungi).

1.3 Prediction of Effects

The prediction of technological hazard effects is closely related to prior risk analysis. By developing a scenario, the probability of events and effects can be predicted. Thus enabling the competent authority to establish an alert system and to provide for the necessary equipment, facilities, hospitals, transportation system for specific scenarios. It will be very important to have a reasonable balance between technical and organizational provisions on site and relief measures which have to be borne by the public. Decision tools will be given by risk analysis and related methods, such as fault tree analysis and event tree analysis.

1.4 Context of Early Warning for Technological Hazards

Because of the complexity and potentially catastrophic or long-term effects, hazards associated with technological development pose particular challenges to the operators of facilities, public policy authorities, and indeed, members of the public which live and work in the midst of hazardous materials that have become an integral part of most societies.

Chemical or industrial releases include incidents or the accidental release of substances to the environment. The pathways are water and air. Water contamination can affect rivers, lakes, groundwater or marine environments, such as by spills. The main emphasis will be directed towards accidental releases where amounts of toxic substances can come into the environment. The transmission of dangerous substances through pipelines also has a potential to produce major accidents. States may equally adopt measures to limit similar risks identified with waste landfills.

Nuclear releases cover incidents with materials which are not only necessarily those involved with nuclear facilities. There is a much wider exposure in the context of all those other facilities using radionuclides or nuclear radiation in industry, research and medicine. Within this scope are radiation sources and liquid or gaseous releases. Another important issue are releases of natural long-lived isotopes from mill tailings, settling tanks and purification ponds.

Incidents with an involvement of structural or infrastructural system failures may consist of technical, operational or organizational failures. As people and pieces of equipment are, themselves, part of the infrastructure a physical breakdown (of either), or serious lapses of

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communication can contribute to the creation of technological hazards. In this respect, safety practices must be regarded as an integral part of contemporary, industrial risk analysis. High tech facilities need a special technical environment for functioning. If such facilities pose the potential for human or environmental risks, then a procedural lapse or a weakened part of the physical infrastructure can create an unacceptable risk.

1.5 Challenges of Technological Hazards

The main emphasis of early warning practices pertaining to future global activities for technological hazards need to be directed toward the following issues:

1. Providing emergency warnings of an imminent technological threat to the environment.
2. Systematic analysis of information, its timely and effective processing, its use and dissemination based on a broad, and multidisciplinary range of specialist involvement.
3. Identification or disclosure of technological hazards with adverse effects on the environment, existing in the midst of communities which are unaware of the threat. Communities may also grow to envelop potentially hazardous facilities, which may have previously been appropriately isolated.
4. Determination of early warning procedures to alert, identify, evaluate and inform the public and/or official authorities concerned with public, or societal, risk about sources of potential risks.
5. The anticipation of appropriate means of prevention or response of multiple-hazard risks, which could follow from causal relationships between natural and technological disasters.
6. Instruments to ensure the timely and adequate notification to authorities of countries which might be affected by a technological hazard.
7. Identification of agreed contents for a prospective convention to minimize the environmental, health and economic consequences of technological hazards.
8. Developing standards for the presentation and use of data, and components of a common information structure, such as an event scale to facilitate the notification, and common understanding of accidents. This would also enable a common understanding of the events among the technical and local communities concerned.
9. Encouraging translation of technical facts for the benefit of improved media and public comprehension.
10. Instituting prompt and consistent information of the public of various aspects pertaining to hazardous materials and public safety.
11. Prepare awareness activities and preparedness plans for emergencies at the local level, including effective community collaboration for responding to industrial accidents.
12. Expanded use of existing conventions, rules and local or regional systems for the development of global nomenclature and advisory standards in dealing with technological hazards.
13. Improved use of the experience and, to the extent that it may be feasible, existing collaborative systems of international organizations, based on the reliability and technical abilities of their partners.
14. Develop a general scheme of relating national and international agencies in order to achieve an effective process of communication and the coordination of emergency assistance, when necessary.

2 Activities of an Early Warning System Which Could be Based on International Agreements

The crucial tasks which have been related to organizational and technical questions can be addressed by establishing specific structures, or harmonizing existing conventions, national regulations and bilateral agreements. Guidelines can provide the basis for promoting and assisting in data collection and the improvement or consolidation of processing systems, communication systems and decision-making procedures. These responsibilities could, by common understanding and commitment, be overseen by an international organization. It bears emphasis, however, that different responsibilities outlined in the following areas of action would have to be borne by operators of facilities, public authorities, national governments, and the local communities themselves, through an ac-

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cepted partnership of the beneficial attributes of reduced risk for the community as a whole from technological hazards in its midst.

2.1 Disaster Prevention and Mitigation

The analysis of major accidents indicates that the majority of them are the result of managerial and/or organizational shortcomings. It is therefore necessary to establish basic and accepted principles for management systems, which can encourage the prevention and control of major-accident hazards, and limit their consequences, should they unavoidably occur.

Differences in the arrangements for the inspection of establishments by the competent authorities may give rise to various levels of protection. Nonetheless, it is desirable to lay down essential requirements with which the systems for inspection established by the subscribing parties should comply.

2.2 Principles

Operators of establishments where dangerous substances are present in significant quantities should be expected to provide the competent authority with information to demonstrate that all necessary activity has been done to prevent major accidents, to prepare contingency plans, and appropriate response measures. This could take the form of a safety report.

Where establishments are sited in such a way as to increase the possibility of major accidents, to aggravate their consequences, or to raise concern about consequential effects, there should be a provision for the exchange of appropriate information and cooperation on public information. Considering the consequences of the accidents in Bhopal, India and Mexico City, which demonstrated the hazard which arises when dangerous sites and dwellings are situated closely together, there is a clear necessity for land-use planning when new installations are authorized or when urban growth and development takes place around existing installations.

There should be criteria for the notification of an accident in such a manner to make it useful for other public authorities so that they may also reconsider their own potential risks with similar systems, facilities or situations.

The event could also be of sufficient importance for wider reporting if it causes permanent or long-term damage to terrestrial habitats.

For assessing damage, appropriate guidelines should be available for application in relation to specific substances, or to the lethal concentration of the species representative of the environment affected and for the criterion dangerous for the environment.

There is a need for common efforts among states working towards greater mutual understanding and harmonization of national principles and practices regarding safety reports. In this respect it is desirable to pool the experience gained through different approaches to the control of major accidents, and to make provisions applicable to all establishments where dangerous substances are present in sufficiently large quantities to represent a major hazard.

An example of a type of internationally recognized process would be the acknowledged procedures in force for analyzing and then publicizing international airplane accidents, their causes, and recommended remedial actions that can be quite specific. The International Civil Aviation Organization (ICAO), an intergovernmental organization, provides what could be a useful example of a mechanism to address technological hazards through collective interests organized to reduce global risks.

2.3 Operator Responsibilities

Explicit risk analysis requirements should apply to any establishment where dangerous substances are present in quantities equal to or in excess of the specified quantities. The presence of dangerous substances should mean the actual, or anticipated, presence of such substances in the establishment, or the presence of those which may be generated during loss of control of an industrial chemical process. It should include all the equipment structures pipework, machinery, tools, private railway sidings, docks, unloading quays serving the installation, jetties, warehouses or similar structures, floating or otherwise, necessary for the operation of the installation.

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2.4 Public Authority Responsibilities for Reporting and Public Information

1. Suitable information needs to be exchanged in an appropriate manner to enable establishments to take account of the nature and extent of the overall hazards of a major accident in their major accident prevention.
2. Provision has to be made for cooperation in informing the public and in supplying information to the competent authority for the preparation of external emergency plans. States should require the operator to produce a safety report for the purposes of:
   - Demonstrating that a major accident prevention policy and a safety management system for implementing it have been put into effect.
   - Demonstrating that major accident hazards have been identified and that the necessary measures have been taken to prevent such accidents and to limit their consequences for man and the environment into the design, construction, operation and maintenance of any installation, storage facility, equipment and infrastructure connected with its operation which are linked to major accident hazards inside the establishment.
   - Demonstrating that internal emergency plans have been drawn up and supplying information to enable the external plan to be drawn up in order to take the necessary measures in the event of a major accident.
   - Providing sufficient information to the competent authorities to enable decisions to be made in terms of the siting of new activities or developments around existing establishments.

These safety reports should contain at least the data and information specified and it should also contain an updated inventory of the dangerous substances present in the establishment safety reports, or parts of reports, or any other equivalent reports produced in response to other legislation, may be combined to form a single safety report for the purposes of this Article, where such a format obviates the unnecessary duplication of information and the repetition of work by the operator or competent authority, on condition that all the requirements of this Article are complied with.

Before the operator begins construction or operation, the competent authority should within a reasonable period of receipt of the report, either communicate the conclusions of its examination of the safety report to the operator, if necessary after requesting further information, or prohibit the initiation or continued use of the establishment concerned. The safety report should be periodically reviewed and where necessary updated.

2.5 Contingency emergency plans

The emergency plans must be established with the following objectives:

1. Containing and controlling incidents so as to minimize the effects, and to limit damage to man, the environment and property.
2. Implementing measures necessary to protect people and the environment from the effects of major accidents.
3. Communicating necessary information to the public and to the emergency services or authorities concerned in the area.
4. Providing for the restoration and clean-up of the environment following a major accident.

It is a fundamental issue that public authorities should ensure that the inventory of dangerous substances is made available to the public as part of their contingency plan. This must necessarily also include a presentation of the environment of the establishment. It should contain a description of the site and its environment including the geographical location, meteorological, geological, hydrographic conditions. If necessary, it should also consider the additional relevance of its history; identification of installations and other activities of the establishment which could present a major accident hazard, and a description of areas where a major accident could occur. A description would be necessary of the main activities and products of the various parts of the establishment which are important from a safety standpoint. This could include sources of major accident risks and conditions under which such a major accident could happen, together with a description of proposed preventive measures; description of processes.

Particular details should include details of the operating methods, an inventory of dangerous substances, including their description in the following terms:

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- the identification of dangerous substances;
- chemical name, CAS number, name according to IUPAC nomenclature;
- the maximum quantity of dangerous substances present or likely to be present;
- physical, chemical, toxicological characteristics and indication of the hazards, both immediate and delayed for people and the environment;
- physical and chemical behaviour under normal conditions of use or under foreseeable accidental conditions; and
- identification and accidental risks analysis and prevention methods.

A detailed description of the possible major accident scenarios and their probability or the conditions under which they may occur should be presented, including a summary of the events which may play a role in triggering each of these scenarios, whether the causes could be internal or external to the installation; assessment of the extent and severity of the consequences of identified major accidents; and a description of technical parameters and equipment used for the safety of installations.

Details should be provided of available measures for protection and intervention to limit the consequences of an accident, including an organization of alert and intervention, description of mobilizable resources, both internally or externally available.

For the purpose of implementing the operator's major accident prevention policy and safety management system, account would have to be taken of the following elements. The major accident prevention policy should be established in writing and it must include the operator's overall aims and principles of action with respect to the control of major accident hazards. The safety management system should include the part of the general management system which includes the organizational structure, responsibilities, practices, procedures, processes and resources for determining and implementing any major accident prevention policy within the establishment or any of its facilities. Overall, the fundamental aspect of the safety management system must address the organization and personnel, the roles and responsibilities of personnel involved in the management of major hazards at all levels in the organization.

Internal emergency plans should be drawn up in consultation with personnel employed inside the establishment and that the public is consulted on external emergency plans.

2.6 Public Authority Responsibilities for land-use and Public Policy Procedures

Designated public officials should ensure that the objectives of preventing major accidents and limiting the consequences of such accidents are taken into account in their land-use policies and other relevant policies. They should pursue these objectives through controls on the siting of new establishments, modifications to existing ones, or for new developments including transportation links. In addition, locations frequented by the public and residential areas in the vicinity of existing establishments should be carefully accessed for risks associated with the siting of facilities or developments which could present the risk or consequences of a major accident.

States should ensure that their land-use and other relevant policies, and the procedures for implementing those policies, take account of the need to maintain appropriate distances between establishments and residential areas, areas of public use and areas of particular natural sensitivity or interest. In the case of existing establishments, this implies the need for additional technical measures so as not to increase the risks to people.

2.7 Communication and Information Exchange

Public authorities should ensure that all designated officials and planning authorities responsible for decisions in this area set up appropriate consultation procedures to facilitate implementation of the policies established. The procedures should be designed to ensure that technical advice on the risks arising from the establishment is available, either on a case-by-case or on a generic basis, when decisions are taken. States should ensure that the public is able to give its opinion in the process of planning for new establishments, when making modifications to existing establishments, and when new public developments are considered for construction around existing establishments.

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With respect to the possibility of a major accident originating within an establishment of one country, with transboundary effects, there is a special obligation for States to provide sufficient information to other potentially affected States. When a subscribing party has decided that an establishment close to the territory of another State is incapable of creating a major accident hazard beyond its boundary, and it would not therefore be required to produce an external emergency plan, it should inform the neighbouring state accordingly.

For the purpose of prevention and mitigation of major accidents, States should provide information as soon as practicable of major accidents which have occurred within their territory. The following details are crucial for any accident reporting:

- the location and State concerned;
- name and address of the authority responsible for the report;
- date, time and place of major accident, including the full name of the operator and the address of the establishment involved;
- a brief description of the circumstances of the accident, including the dangerous substances involved;
- the immediate effects on people and the environment; and
- a brief description of the emergency measures taken and of the immediate precautions necessary to prevent recurrence.

Subscribing parties should, as soon as the information is collected, inform the result of their analysis and recommendations using a report form established and kept under review. The names and addresses should also be conveyed of any body which might have relevant information on major accidents and which may be able to advise the competent authorities of other States which have to intervene in the event of such an accident.

States should also be prepared to exchange information on the experience acquired with regard to the prevention of major accidents and the limitation of their consequences. An international register and information reporting system could be maintained that records details of major accidents which have occurred within the territory of individual States. This could serve the purpose of providing:

- rapid dissemination of the information supplied by States among all competent authorities;
- the distribution to all authorities concerned of an analysis of the causes of major accidents and the lessons learned from them;
- the supply of information to competent authorities on relevant preventive measures; and
- the provision of information on organizations able to provide advice or relevant information on the occurrence, prevention and mitigation of major accidents.

The register and information system should contain at least the following information:

- analysis of the causes of the accidents;
- lessons learned from the accidents;
- preventive measures necessary to prevent a recurrence.

Access to the register and information system should be open to government departments national authorities, industry or trade associations, trade unions, non-governmental organizations and public interest groups involved with protection of the environment and other international or research organizations working in the field.

States should ensure, in the interests of transparency, that the competent authorities are required to make information received available to anyone who demonstrates reasonable legitimacy. Information obtained by the authorities may, where national provisions so require, be kept confidential if it calls into question any of the following concerns:

- the confidentiality of the deliberations of the competent authorities;
- the confidentiality of international relations and national defence;
- matters of public security;
- the confidentiality of preliminary investigation proceedings or of current legal proceedings;
- commercial and industrial secrets, including intellectual property;
- personal data;
- data supplied by a third party if that party requires that they be kept confidential.

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2.8 Certification and Licensing Issues

Without prejudice to the operator's responsibilities, public licensing or regulatory agencies should prohibit the use of any establishment, installation or storage facility where the measures taken by the operator for the prevention and mitigation of major accidents are seriously deficient.

For an effective licensing regime to be maintained, it is essential that the competent authorities organize a system of inspections.

2.9 Preparedness

Internal emergency plans should contain names or positions of persons authorized to set emergency procedures in motion and the person in charge of coordinating the on-site activities. People with responsibility for liaising with the authority responsible for the external emergency plan should also be indicated. For foreseeable conditions or events which could be significant in bringing about a major accident, a description of action necessary to control events should be cited. Arrangements for training staff in the duties they will be expected to perform, are essential, should be coordinated with off-site emergency services.

External emergency plans with names or positions of persons authorized to set emergency procedures in motion and of persons authorized to take charge of and coordinate off-site action Arrangements for receiving early warning of incidents, and alert and call-out procedures.

The following practices are important preparedness measures that should be implicit in any early warning and preparedness strategy:

- operational control: adoption and implementation of procedures and instructions for safe operation, including maintenance, of plant, processes, equipment and temporary stoppages;
- management of change: adoption and implementation of procedures for planning modifications to, or the design of new installations, processes or storage facilities;
- planning for emergencies: adoption and implementation of procedures to identify foreseeable emergencies by systematic analysis and to prepare, test and review emergency plans to respond to such emergencies;
- monitoring performance: adoption and implementation of procedures for the ongoing assessment of compliance with the objectives set by the operator's major accident prevention policy and safety management system, and the mechanisms for investigation and taking corrective action in case of non-compliance; and
- audit and review: adoption and implementation of procedures for periodic systematic assessment of the major accident prevention policy and the effectiveness and suitability of the safety management system, including the documented review of performance of the policy and safety management system and its updating by senior management.

2.10 Relationship to Emergency Relief Actions

- The public should be informed of the name of the operator and address of the establishment.
- Identification, of position held, of the person giving the information.
- Confirmation that the establishment is subject to the and that the safety report has been submitted to the competent authority.
- Adequate information on how the population concerned will be warned and kept informed in the event of a major accident.
- Adequate information on the actions the population concerned should take, and on the behaviour they should adopt, in the event of a major accident.
- Confirmation that the operator is required to make adequate arrangements on site, in particular liaison with the emergency services, to deal with major accidents and to minimize their effects.
- A reference to the external emergency plan drawn up to cope with any off-site effects from an accident.

States should ensure that, as soon as practicable following a major accident, the operator should be required, by the most appropriate means, to inform the competent authorities and provide the following information as soon as it becomes available:

- circumstances of the accident,
- dangerous substances involved,
- data available for assessing the effects of the accident on people and the environment,

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- emergency measures taken,
- inform steps envisaged to alleviate the medium and long term effects of the accident,
- means to prevent any recurrence of such an accident, and
- measures to update the information provided if further investigation reveals additional facts which alter that information or the conclusions drawn.

All subscribing parties should require that competent authorities be designated to

- ensure that any urgent, medium and long term measures which may prove necessary are taken;
- to collect, by inspection, investigation or other appropriate means, the information necessary for a full analysis of the technical, organizational and managerial aspects of the major accident;
- to take appropriate action to ensure that the operator takes any necessary remedial measures; and
- to make recommendations on future preventive measures.

For relief actions the activities of authorities and of acting groups must be coordinated. In principle, this demands the following functions be undertaken:

1. Alert system measurement
   - data transfer
   - data interpretation and conclusions alarm
2. Action of local authorities, fire brigade etc. Activities involved, on-site and off-site
   - evacuation
   - hospitalization
   - further measurements
3. Involvement of regional authorities, groups Development of disaster relief program
   - Cooperation of different groups to bring together measurement data of different kind, including chemical specifics, measurements, meteorological data, geographical information systems, modelling of the behavior of substances in the environment
   - action plan
4. Involvement of multinational organization levels Alert of transboundary effects
   - assistance requirements
   - actions to reduce immediate effects

Incorporate other national, international activities and organizations as the WMO Environmental Emergency Response Activities Programme, structures from the implementation of the IAEA Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

3 Structure of an Early Warning System

3.1 Elements of a Warning System for Technological Hazards

Considering the information in the foregoing sections, the essential elements of an early warning system for technological hazards is outlined here. The structure should be distinctive in reflecting the organizational and technical infrastructural elements involved that are pertinent to a specific location and/or set of operational circumstances. In addition, the structure must reflect both the on-site criteria, which relate to internal establishment procedures indicated in contingency preparedness plans, and additional off-site considerations applicable at local, regional, national, and if necessary, international levels of responsibility. The essential elements of a technological hazards warning system include:

An infrastructure to prevent accidents

Qualification of personnel with the use of the facilities
Training program
Information program
Alarm and alert systems
Quality assurance management
Maintenance works, control functions
Facility design
Material control
Process planning
Risk analysis

Basic infrastructure for alerting systems

Consequence analysis
Pathway analysis
Reaction products under different conditions of accidental release, including weather conditions and reaction products under specific weather conditions

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Cooperation plans with off-site groups (fire brigade, ambulance, hospitals, specialized equipment providers, transportation, chemicals, water cleaning systems)

Infrastructure of detection and response

Detection systems, specification of location
Weather conditions
Prediction modelling and simulation
Communication system, local, regional, cross-boundary
Transport units
Evacuation plans
Emergency operations
Fire brigade, ambulance, warning time, arrival time

Technical and organizational infrastructure

(for control of facilities and licensing procedures).
Organization on site
Local authorities
Regional authorities
National authorities
International cooperation
Conventions
Acting bodies
Data exchange
Emergency assistance
Public information
Modelling
Physical aid, personnel. equipment

3.2 Role of Local and Regional Authorities

Taking into account that time is a very important factor for counter measures, the principal task should be to establish systems which can act very quickly and adequately. It is thought that complicated decision-making systems on levels, where no practical connection is given should be avoided so as not to interfere in the local actions being taken.

A contamination that is treated in a quick and appropriate way will not pose a national or international problem. The same contamination which is not treated because of complicated responsibility concepts, where the information has to go back and forth for decision-making, could lead to an environmental disaster.

Concepts should therefore foresee that immediate actions are identified as the responsibility of local organizations and that they are provided with the necessary equipment and information. The information is also going to regional authorities where decisions should be taken about the involvement, if necessary, of additional groups, experts, or equipment which is not available at the local level. All of these details, together with the information about decisions, should reach the national level of responsibility, as it is there, where decisions would be taken about any international information or involvement, as when transboundary effects are expected. This will also include any requests for international assistance deemed to be necessary, such as the provision of material, experts, equipment etc.

The role of the local authorities and of local response groups should be supported by higher levels of responsibility. They should have access to the information which is necessary for a disaster relief plan and for immediate actions. They must know about possible hazards, potential damage (obtained through prior risk analysis). Associated raining concepts have to be based on actual scenario analysis which local capabilities can relate to. In this respect there is need for familiarity and information about hazardous substances, concentrations, velocities of transport means (water, air), direction, different meteorological parameters. Fortunately, much of this information is now easily available in portable form through universally accessible databases or by means of other modern forms of communication and information technology. Furthermore, the most suitable methods of communications must be taken into account, from the initial sounding of an alarm, through the different levels of actions, as well as extending important current, and accurate, information to the public, taking into account existing communication systems and reaction time.

The nationally responsible authority should not interfere in the immediate local actions which can be best prepared based on the information provided by the operator to the authorities. The national authority responsible should also keep all necessary contacts, coordinate additional help, all actions and independent on the national level. For greatest effectiveness, this must be based on concepts which have been developed earlier, maintained to reflect

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current situations or designated authorities and contact information, approved by, and known to, all authorities concerned.

In the case of an accidental release of substances which could harm people and the environment the fact of the release will be known. Measurements in the environment will give a rough estimation of the concentration of substances, the connection of these data with meteorological data based on specific situations, as temperature, humidity, wind velocity, direction and specific data from the accident will be used for the necessary decisions. These assessments will take into account release paths, substances released by fire, explosion, pipe rupture, etc. These will help to establish a model of the amount of material released, the direction, form of the substances, and will therefore facilitate first relief actions.

More specific information about the details of contamination for specific actions can be gained by automatic detection systems. Such systems consist of mobile detection units with specific equipment. Theses units also can be connected via telephone or radio to the collection unit. The cyclic information processing is recorded on a Geographic Information System which can then provide an overlay of meteorological, population density, or other relevant data so that measures for action, evacuation, prediction of concentrations can be estimated. This can greatly assist the decision-making processes. These information systems can be connected to national or international data systems for use in either real time analysis and application or for subsequent post *mortem* analysis from the accumulated data received during the course of the event.

3.3 International Efforts for Disaster Prevention and Relief

There are many examples of international effort for disaster prevention, mitigation and early warning and relief. The IAEA conventions have been cited. Another is the Open Partial Agreement of the EUR-OPA Major Hazards Agreement to which twenty-one States have acceded to its agreements. This important initiative has the main aim of establishing closer cooperation between Member States in a multi-disciplinary context to ensure better prevention, protection and organization of relief in the event of major natural or technological disasters. The Commission of the European Community, UNESCO, WHO and the United Nations Department of Humanitarian Affairs participate in the Agreement. The International Federation of Red Cross and Red Crescent Societies, similarly, is associated in its work. The Agreement includes also the European Early Warning System. Within the United Nations, the Joint UNEP/DHA Environment Unit has been in operation since 1994, pursuing activities in the field of coordinated sharing of preparedness and response information, and the promotion of improved international response capabilities.

Many organizations deal in the course of their respective mandates, interests and abilities with issues related to technological hazards. Clearly, each organization has its own existing structures. Hence, for any organization that may be tasked with early warning responsibilities in the field, the activities and responsibilities of the existing national and international structures should be taken into account. They include the following organizations:

3.4 United Nations Agencies and Departments

- *UN* Department of Humanitarian Affairs DHA (renamed the Office for the Coordination of Humanitarian Affairs OCHA), including The Joint UNEP/DHA-OCHA Environment Unit
- The Regional United Nations Economic Commissions for Europe, Africa, Latin America, Asia and the Pacific ECE, ECA, ECLAC, ESCAP
- United Nations Development Programme UNDP
- United Nations Conference on Trade and Development UNCTAD
- UN Industrial Development Organization UNIDO
- UN Environment Programme UNEP, including the specific UNEP bodies:
  - Industry and Environment Programme Activity Centre IE/PAC
  - Awareness and Preparedness at the Local Level APELL
  - The Global Resources Information Database GRID
  - The Oceans and Coastal Areas Programme Activity Centre OCA/PAC

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- Earthwatch
- UNEP Regional Offices
- Secretariat of the Basle Convention on the Transboundary Movements of
- Hazardous Wastes
- The International Register of Potentially Toxic Chemicals IRPTC
- The International Maritime Organisation (IMO)
- World Health Organisation WHO
- Food and Agricultural Organisation FAO
- International Atomic Energy Agency IAEA

3.5 Other International Bodies

- European Commission Bodies
- Organization for Economic Cooperation and Development OECD

3.6 Non-Governmental Organizations

- Verification Technology Information Centre, VERIC, London, UK
- Science Application International Corporation, SAIC, Virginia, USA
- Conseil Européen de l'Industrie Chimique, CEFIC, Brussels

3.7 National Agencies and Authorities

- Existing national early warning systems
- Existing models of data communication on bilateral basis
- Existing national, regional and local catastrophe management systems (military equipment and organizations, police, fire brigade, ambulance, hospitals)

3.8 International Databases for Hazardous Substances

For communication and international assistance, common databases are necessary. For hazardous substances databases from other international conventions can be used. In the case of chemicals use could be made of the scheduled chemicals of the Annex in the Convention for the Prohibition of Chemical Weapons.

Other databases also exist, as for example, the database utilized in the AEWS system. It is known as the "BIG" Software, and it is available on CD-ROM (in English, French, Spanish, Portuguese, German, Dutch, Italian), and is updated annually. This product of the Braandweer-Informatiecentrum Gvaarlijke Stoffen, Schoolstraat 43 A, B-2440 Geel, Belgium, is a database of more than 8000 substances, corresponding with more than 170,000 product names and it provides the chemical, physical and toxicological characteristics about polluting.

4 Recommendations

Given the growth in international risk factors and the potential human, environmental, and material costs of consequences there is a priority need to tasking an existing international organization with the issues of ensuring early warning systems capabilities for technological hazard on a global basis. Priority tasks in relating early warning capabilities to preventing technological disasters should include the following actions:

1. Existing conventions, agreements, guidelines, regulations and laws should be the basis for a global capability pertaining to early warning systems for technological hazards. A survey should be done regarding questions of appropriate interfaces between information systems, data exchange and measures taken, when bilateral problems are involved.
2. The installation, or designation of an already-existing global network of communication, information exchange and coordinated action arising from existing organizations and cooperation with existing organizations and institutions.
3. Define necessary future work, this should include the continuous review of technological developments with the aim to identify necessary fields of actions.
4. Establish criteria for the global notification of an accident to be accomplished through a designated organization.
5. Make use of existing regulations, guidelines and structures and harmonize these activities for a global application.
6. Special emphasis should be directed to accident prevention (including on-site measures), hazard detection, prediction, communication, decision-making, and action.

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7. The use, processing or gathering of global data to identify possible priority needs for action.
8. Identify necessities of specific measurements for certain industries, technological areas such as production, releases to the environment, post consumer product phases, and the related technical processes involved.
9. Identify necessities for the development of measurement of risk criteria for specific substances.
10. Enhance the development of methods for the identification, estimation, comparative assessment and management of risks of industrial processes (regular activities and accidents) and of products.
11. Enhance the development of industrial processes and techniques which reduce the risks to men and environment; the development and/or improvement of both preventive and remedial technologies.
12. Enhance the dissemination and the improvement of exposure assessment methods for hazards to health from chemicals in the environment (Including methods for exposure prediction and for early indicators of exposure.
13. Enhance the development of validation methods of health effect assessment methodologies with emphasis on early indicators of adverse effects resulting from exposure to environmental pollutants.
14. Strengthen the scientific basis underlying risk assessment of environmental chemicals (particularly genotoxic chemicals).
15. Develop environmental health impact focal points for air, water and soil quality to establish co-operation in the areas of
    - data transfer
    - modelling
    - practical scenario exercises to address matters of detection, data acquisition and use, decision-making and operational actions using existing structures
    - scenario analysis
    - communication systems
    - data coupling
    - measurement nets
    - risk analysis
    - application of environmental technologies and "best available technology" as a common basis for process and facility design, thereby reducing the demand for facility-specific risk analysis
    - use of satellite environmental data to specific pollution areas in air, land and water.
    - encourage technology transfer
    - develop technical and organizational guidelines
    - harmonize data systems, communication linkages, decision-making processes, and risk levels for alarm, intervention and information exchange
    - provide a clearinghouse function for the wide, and inter-disciplinary exchange of information
16. Identification of similarities and differences between systems for management and assessment of occupational health, safety and quality to develop criteria for integrated safety management and assessment systems
17. Provide guidelines for industrial facilities to prevent accidents, which will include concepts and models for risk analysis, alert plans, data communication, risk assessment and management. The aim is to use or develop methodologies and tools to assess and manage risks evolving from technological hazards, critical analysis of existing safety management systems, industrial best practices, use of accident and precursor data, examination of variations in safety hazard and risk analysis, determination of state-of-the-art chemical accident risk analysis, prevention and management, and related training and the development of appropriate tools for the wide dissemination of knowledge.
18. Planning on- and off-site emergency procedures building on analysis of problems of cooperation between organizations.
19. Provide information by workshops, expert group meetings, cooperation with involved organizations, participation in respective programs and establishing guidelines for technical and organizational procedures.
20. Provide the basis to ensure necessary logistic frameworks to prevent, mitigate and remedy the consequences of technological hazards exist at national levels and can be applied by designated authorities.
21. Ensure that the necessary infrastructure in equipment, personnel and materials based on commonly agreed requirements are available and usable.
22. Ensure that provisions for communication pathways are established for communication

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from the site of a possible accident to action groups in local, regional and national decision-making levels of responsibility.

23. National authorities should be encouraged to communicate the main provisions of domestic laws, information on their respective management systems and the organization of the establishments, with a view to the prevention of major accidents.
24. Publicize data and information to be included in national emergency plans, including information to be provided to the public, including: plant schemes for the utilization of scheduled chemicals and/or the processes concerned, with regard to their amount, release pathways, proximity to specific elements of the natural environment (rural, urban, lakes, rivers; agriculture, fisheries, etc.), accident level, and established response capacities at plant, local, regional, bilateral, and global levels.
25. Anticipate and assess new challenges of potential technological hazards, such as the problem of species being transferred by technical or transportation systems (aircraft, cars, shipment).
26. Anticipate and plan for problems associated with gentechnological production and possible accidental releases into the environment.
27. Consider potential technological hazards associated with abandoned military establishments, installations or storage facilities.
28. Continuous assessment and surveillance of the transport of dangerous substances and intermediate temporary storage by road, rail, internal waterways, sea or air. The transport of dangerous substances in pipelines, including pumping stations should also be surveyed considering the importance of their transboundary implications.
29. Monitor the activities of extractive industries concerned with exploration for, and the exploitation of, minerals in mines and quarries or by means of boreholes; waste and land-fill sites.
30. In the case that preventive measures for a major accident fail, then the following information should be provided and integrated in an interactive data and decision support network. This network consists mainly a data bases structure and of a software to combine specific accident information data with validated models providing the necessary decision support for relief forces and authorities:
    - time, location and nature of accident,
    - facility, substances involved,
    - cause and foreseeable development relevant to the transboundary effects of materials involved,
    - general characteristics of released materials, their physical characteristics, chemical form, quantity, composition, etc.,
    - results of environmental monitoring,
    - off-site protective measures undertaken or activated, and
    - predicted behaviour of the released materials over a specified time.

It is obvious that this task list which is based on the analysis of past experience, demands more flexible international structures, especially in the case of relief actions. A main problem consists in structuring the information portals between national and international data bases, considering the problem of confidentiality. Modern communication systems allow structures where the problems of confidentiality and data validation can be solved. Data and information must not go through open access systems to be available on a global net. Information exchange can be organised in a way that sensitive data will not go beyond a threshold server defined by the involved parties, while data and codes necessary for risk assessment of specific situations and also in the case of disaster relief actions can be used by the client alone.

It has also to be considered that disaster information systems are primarily regional problems. Therefore they should use the development of regional data exchange networks, make use of the development of commercial communication networks and use the devices developed for the daily purpose. Disaster management when integrated in the development of industrial society should avoid costly and specific concepts, peripheral systems and devices demanding special training. Disaster management should be organised so that branching from the big commercial communication structure takes place as late as possible to avoid all unnecessary costs. But communication with the necessary bandwidth must be ensured in case of a disaster.

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Early Warning Systems for Mitigation of Earthquake-Related Technological Risks

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Abstract

This paper highlights recent developments on early warning systems for mitigation of earthquake-related technological risks in Japan. To avoid earthquake-related secondary disasters to transportation, to lifeline systems and other urban facilities, several earthquake monitoring networks have been established in order to use earthquake information for early warning or early damage assessment. UrEDAS of Japan Railway (JR) group and SIGNAL of Tokyo Gas Company are the pioneers of such systems. After the 1995 Hyogoken-Nanbu Earthquake, installation of seismometer networks and development of early damage assessment systems by national and local governments as well as utility companies in Japan boomed. Public highway corporations are also moving in a similar direction. Some automated seismic-reaction systems for power, gas and water supply lifelines and elevator systems also exist. This paper provides an overview of the current state of these systems and discusses future directions of such early warning systems are discussed.

1 Introduction

The 1995 Hyogoken-Nanbu (Kobe) Earthquake in Japan and the 1994 Northridge Earthquake in the United States led us to recognise the importance of emergency response just after the occurrence of earthquakes. Although some early warning systems and rapid damage assessment systems existed previously in Japan and the United States, the development of such systems boomed after these earthquakes.

Figure 1 shows the classification of "real-time" earthquake disaster mitigation systems by Toki (1995). Based on the time elapsed after the occurrence of an earthquake (or more precisely, the time elapsed after the arrival of seismic waves to the instruments), Toki classified the systems into four categories: "response control", "information transmission", "damage estimation" and "recovery support". Automated seismic-reaction sensors, e.g., gas shutoff valves, can be classified as a "response control system" in a broad sense. Although the definition of "real-time" or "early warning" varies depending on people and situations, this paper covers the systems falling under the first three

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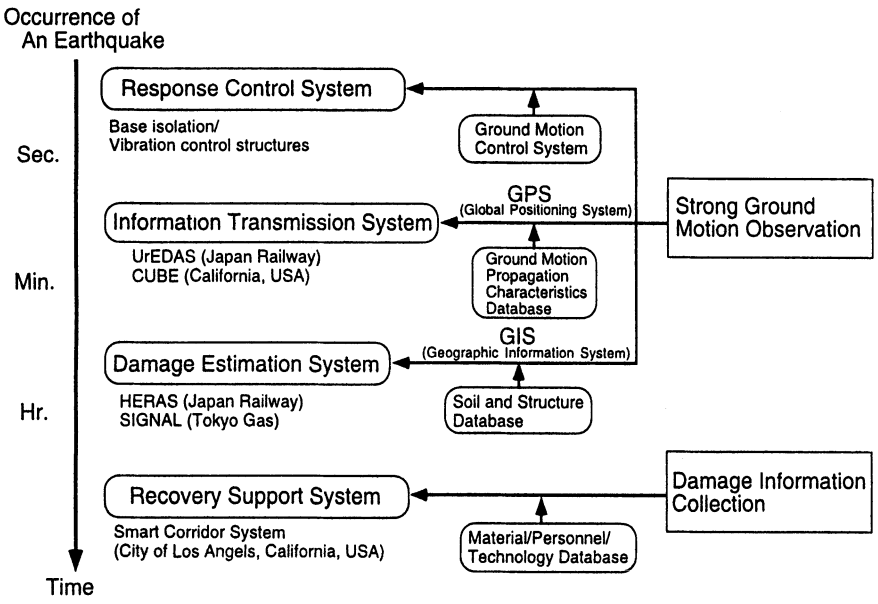


Fig. 1. Real-time earthquake disaster mitigation systems classified by Toki (after Noda and Meguro 1995)

categories, which are implemented within about one hour following the earthquake event. To achieve prompt responses, it is necessary to develop/prepare technologies and databases before the occurrence of earthquakes. Seismic instruments, telecommunication networks, and geographic information systems (GIS) are typical examples of such key technologies.

The concept of early earthquake warning was thought of long ago, it was, however, only realized recently. The first practical early earthquake warning system may in fact be the UrEDAS (Urgent Earthquake Detection and Alarm System) of the Railway Technical Research Institute, Japan (Nakamura 1988). Detecting the arrival of the P-wave at near source, the system estimates the location and magnitude of an earthquake very quickly. The system then uses this information to stop or reduce the speed of high-speed trains before the arrival of the S-wave. The first UrEDAS network began operation in 1989.

Several rapid damage assessment systems using early seismic information were also developed in Japan. The SIGNAL (the Seismic Information Gathering and Network Alert) system of the Tokyo Gas Company may be the pioneer in this field (Yamazaki et al. 1994). The system performs damage estimation of a natural gas network based on extensive earthquake monitoring and GIS. The system has been functioning since early 1994, about a year before the Hyogoken-Nanbu Earthquake.

Almost at the same time, EPEDAT (the Early Post-Earthquake Damage Assessment Tool) was developed in the United States to estimate building and lifeline damage in southern California (Eguchi et al. 1994). Rapid damage assessment systems of Kawasaki City and Tokyo Fire Department, both developed in 1994 for the purpose of emergency management, also fall in this category. A number of similar rapid as well as off-line damage assessment systems have been developed by national and local government agencies in Japan, especially following the Hyogoken-Nanbu Earthquake.

Seismic information is the key issue for early warning and rapid damage assessment systems. In this regard, the Japan Meteorological Agency (JMA) determines the location and magnitude of an earthquake and disseminates this information nationwide via public TV and radio within a few minutes after the event. Recently, the CUBE (The Caltech-USGS Broadcast of Earthquakes) system started a similar service in southern California for CUBE subscribers via commercial radio pager service (Kanamori et al. 1991).

Seismic networks for expressway systems in Japan were also strengthened recently. Observed data are utilized for the closure of expressways just after the occurrence of earthquakes. Automated seismic-reaction systems for power, gas and water supply lifelines and elevator systems are also in use. This paper provides an overview of early warning and rapid damage

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assessment systems and their future directions are discussed.

2 Early Warning Systems for Railway Networks

High-speed railways are one of the most important targets of early warning systems. If an earthquake occurs, trains should be stopped as soon as possible to avoid disasters. In the 1995 Hyogoken-Nanbu Earthquake, several trains were derailed due to strong shaking (Fig. 2) and a large number of bridges and embankments collapsed. Fortunately, however, the number of trains and passengers on them were very low due to the early hour (5:46 a.m.) and no significant human injuries were reported. The elevated sections of Shinkansen (bullet train) also collapsed at several locations. Since the first train was scheduled to leave Osaka Station at 6:00 a.m. and to reach the collapsed sections at about 6:10 a.m., the timing of the earthquake was extremely fortuitous.

Although the idea of early earthquake warning has existed for a long time, UrEDAS of the Railway Technical Research Institute (RTRI) may be the first practical tool of an early earthquake warning system in the world. The prototype of the system was constructed more than ten years ago (Nakamura & Ueno 1986). Detecting the arrival of the P-wave by its seismic network at near source, the system estimates the location and magnitude of an earthquake very quickly. In order to issue alarms promptly, UrEDAS uses three-component recording at only one point. Transmitting the signal by telecommunication lines, the alarm is used to stop high-speed trains before the arrival of the S-wave.

The first UrEDAS network with five instruments was deployed in the Tokyo metropolitan area in 1989. Since then, several UrEDAS networks have been deployed for other rapid railway systems in Japan as shown in Figure 3. The first UrEDAS network for rapid railway systems began operation in 1992 with 14 instruments on the Tokaido (between Tokyo and Osaka) Shinkansen. Following the Hyogoken-Nanbu Earthquake, a UrEDAS network for the Sanyo (between Osaka and Fukuoka) Shinkansen was also introduced. Other UrEDAS networks, e.g., Seikan (between Aomori and Hakodate) Tunnel, and a test site in Pasadena, California, have also been in operation. UrEDAS is considered to be one of the most important earthquake countermeasures for railway systems in Japan.

It should be noted that the system works only for earthquakes with some source-site distance. For near-field earthquakes like the Hyogoken-Nanbu, there is not enough time to send an alarm to trains. Hence the strengthening of railway structures against earthquakes should not be neglected, even though an early warning system has been introduced.

The RTRI also developed a system named HERAS (Hazards Estimation and Restoration Aid System), which estimates the degree of damage to railway systems caused by an earth-



Fig. 2. Train derailed due to the 1995 Hyogoken-Nanbu Earthquake in Nishinomiya City, Japan

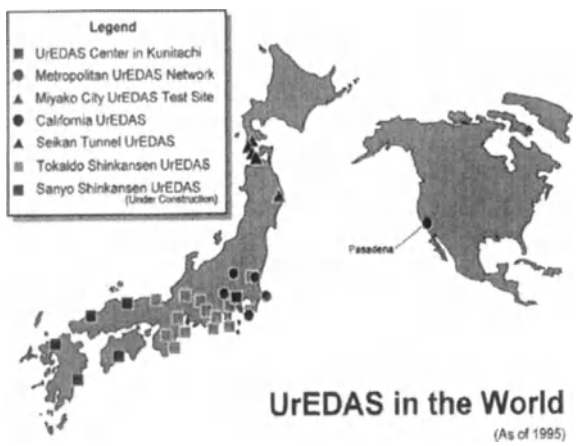


Fig. 3. UrEDAS networks deployed by the Japan Railway Group (after http://www.rtri.or.jp)

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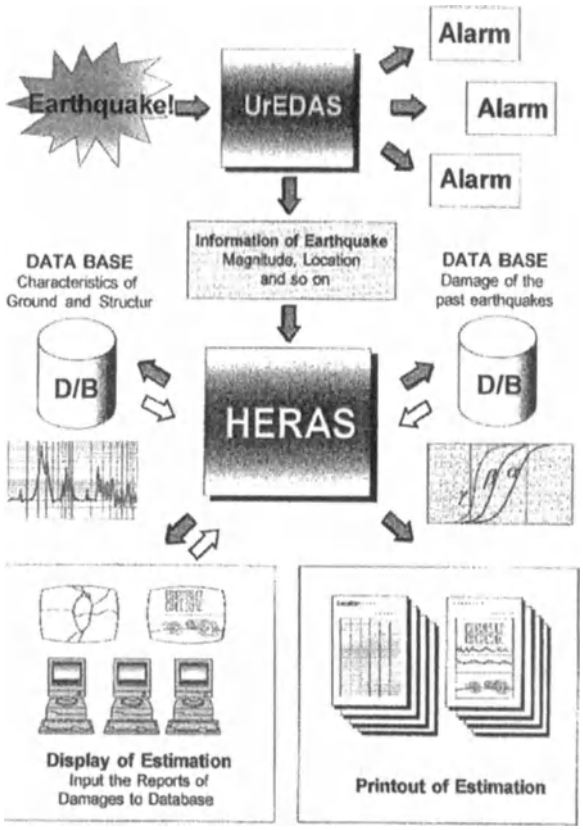


Fig. 4. Concept of UrEDAS and HERAS of the Railway Technical Research Institute (after http://www.rtri.or.jp)

quake (Nakamura 1996). Using the information from UrEDAS, the database on characteristics of ground and railway structures, and the damage experiences of past earthquakes, HERAS can provide damage estimates of railway systems within five minutes after an event (Fig. 4). A prototype of HERAS was completed in 1992.

If a train service is suspended due to earthquakes, inspection of railway lines will be conducted before re-starting the service. Hence the rapid damage assessment itself does not have much importance. The damage assessment system is used more often for retrofit planning and emergency restoration planning.

3 Early Warning Systems for City Gas Networks

The natural gas system in the Kobe area, operated by Osaka Gas Company, was seriously affected by the 1995 Hyogoken-Nanbu Earthquake (Oka 1995). Numerous breaks in distribution and service pipes were reported. Osaka Gas stopped the gas supply to 860 thousand customers in the hard-hit areas, but it took 6 to 15 hours before the decisions to shut off supply were made because the collection of information on the extent of damage was extremely difficult just after the earthquake. Due to the massive damage to gas pipes and disruption of road networks, the service restoration took about three months.

To cope with earthquake-related secondary disasters, e.g. fires (Fig. 5) and explosions, city gas companies in Japan have promoted several countermeasures in the last two decades e.g.: increasing seismic resistance of facilities and pipelines, segmentation of gas networks into blocks, earthquake monitoring by seismometers and installation of intelligent gas meters with a seismic sensor.



Fig. 5. Fire following the 1994 Northridge Earthquake along Balbor Boulevard in Granada Hill, California. The fire was ignited by a spark from a car engine starter to leaked natural gas from a broken gas main (photo by EQE International)

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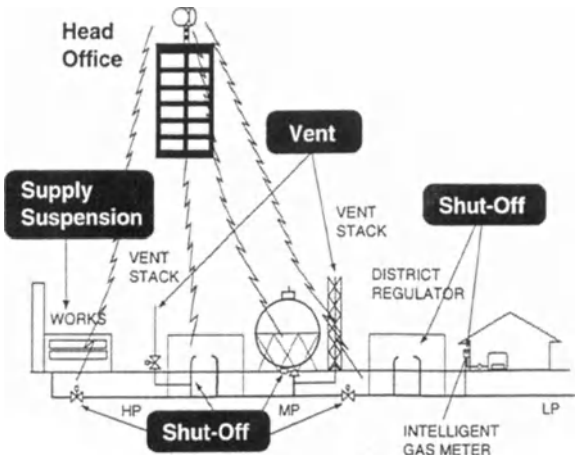


Fig. 6. Emergency operation systems of the city gas network of Tokyo Gas (Yoshikawa et al. 1997)



Fig. 7. Location of earthquake sensors of SIGNAL system

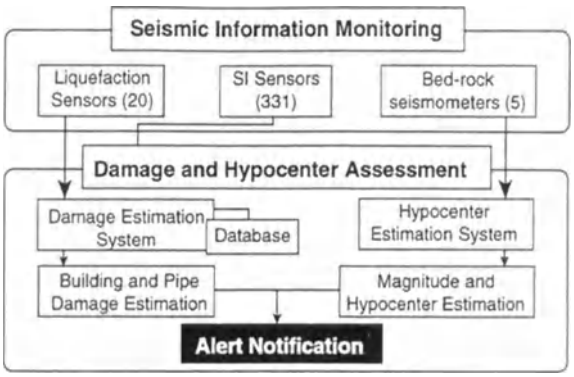


Fig. 8. Flowchart of damage assessments in SIGNAL (Yoshikawa et al. 1997)

Figure 6 shows emergency shutdown systems of the Tokyo Gas Company with 8.1 million metered customers. Gas pressure and flow of production facilities and high-pressure (HP) pipelines are always monitored in case problems arise. Primary facilities are equipped with remote-control emergency shutoff valves.

Segmentation of gas networks is carried out at two levels: one for medium-pressure (MP) lines and another for low-pressure (LP) lines. Emergency shutoff of gas networks can be carried out for these units, called K-blocks for medium-pressure lines and L-blocks for low-pressure lines. At each customer, an intelligent gas meter stops gas supply automatically if earthquake motion larger than about 0.2 G is detected.

For low-pressure lines, emergency shutoff is carried out automatically based on measured SI (Spectrum Intensity) values at district regulators. However, for medium-pressure lines, an automated shutoff system is difficult to install because the service areas and the effects of emergency shutoff are much greater than those of low-pressure lines. It is also not easy to detect pipe breaks just after an earthquake based on changes in gas flow and pressure, because pipe breaks and automated shutoffs affect conversely. Thus, a rapid damage assessment system, SIGNAL, was introduced (Yamazaki et al. 1994; Yoshikawa et al. 1997).

The unique feature of SIGNAL is its extensive earthquake monitoring network, probably on the largest scale in the world. The monitoring system measures the peak ground acceleration (PGA) and spectrum intensity (SI) at 331 locations in the service area by SI-sensors (Katayama et al. 1988) as shown in Figure 7. Acceleration time histories at 5 locations and porewater rises at 20 locations are also observed. Once an earthquake occurs, these values are sent to the supply control center of the headquarters by the company's radio network and are used in the decision making process for gas supply shutoff for medium-pressure trunk lines.

The early warning system consists of hypocenter estimation and damage estimation subsystems (Fig. 8). For the damage estimate, data on the service area, e.g. soil conditions and customers' buildings and pipelines, are stored on a workstation using GIS with pixels of 175×250 m. The prototype of SIGNAL was completed in 1992 and the actual system has

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Fig. 9. A bus scarcely stopped before a collapsed section of the Hanshin Expressway Route No. 3 in Nishinomiya City immediately following the 1995 Hyogoken-Nanbu Earthquake

been operating since June 1994. Information on SIGNAL and the recorded PGA and SI values from recent earthquakes are available at the homepage of Tokyo Gas (*http://www.tokyo-gas.co.jp/signal*).

Since seismic safety has high priority for city gas supply systems, other major gas companies in Japan have also recently developed earthquake monitoring and rapid damage assessment systems like SIGNAL. Installations of intelligent gas meters with a seismic sensor have also increased, and almost all the customers of major gas companies now have this kind of meter.



Fig. 10. Location of accelerometers for expressway networks in Japan

4 Early Warning Systems for Highway Networks

To secure safety for cars and trucks during and after earthquakes, early earthquake information may also be important for highways (Fig. 9). However, since we currently do not have a good way to send urgent signals or signs to individual automobiles on highways, an early warning system such as the UrEDAS introduced for high-speed railways has not been emplaced for highway systems. At the moment, early warning for highway networks consists of displayed traffic control signs or highway closure soon after the occurrence of an earthquake.

Japan Highway Public Corporation (JH) owned expressway networks with a total length of 6395 km as of April 1998. In order to gather earthquake information at an early stage and to establish efficient traffic control immediately after an earthquake, JH had deployed 123 accelerometers along its expressways (one instrument per 40 km) prior to the Hyogoken-Nanbu Earthquake on January 17, 1995. JH further deployed 202 new seismometers along its expressways (one instrument per 20 km) after the Hyogoken-Nanbu Earthquake as shown in Figure 10. The new instruments can measure the spectrum intensity (SI) and the instrumental JMA intensity (Shabestari & Yamazaki 1998) as well as the peak ground acceleration (PGA) and peak ground velocity (PGV).

Using earthquake information from these instruments, JH closes expressways if a PGA is greater than or equal to 80 cm/s^2 is recorded, or reduces the maximum speed limit if a PGA greater than or equal to 50 cm/s^2 is recorded.

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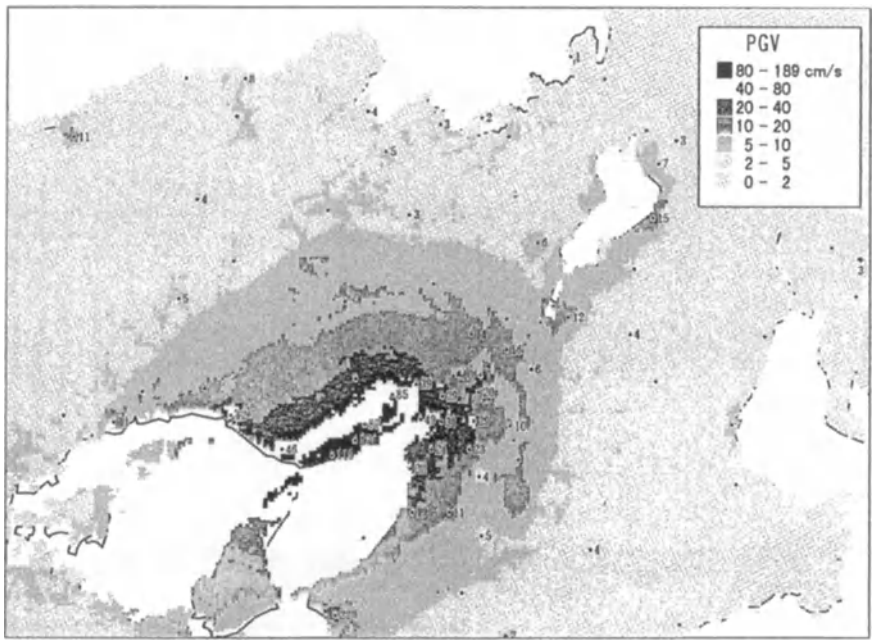


Fig. 11. Estimated distribution of peak ground velocity in the Hyogoken-Nanbu Earthquake by the Kriging technique (Yamazaki et al. 1998)

These traffic regulations remain in place until safety inspections of roadways have been completed. However, these current regulation criteria need to be examined taking into consideration the increased number of instruments, the higher sensitivity of new instruments and the recent experiences of damaging and non-damaging earthquakes in Japan.

Hence, it is important to clarify the relationship between the earthquake damage to expressway structures and the strong ground motion indices (Yamazaki et al. 1998). To do this, the damage data of the JH's expressway structures in the recent earthquakes were collected and the ground motion indices along the expressways were estimated based on observed records using a stochastic interpolation (Kriging) technique (Fig. 11). Comparing these results, fragility curves for the expressway structures (bridges and elevated structures) in Japan were constructed (Fig. 12). A similar study for bridge structures in the United States is found in Kiremidjian and Bosöz (1997). These fragility curves may be used for rapid damage estimation of highway structures as well as off-line risk assessments.

For highway traffic control immediately after an earthquake, the effect of seismic motion on driving cars should be considered as well as structural damage. Some drivers who experienced the Hyogoken-Nanbu Earthquake on expressways reported that it was almost impossible to maintain control of their cars due to strong jolts. Even though highway structures have been strengthened, traffic accidents associated with shaking might occur. Together with developing methods of information transmission to drivers on highways, future research on this topic may be necessary.

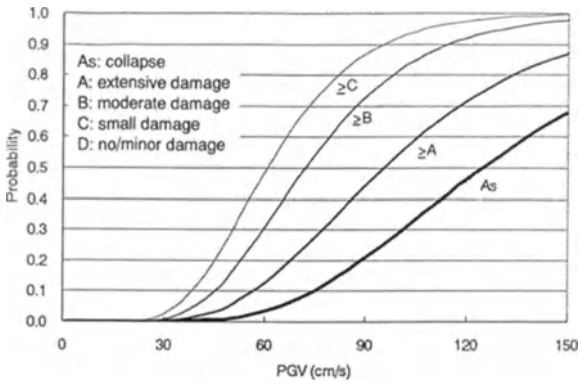


Fig. 12. Empirical fragility curves for highway bridge structures in Japan based on the damage data from the Hyogoken-Nanbu Earthquake

5 Early Warning Systems for Other Lifelines and Urban Facilities

5.1 Water Supply System

Water supply systems have often been affected by past earthquakes in the world. In these systems, buried pipes are most vulnerable to earth-

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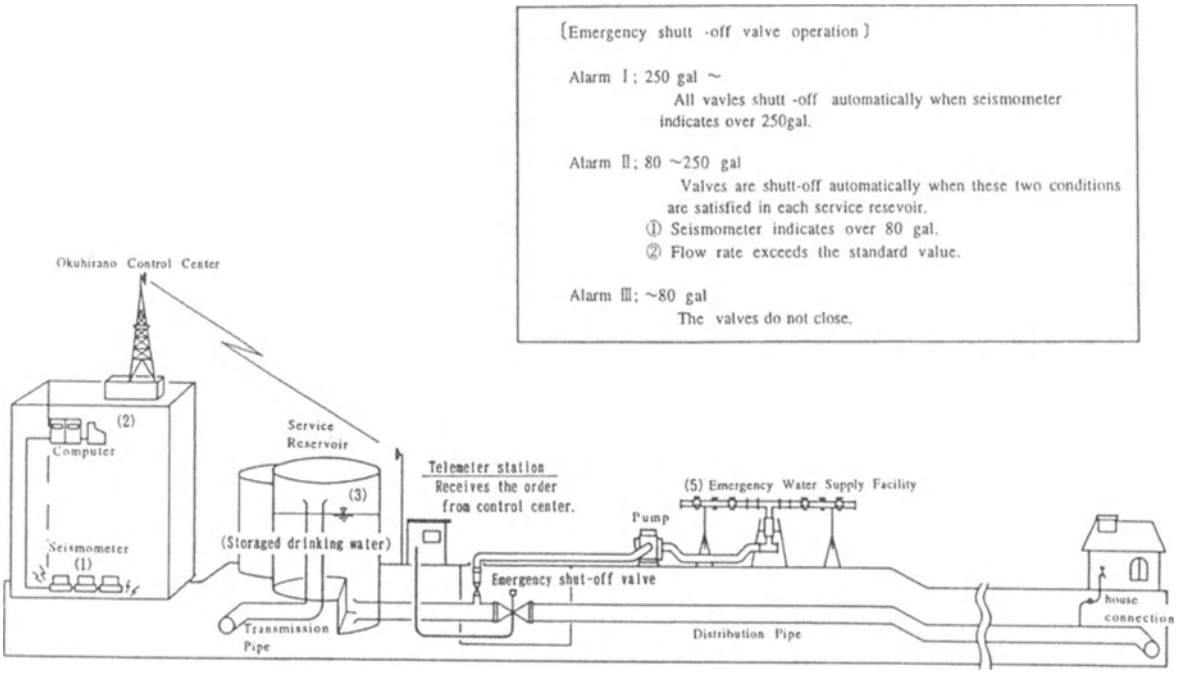


Fig. 13. Water supply system of Kobe City and automated shutoff valves (Matsushita 1995)

quakes. Although seismic damage to water supply systems can be reduced by introducing modern technologies, it requires a lot of time and money to strengthen water supply systems for earthquakes. In the 1995 Hyogoken-Nanbu Earthquake, the Water Department of Kobe City suffered from numerous breaks in distribution lines (13 785 breaks) and service pipes (50 828 breaks) and full restoration took 73 days.

One of the most important tasks for water supply systems just after earthquakes is to secure water for emergency water supply. Since pressurized water easily escapes through broken pipes, some water supply systems have emergency shutoff valves with seismic sensors at service reservoirs. The Kobe Water Department already had emergency shutoff valves at one of the twin service reservoirs at most locations (Fig. 13) when the Hyogoken-Nanbu Earthquake struck (Matsushita 1995). The emergency shutoff valves were equipped with a three-component accelerometer and a water pressure gauge. Three operation levels are set for the emergency shutoff valves: (1) shut-off automatically if the accelerometer detects ground motion greater than 250 cm/s^2; (2) shut-off automatically if the accelerometer detects ground motion greater than 80 cm/s^2 and the flow rate exceeds the standard value; (3) no valve operation if ground motion is less than 80 cm/s^2.

When the Hyogoken-Nanbu Earthquake struck, the emergency shutoff valves were activated at most locations, and hence the water could be saved in one of each of the twin reservoirs. The secured water was used for emergency water supply after the earthquake. Water in the twin reservoirs without shutoff valves ran out very quickly due to the numerous pipe breaks. The shortage of water made fire fighting activities very difficult after the earthquake.

In contrast to natural gas, water itself is not hazardous. It is also not difficult to detect the location of pipe damage by the pressure meters in a network control center and from the observation of actual water leakage. Valves on water mains should be closed to isolate damaged segments from the network if water leakage is detected. The objective of earthquake early warning for water supply systems is to take measures of saving water from pipe breaks, not to avoid secondary disasters.

5.2 Electric Power Supply Systems

Electric power supply systems have several seismic countermeasures for the period of immediately after earthquakes. Seismic instruments are usually installed equipped for turbines in power generation stations. If the instruments detect vi-

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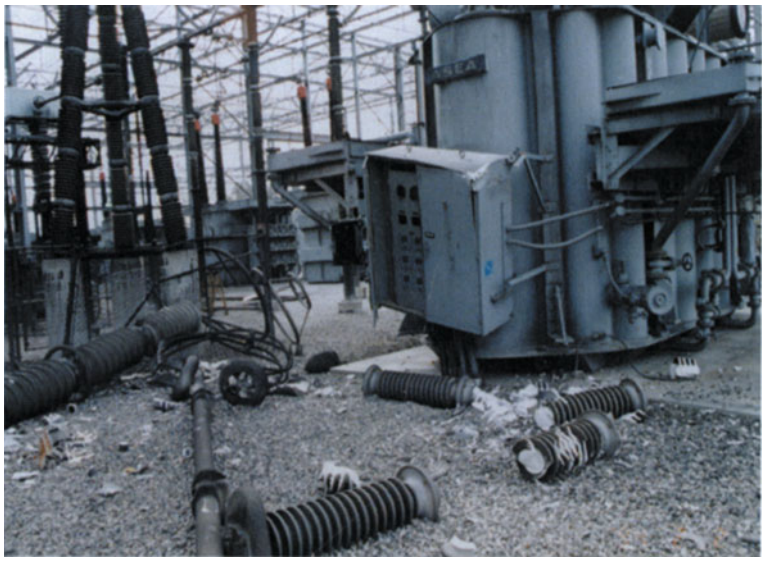


Fig. 14. Collapsed ceramic members of lighting arresters in Sylmar Converter Substation due to the 1994 Northridge Earthquake

bration exceeding a critical level, power generation is shut down to protect facilities. Seismic monitoring and safety procedures are much more extensive for nuclear power stations.

In a power supply system substations are, in general, most vulnerable to earthquakes. Ceramic parts of substation equipment experienced heavy damage in recent earthquakes in Japan (Yamazaki et al. 1995) and the United States (Fig. 14). Circuit breakers automatically disconnect power lines if abnormal currency is detected. An automated recovery system is usually equipped for substations. For a power supply system, the currency flow of the network can be monitored at its network control center. Hence the location of a problem is easily identified. For this reason, rapid damage assessment for power supply systems is not that important.

In the 1995 Hyogoken-Nanbu Earthquake, many electrical fires were reported. Learning from this lesson, home circuit breakers with seismic sensors were developed in Japan. Although such seismic breakers are still not that common, customers can install them at their own expense. Automated shutoff of power supply to avoid secondary disasters is, however, not supported by most electric power customers, because power shutoff may cause more serious trouble and make emergency response activities difficult. Emergency power supply from batteries and standby generators is common for critical facilities and equipment.

5.3 Elevators

Elevators are one of the most vulnerable parts of buildings during strong earthquake motion. In the Hyogoken-Nanbu Earthquake, 2634 (36.7%) elevators out of a total of 7177 in Kobe City were damaged (27.7%) or part of a collapsed building (9.0%). 29 people were reported trapped (0.4%) in elevators in the city. Since the earthquake occurred early in the morning (5:46 a.m.), the number of people trapped was rather small. But if it had occurred during the day, a large number of people might have been trapped.

Elevators in Japan have been attached with automated stopping systems depending on the height of the building and the type of elevator. For example, an elevator in a building lower than 45 m should automatically stop at the nearest floor if a sensor detects acceleration larger than 80 cm/s^2 in the horizontal direction. If the acceleration is less than 120 cm/s^2, the elevator can soon resume normal operation. If, however, the acceleration is equal to or greater than 120 cm/s^2, the elevator must be inspected before resuming operation. Note that seismic sensors detecting initial P-waves have been developed and have been applied to new elevators to make the decision faster.

Since the critical acceleration for stopping elevators is set at a rather low value (e.g. 120 cm/s^2), non-damaging earthquakes cause inconvenience by stopping elevators. In the Tokyo Bay Earthquake on February 2, 1992, most of the elevators in Tokyo were stopped (Fig. 15) although almost

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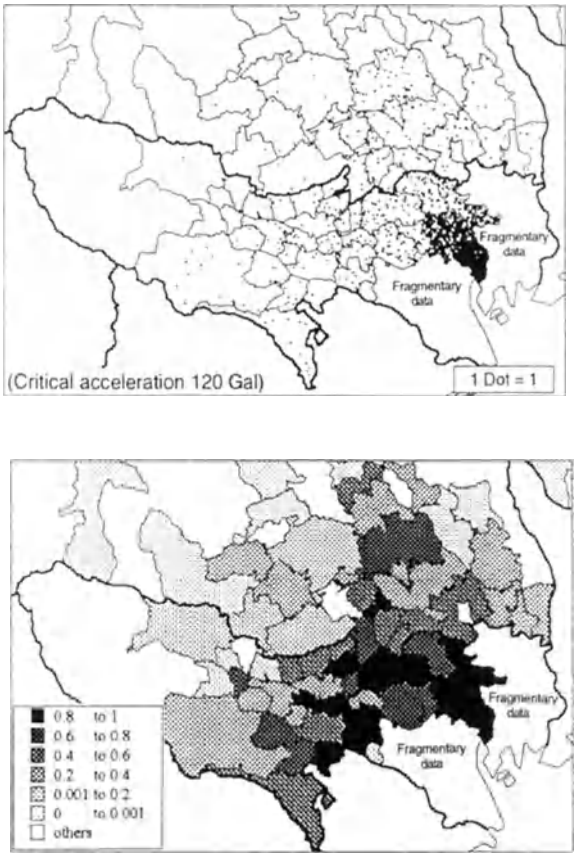


Fig. 15. Elevators stopped by the 1992 Tokyo Bay Earthquake. Almost all the elevators in midtown Tokyo were stopped due to this non-damaging event (Kato et al. 1994)

no physical damage was associated. As it was Sunday, the resulting problems were fortunately not that significant. However, it took more than one day for full recovery. Hence, it might be important to set appropriate levels of elevator control, balancing safety and inconvenience.

6 Seismometer Networks in Japan

There have been thousands of seismometers of various kinds deployed in Japan. The number of new digital accelerometers is increasing although seismometers of older types still remain. After the 1995 Kobe Earthquake, installation rate of new seismometers increased considerably. The following are some of the new seismometer networks introduced for the purpose of early warning and rapid damage assessment (Yamazaki 1996).

6.1 Seismic Network of the JMA

The JMA is in charge of earthquake information in Japan. Previously, the JMA used mostly displacement-type seismographs. Since 1987, the JMA has been deploying new JMA-87-type accelerometers in recording stations throughout Japan (Molas & Yamazaki 1995). These new accelerometers have a flat sensitivity from 0.05 to 10 Hz and can measure accelerations from 0.03 to 980 cm/s^2. The network started with 76 stations.

In 1993 and 1994, several damaging earthquakes occurred in northern Japan (Yamazaki et al. 1995). As a consequence, the number of accelerometer stations mainly for early tsunami warning, was increased to 268. After the Hyogoken-Nanbu Earthquake, in order not to miss localized heavily damaged areas, the number of stations was further increased to 574 as of April 1996 (Fig. 16). At these locations, newly developed "seismic intensity meters" are situated. Note that the new JMA intensity scale is calculated automatically based on three-component acceleration time history in a seismic intensity meter (Shabestari & Yamazaki 1998), such that it is compatible with the old JMA intensities judged subjectively by JMA officers.

Using time histories from several stations, the JMA determines the location and magnitude of an earthquake within a few minutes after it has occurred. The JMA seismic intensities at the 574 stations are also collected by

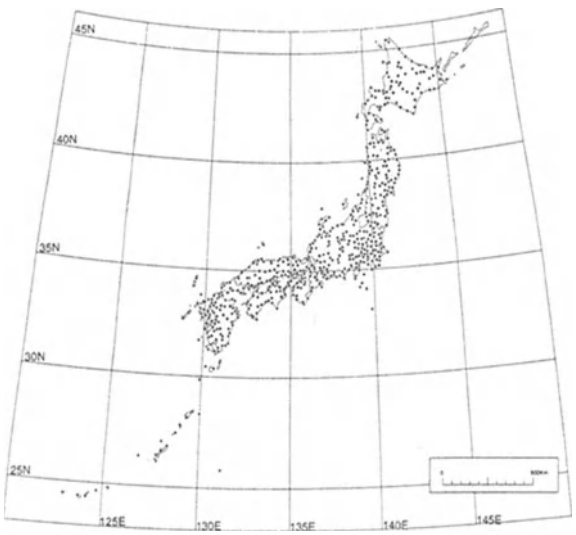


Fig. 16. Seismic intensity measurement stations of JMA as of April 1996 (574 sites in total, after Doi 1998)

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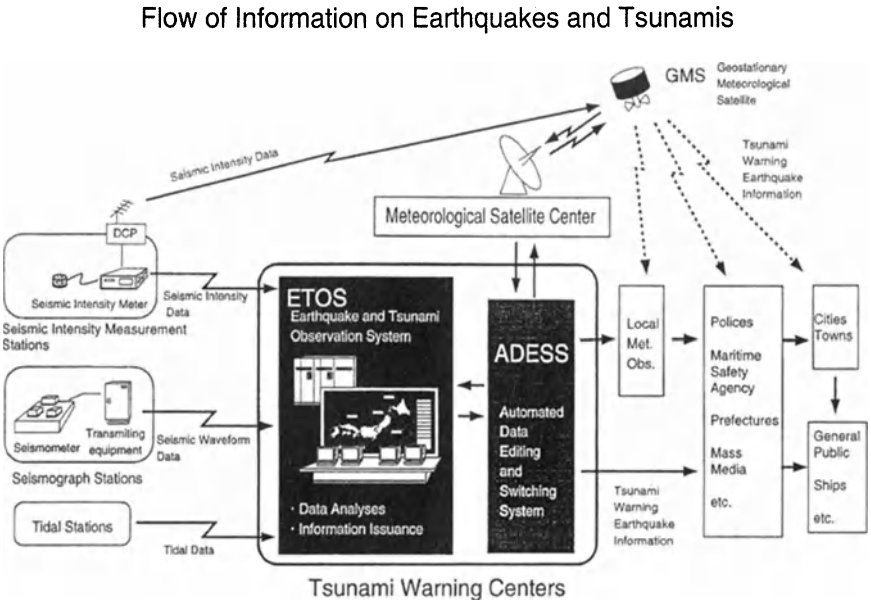


Fig. 17. Flow of information on earthquakes and tsunamis by JMA (after Doi 1998)



Fig. 18. Locations of 1000 strong motion accelerometers of K-NET deployed by the Science and Technology Agency

JMA's telecommunication system at the headquarters, and disseminated nationwide through mass media. As a telecommunication line connected to the JMA Kobe Observatory developed a fault soon after the Hyogoken-Nanbu Earthquake, the JMA recently strengthened the communication network to have a backup system via satellites (Fig. 17).

6.2 Seismic Network of the STA: K-Net

After the Hyogoken-Nanbu Earthquake, the National Research Institute for Earth Science and Disaster Prevention (NIED) of the Science and Technology Agency (STA) deployed a total of 1000 strong-motion accelerometers throughout Japan (Fig. 18). This network is named "Kyoshin Net", or "K-NET", and the average distance between stations is 25 km. Each station has a digital accelerometer having a wide

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frequency band and wide dynamic range. The maximum acceleration measured by the instrument is 2.0 G. Instruments are placed on open field. At each site, P- and S-wave velocities are measured by down hole PS-logging as well as SPT N-values.

Each instrument has two communication ports. The first one is directly connected to a modem belonging to a municipality. The municipality can use the information for emergency management. The second port is connected to the control center of NIED. After receiving prompt information from the JMA that an earthquake has occurred, the control center starts to gather records using this port. The control center compiles these records, then makes them available on the Internet. The center maintains databases of strong-motion and site information for scientific studies and engineering applications. Information about K-Net is available at the NIED homepage (*http://www.bosai.go.jp*).

6.3 Seismic Network of the Fire and Disaster Management Agency

Recently the Fire and Disaster Management Agency (FDMA) of the Japanese Government also ventured upon a project to deploy one accelerometer in each municipality (3255 in total) in Japan, excluding those municipalities having JMA's or K-NET's instruments as shown in Figure 19. When this network is completed, the distribution of strong ground motion for an earthquake can be estimated even in case of a very localized event. Once an earthquake occurs, the control center of FDMA will collect the JMA seismic intensities (calculated from records) via ISDN (Integrated Services Digital Network) of the NTT (The Nippon Telegraph and Telephone Corporation). The FDMA and the JMA also exchange their collected data via private communication lines. The FDMA uses the collected information for identifying affected areas and preparing for fire-fighting and rescue operations aided by the national government.

6.4 Other Seismic Networks of Local Governments in Japan

In addition to the three national networks in Japan, some local governments have started to or are planning to deploy seismometer networks within their territories.

Yokohama City deployed a very dense strong-motion accelerometer network with as many as 150 instruments and three control centers (Fig. 20). The system was completed on March 1997. Once an earthquake occurs, re-



Fig. 19. New seismometer network for all the municipalities in Japan deployed by Fire and Disaster Management Agency

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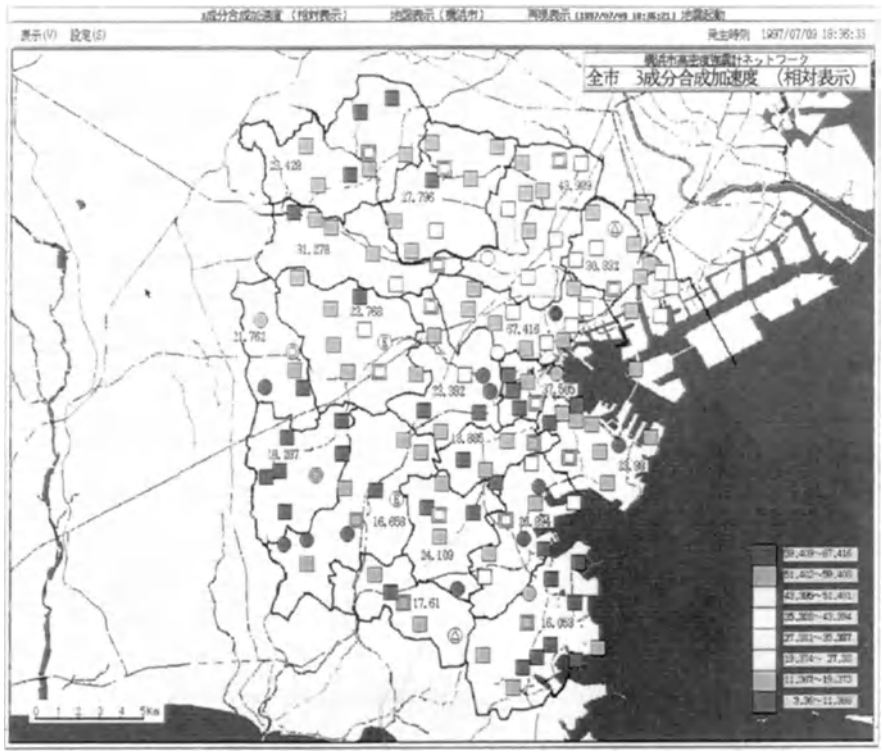


Fig. 20. Dense accelerometer network of Yokohama City with 150 instruments

corded data will be sent to the control centers via ISDN and digital private lines within three minutes. The collected data will be used for crisis management of the city. Yokohama City is now developing an early damage estimation system using the strong-motion data from the network and GIS data of the city (Midorikawa & Abe 1998).

Tokyo Metropolitan Government has also developed a strong-motion network, with about 100 instruments (Tokyo Metropolitan Government 1996). These instruments are placed at ward offices, city halls, and fire stations. Soon after an earthquake occurs, seismic intensities (calculated from records) will be gathered at the headquarters of the Metropolitan Disaster Prevention Center and at the Command and Control Center of the Tokyo Fire Department by the disaster prevention administrative radio network. The exchange of collected information with other disaster prevention agencies is also planned.

Some other large cities, such as Kyoto and Nagoya, also developed their own strong-motion observation and telemeter networks for the purpose of obtaining seismic information at an early stage.

7 Rapid Damage Assessment Systems for General Emergency Management

Earthquake information obtained at an early stage is often used for rapid damage assessment of urban areas. For the most part, local governments are in charge of development and operation of such systems. GIS-based general damage assessment systems and methodologies have been developed in Japan (Yamazaki 1996) and in the United States (Eguchi et al. 1997; Whitman et al. 1998). The following are examples from Japan.

7.1 Damage Assessment System of the Tokyo Fire Department

The Tokyo Fire Department has developed an early damage assessment system for fire fighting and rescue operations. The system is basically a computer package of damage assessment tools for scenario earthquakes. The system has a database including soil conditions, buildings, fire occurrence risk, and time-dependent population. If the magnitude and location of an earthquake are given, the system first estimates the distribution of PGA, seismic intensity and

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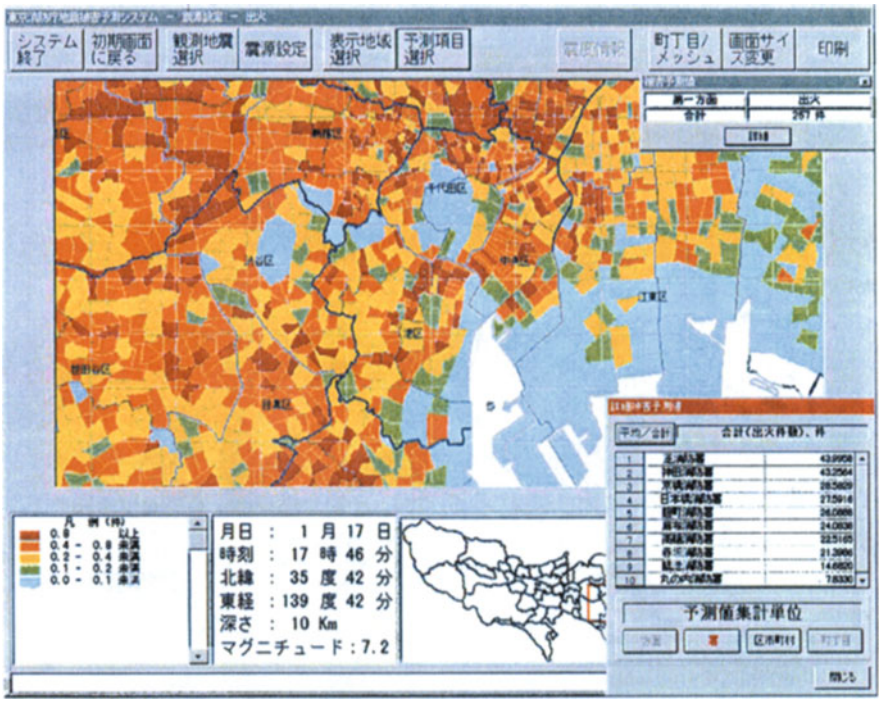


Fig. 21. Estimated number of fire breakouts after an M = 7.2 earthquake according to the damage assessment system of Tokyo Fire Department

liquefaction hazard throughout the Tokyo Metropolis in a 500 m × 500 m mesh using an attenuation relation of earthquake ground motion and soil classification. Then the number of collapsed buildings, fire breakouts (Fig. 21), and human casualties are estimated based on empirical formula for each pixel. The area that the fire might cover one hour after an event is also estimated. These results will be used to prepare for fire-fighting and search-and-rescue operations in the early stage. The first version of the system was completed in 1994. The system was upgraded recently so that the strong-motion data from the newly constructed seismometer network of Tokyo can also be used for estimates of ground motion distribution.

7.2 Damage Assessment System of Kawasaki City

As a tool for emergency management, Kawasaki City has developed a damage assessment system (Mochida 1994) for this city which has a population of about 1.2 million. The system consists of three modules: (1) estimation of the distribution of seismic intensity, (2) prediction of various hazards, structural damage and human casualties and (3) recommended management policy. This system is unique in that it not only predicts damage statistics but also serves as an emergency operation manual.

The earthquake information is collected via the city's radio system from seismometers installed at each ward office, as well as from the JMA. The damage assessment system uses GIS to predict hazards such as tsunamis, liquefaction and landslides, damage to buildings, roads (Fig. 22), bridges, river embankments and lifeline systems (power, water, gas, telephone), and human casualties. A 500 m × 500 m square mesh, which is commonly used for damage assessment in Japan, is employed in the system. The system was installed at the Disaster Prevention Center in the city hall, and a terminal system was installed at each of the seven ward offices. Test operation of the system started in April 1994. The system will be revised soon to incorporate a detailed GIS of the city.

7.3 Damage Assessment System of the National Land Agency, Japan

After the Hyogoken-Nanbu Earthquake, there was a boom in early damage assessment system development both by public and private organizations in Japan. As a typical example, the National Land Agency, which is in charge of disaster management for the Japanese government, developed the first version of an early damage assessment system (Fig. 23) which began operation on April 1996. Using the intensity and source information from the JMA and

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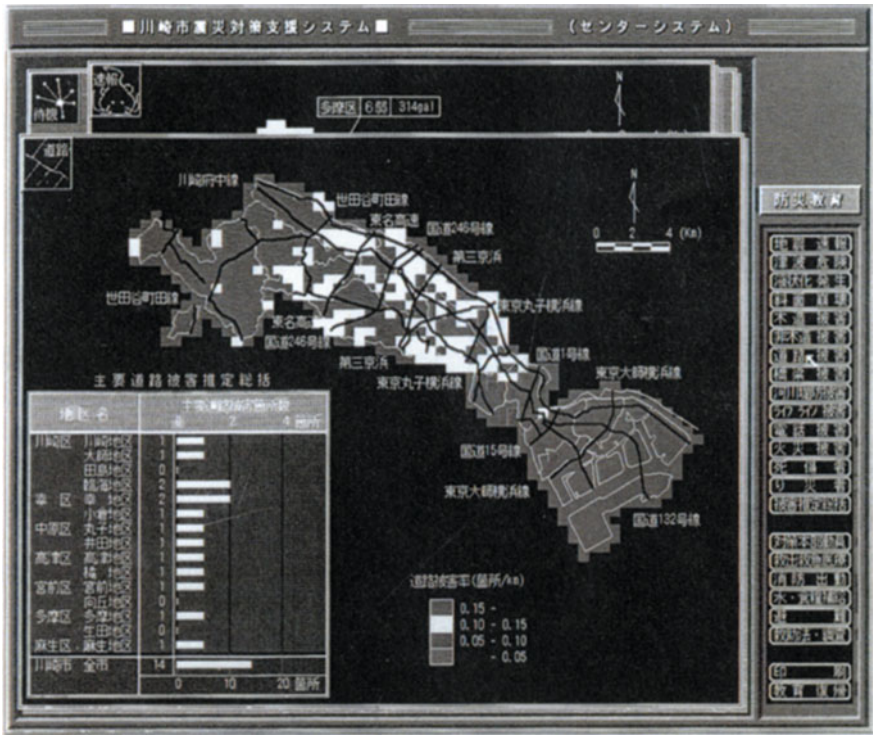


Fig. 22. Estimated road damage ratio determined by the damage assessment system of Kawasaki City

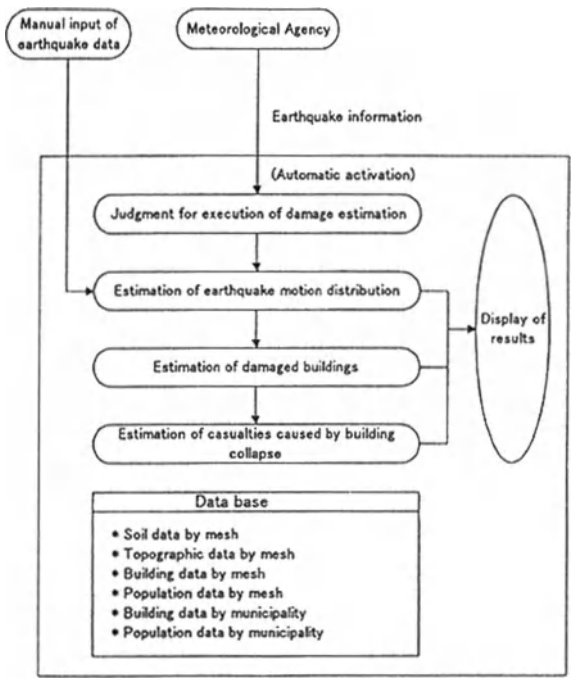


Fig. 23. Flow of the early damage assessment system of the National Land Agency (after Okayama 1998)

the GIS data for entire Japan in 1 km×1 km square mesh extracted from the Digital National Land Information, this system estimates the seismic intensity, the number of collapsed wooden houses, and the number of deaths due to collapse of houses in each pixel. Distribution of tsunami height and flooded area is also estimated by this system. In the case of devastating disasters like the Hyogoken-Nanbu Earthquake, there is a delay in the flow of damage information to the government. Hence, damage estimates made by the new system can be effectively used in the early stage of crisis management by the Japanese government. The National Land Agency is now developing a more integrated emergency management system called the Disaster Information System (DIS). The damage assessment system discussed above will be a part of this integrated system.

8 New Roles and Developments of Early Warning Systems

The concept of early warning prior to the arrival of seismic waves was first realized by UrEDAS for high-speed trains. As yet, however, no other practical tool exists for other transportation and lifeline systems or for ordinary citizens. The JMA recently started a project named "Nowcast" including the research and development of real-time issues of earthquake information (Fig. 24). The idea of issuing a fast alarm is similar to the UrEDAS concept, i.e. utilizing the difference in P- and S-wave velocities and

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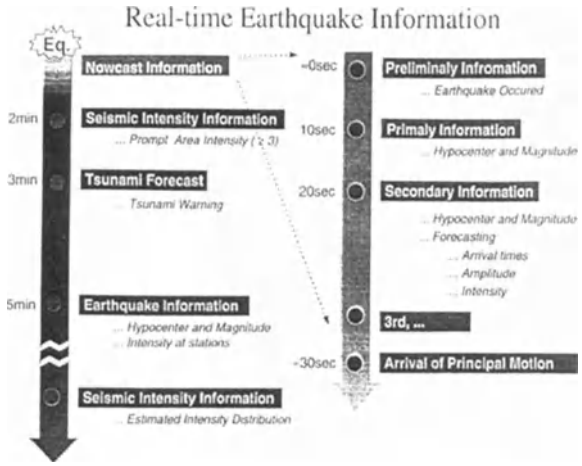


Fig. 24. Schematic figure of real-time earthquake information planned by JMA (after Doi 1998)

the source-to-site distance. If you have instruments and a telecommunication network, it is technically not that difficult to install such a system. But there are several issues to clarify before actual installation: (1) what can you conceivably do if you have a few seconds warning prior to the arrival of seismic motion; (2) what kind of problems may follow if an alarm is false or not accurate; (3) how can an alarm be transmitted to the general public, e.g. car drivers on expressways etc.

Earthquake early warning systems show promise for the mitigation of damage and casualties in critical urban facilities. Since it is very difficult for men to make a quick decision within a few seconds based on little information, it is desirable to make seismic reaction systems as automated as possible. Intelligent gas meters and seismic sensors for elevators are examples of such automated systems.

Japan also has experience in rapid earthquake damage assessment systems. SIGNAL of Tokyo Gas, which represents the largest scale strong motion monitoring system, began operation in 1994. Kawasaki City and the Tokyo Fire Department also developed early damage assessment systems almost at the same time. The Hyogoken-Nanbu Earthquake triggert much new development of strong motion monitoring networks and early damage assessment systems in Japan.

Although the number of instruments in Japan may be by far the largest in the world, problems still remain to be solved. The first issue regards information sharing. As the pioneering systems were created by private sectors or local governments, the systems and associated earthquake information have often been developed to be used only within a single organization. To establish an information sharing system for all the disaster prevention agencies and companies may be very important. Considering mutual aid in the case of a disaster, the coordination between neighboring cities and prefectures is also very important. Establishing communication measures is necessary in order to realize such coordination. New communication tools such as ISDN, satellite communication and the Internet may prove promising for this purpose. In order to avoid a lack of information just after an earthquake, early damage assessment systems with intensive earthquake monitoring are expected to play a vital role in disaster management.

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CHAPTER 7.3

A New Concept for the Earthquake Vulnerability Estimation and its Application to the Early Warning System

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Abstract

It has been widely recognized that systematic and continuous monitoring of earthquakes is necessary for early warning. On the other hand, investigation of the durability of surface ground and structures should always have priority, when estimating the damage caused by destructive earthquakes. To estimate the vulnerability of both surface ground and structures, Nakamura (1997) proposed an effective approach called the K-value method. In this method, the deformation characteristics are approximated based on the amplification and the natural frequency information determined from microtremor measurements. These K-values, together with the acceleration are then used to calculate the strain of the ground and structures. Nakamura (1997) verified this approach for several real earthquake cases by comparing estimated and actual damage. It was proven that it is possible to effectively estimate actual damage by combining continuously monitored earthquake motion with investigated characteristics of ground and structures. This paper addresses the formulation of the K_d value (K-value for the derailment of trains), proposing the new characteristic parameters PI (P-wave Index) and DI (Damage Intensity) proposing to help define the destructiveness of the earthquake and effectively realize the P-wave alarm system. During an earthquake, as soon as P-waves arrive, the DI function can be calculated in real time. This new characteristic DI-value (DI_v) has a clear physical meaning and agrees very well with the instrumental seismic intensity of the Japan Meteorological Agency (I_{JMA}). The relation between DI_v and I_{JMA} can be approximately given as $I_{JMA} = DI_v - 0.6$. This enables one to estimate the instrumental seismic intensity from DI_v. Using this approach, it has been proved that, as with K-values, PI- and DI_v-values can be used for early warning studies. In addition, actual damage can be accurately estimated and effective response can be decided on quickly.

1 Introduction

One of the fundamental problems of earthquake disaster prevention is to increase the durability of ground and structures beyond the presumed seismic force. Even if enough durability exists initially, it may decrease with time due to deterioration under a presumed seismic force. To be able to precisely estimate durability "at the present time" is therefore fundamental for disaster prevention.

The occurrence of earthquake damage depends on strength, period and duration of seismic motion. These parameters, of course, de-

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pend on the earthquake itself, but they are also strongly influenced by the seismic response characteristics of surface ground and structures. Points damaged by earthquake motion are weak points revealed by earthquake. These weak points can be investigated in advance by understanding the seismic characteristics of surface ground and structures, and using this information to reinforce the structures before being hit by an earthquake. Furthermore, if seismic characteristics of ground and structures are already known, seismic intensity distribution of an earthquake area can be precisely estimated.

To estimate the vulnerability of both surface ground and structures, the K-value method was proposed by Nakamura (1997). This methodology is briefly summarized in the present study. K-values are simply calculated based on the amplification and predominant frequency characteristics of the ground obtained by microtremor measurements. The strain of the ground and structures are then calculated based on this value, together with the acceleration. Starting from the formulation of K-value, the new parameters PI (P-wave Index) and DI (Damage Intensity) are proposed in this study to define the destructiveness of earthquakes and to realize the P-wave alarm system. As soon as the P-wave arrives at the observation station, PI is calculated from the P-wave initial motion. DI (DI_v) is calculated after the arrival of the S-wave. Calculated DI_v agrees very well with the instrumental seismic intensities of the Japan Meteorological Agency (I_{JMA}). Comparison of calculated DI_v with I_{JMA} for different cases shows that the relationship between DI_v and I_{JMA} is approximately $I_{JMA} = DI_v - 0.6$. In contrast to I_{JMA}, DI_v has the advantage of having a clear physical meaning. The formulation for the calculation of DI and examples for the data recorded by K-Net are given in the following sections.

As with K-values, PI- and DI_v-values can also be used for early warning studies by helping to define the actual damage and by making rapid decisions on effective responses.

2 Estimation of Seismic Characteristics and Vulnerability Indices of Ground and Structures (K-values)

The seismic characteristics of surface ground can be directly correlated with earthquake damage. In contrast to the difficult process of borehole production, these characteristics can be simply understood by precise measurements, and an estimation of earthquake damage can be made. For this purpose, the spectral ratio of the horizontal to vertical component (QTS: Quasi-Transfer Spectrum, or H/V ratio) of microtremors measured simultaneously on structures and their foundation ground was introduced by Nakamura (1989). QTS of microtremors on structures are approximated by combining characteristics of both the ground and structures. The formulation of vulnerability indices (K-values) from Nakamura (1997) is briefly given in following section. The results of microtremor measurements at 100 m intervals along railway lines are shown as an example. All examples suggest good agreement between QTS and geological and topographic structures.

At the time of an earthquake, vulnerability indices (K-values) derived from the strain of ground and structure were proposed by Nakamura (1997) as follows:

2.1 For Ground

● represents the shear strain of surface ground. Table 1 shows the relationship of ● to ground destruction as compiled by Ishihara (1978). The Table indicates that from ● $\cong 1000\times10^{-6}$, ground begins to show non-linear characteristics and at ● $>10000\times10^{-6}$ large deformation and collapse occur.

By simplifying the shear strain deformation of surface ground as shown in Fig. 1, average shear strain (●) of surface ground can be estimated by the following formula:

$$\gamma = A_g \cdot \frac{d}{H} \tag{1}$$

where, A_g is the amplification factor, H is thickness of the surface layer, and d is seismic displacement of the basement ground. Putting S-wave velocities of basement and surface ground as V_b and V_s respectively, proper dominant fre-

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Table 1. Strain Dependence of Dynamic Soil Properties

Size of Strain•	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}
Phenomena	Wave, Vibration	Crack, Diff Settlement			Landslide, Soil Compaction, Liquefaction	
Dynamic Properties	Elasticity		Elasto-Plasticity	Repeat-Effect, Speed-Effect of Loading		

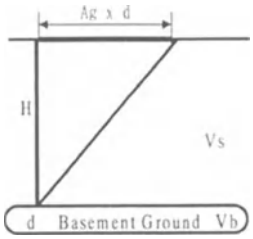


Fig. 1. Surface ground deformation

quency of surface ground (F_g) is approximately expressed as:

$$F_g = \frac{V_b}{4A_g \cdot H} \tag{2}$$

Acceleration of basement ground a_b is expressed as;

$$a_b = (2\pi F_g)^2 \cdot d$$

and γ is expressed by F_g, A_g and V_b as follows:

$$\gamma = \frac{A_g \cdot a_b}{(2\pi F_g)^2} \cdot 4A_g \cdot \frac{F_g}{V_b} = \frac{A_g^2}{F_g} \cdot \frac{a_b}{\pi^2 V_b} \tag{3}$$

If the efficiency of applied dynamic force is assumed to be e % of static force, effective γ_e is:

$$\gamma_e = K_g(e) \cdot a_b \tag{4}$$

$$K_g(e) = e \cdot \frac{A_g^2}{F_g} \cdot \frac{100}{\pi^2 \cdot V_b} \tag{5}$$

The value of V_b is expected to be nearly constant over a broad area. Thus, K_g, which is expected to be useful in detecting the weak points of the ground, can be considered as an index to ease of deformation at measurement points.

Assuming $V_b = 600$ m/s, we obtain $1/(\pi^2 v_b) = 1.69 \times 10^{-6}$ (s/cm). If e is taken as e=60%, then $K_g(e) \cong A_g^2/F_g$ and the effective strain can be estimated by multiplying $K_g(e)$ by the maximum basement ground acceleration in Gal (= cm/s^2).

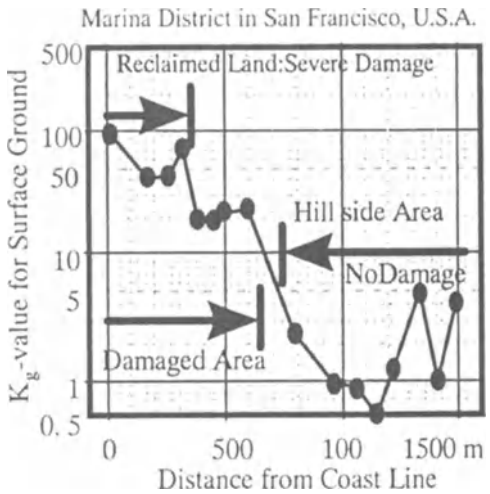


Fig. 2. K_g-Values derived from QTS of microtremor in S.F.

Figure 2 indicates K_g-values obtained in the San Francisco Bay area after the 1989 Loma-Prieta Earthquake. The results along a line from the sea coast to the Marina district is shown. For the sites with high deformation characteristics, K_g is greater than 20. For non-damaged areas, K_g is less than 5. Based on observations, maximum basement acceleration is estimated at 50 Gals around the area. From the difference in characteristics of the data in Fig. 2, the K_g-value can be taken as Kg=20, and $\gamma = 1000 \times 10^{-6}$ according to equation 4. This value separates liquefied and non-liquefied areas.

2.2 For Derailment/Overturn of Trains

To study derailment/overturn of trains, the work done by earthquake motion per unit time (work rate) is considered. Work rate (w) is proportional to the product of response acceleration $A \times a_b$ and response velocity $A \times v_b$. As $v_b = a_b/2\pi F$.

$$w = m \cdot A \cdot a_b \cdot A \cdot v_b = \frac{m}{2\pi} \cdot \frac{A^2}{F} \cdot a_b^2$$

$$= \frac{m}{2\pi} \cdot K_d \cdot a_b^2 \tag{6}$$

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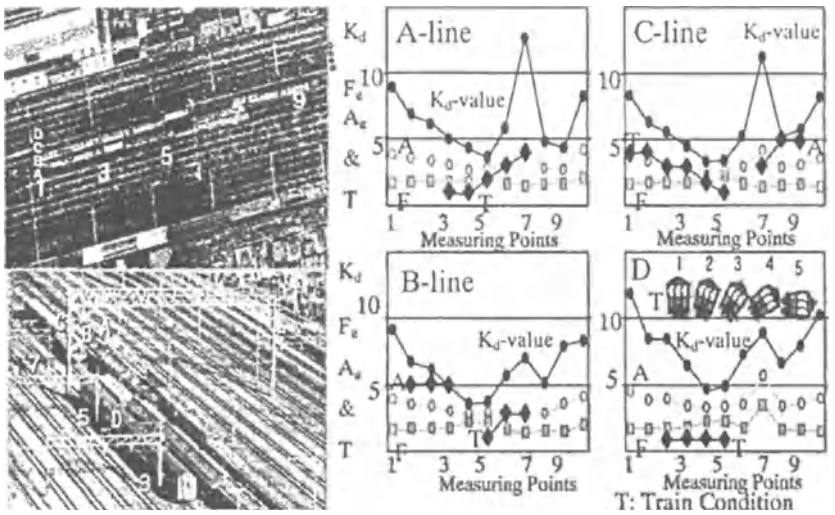


Fig. 3. Relationship between vulnerability indices obtained by microtremors and derailment/overturn of trains in JR-Takatori Yard

$$K_d = \frac{A^2}{F} \tag{7}$$

where m is the mass of the object undergoing seismic acceleration. It may be possible to adopt K_d-values not only for train derailment/overturn but also to structure damage or jumping stones due to strong motion. The dominant frequency (F) and amplification factor (A) are directly related to the seismic motion applied to the train body. The dynamic characteristics of the trains are known in general. F and A can be estimated from F_g and A_g for a train resting on the ground surface. For a train resting on a structure, these values are termed as F_{sg} and A_{sg} for both structures and ground. Site characteristics are reflected by the K_d-value. In the case of a large K_d-value, work rate (w) and the possibility of derailment/overturn are also large. The K_d-value is therefore considered as an index of vulnerability of trains to derailment/overturn.

Figure 3 shows derailment/overturn of parked trains in the JR-Takatori yard after the 1995 Hyogo-Ken-Nanbu Earthquake. Severe derailments occur where K_d-values are highest. Figure 4 indicates derailments of moving trains at the time of the 1995 Hyogo-Ken-Nanbu Earthquake. K_d-values are shown for every 20 m near the derailment sites. It shows that the derailment of trains closely depends on the K_d-values of the sites where trains were moving.

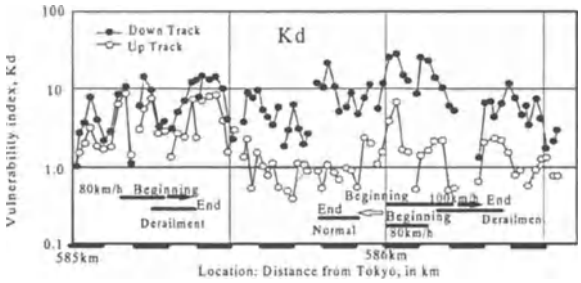


Fig. 4. Relationship between K_d distribution and actual situation of trains along railway

3 Monitoring of Seismic Motion Using a New Characteristic Damage Intensity (DI) Function

3.1 A Proposal for a DI Value to Indicate Seismic Intensity and Earthquake Damage

K-values for a train derailment/overturning (K_d) were defined in equation (7). As previously mentioned, this formula is directly related to the power of earthquake motion. It has also been clearly shown that there is a strong relation between K value and damage. Starting from equation (7), DI function is also considered to be a product of acceleration and velocity, and is also directly related to damage. The relationship between DI and acceleration and velocity can be written simply as:

$$DI = \log |a \cdot v| \tag{8}$$

where a is acceleration (in Gal = cm/sec^2) and v is velocity (in mkine = 1/1000 cm/s). In practice, DI is calculated as the sum of products of

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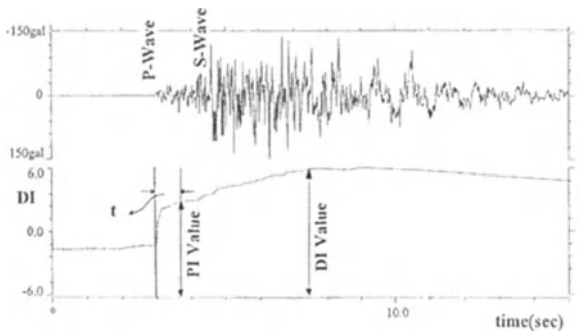


Fig. 5. Change of DI as a function of time

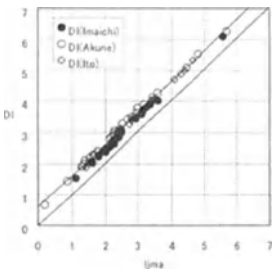


Fig. 6. Relationship between DI and I_{JMA}

acceleration and velocity for three components. DI_v is defined as a maximum value of the DI function after the S-wave arrival.

A dominant circular frequency of earthquake motion ($\omega = 2\pi/T$) can be obtained from the ratio of a/v, and a period T can be expressed as $T = 2\pi \cdot v/a$. Therefore, $v = aT/2\pi$. Substituting this into equation (8):

$$DI = \log\left(\frac{a^2 \cdot T}{2\pi}\right) = 2\log a + \log T - \log(2\pi) \tag{9}$$

Figure 5 shows the change of DI as a function of time. When the P-wave arrives, DI increases drastically. PI-value is defined as the maximum DI-value within about t seconds of P-wave detection. It is suggested that this value be used for the P-wave alarm. In this study, the preset time t is taken to be 1 second. The value of t can be increased to a maximum of PS time. After this, DI continues to increase slowly until the S wave arrival. After the arrival of S wave, it reaches its maximum level (DI_v). This value can be related to I_{JMA} and can be used to estimated damage.

The formulation for DI, equation (9), is similar to that for the instrumental seismic intensity of Japan Meteorological Agency I_{JMA}:

$$I_{JMA} = 2\log a_0 + 0.94 \tag{10}$$

where a_0 is the acceleration (in cm/sec^2) filtered with a band pass filter from 0.5–10 Hz, and tapered with $f^{-1/2}$. a_0 corresponds to a time accumulated distribution of amplitude of seismic motion at 0.3 sec (Sekita 1996). I_{JMA} is considered the same as the intensity estimated based on human sensory response, and it is statistically related to earthquake damage. It has, however, disadvantages in its application, as it can only be calculated after termination of the earthquake and its physical meaning is not clarified because of the complicated procedure explained above.

Figure 6 shows an example of the comparison of calculated DI_v with I_{JMA}. It illustrates the case of many earthquakes that have been observed at three different stations of the K-Net service in Japan. Both values completely corresponded to each other, with a shift in constant value, which varies between 0.5 and 0.7 for different stations. This difference is mainly due to the different source and site characteristics between the stations. By taking the average of this constant it has been found that DI_v is about 0.6 larger than I_{JMA}.

As previously mentioned, I_{JMA} can be determined only after termination of the earthquake. DI_v, on the other hand, has a very important practical advantage, as it can be calculated in real-time soon after the P-wave arrives. Additionally, in contrast to I_{JMA}, DI_v has a clear physical meaning, and as with the K-value, DI_v is strongly related to earthquake damage. Since, the relation between DI and I_{JMA} has been clarified, the relation between DI_v and damage is also guaranteed. Therefore, with the continuous observation of the DI function, earthquake alarms can be efficiently issued, and damage can be precisely estimated.

3.2 Why is it Better to Issue an Alarm Based on PI and DI Rather Than Based on Maximum Acceleration?

Seismic acceleration includes a high frequency vibration. This vibration masks the part of the record which is related to damage, and makes the relation between maximum acceleration and damage unclear. Because of this problem, alarm seismometers of Japan Railways (JR) were set

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up to cut the high frequency motion by more than 5 Hz. Even these measures are not enough to clarify the relation between maximum acceleration and damage. Despite being aware of this problem, conventional alarm systems still issue alarms using this relation, and therefore issue more than 90% unnecessary alarms. In the present study, instead of using maximum acceleration, the new PI and DI_v, which have a strong relation with damage, are used for issuing of alarms. A precise and quick damage estimation is possible based on this approach, as explained in a previous section. In this case maximum acceleration is given as the maximum value of the vectorial sum of two horizontal components filtered at 5 Hz. The alarm can be issued soon after the P-wave detection by using the value of PI. This is much earlier than an alarm issued based on maximum acceleration. If P-wave detection is not possible, then the alarm can be issued after the S-wave detection using DI_v. This is same as issuing an alarm based on maximum acceleration value. Whatever the case, if an alarm is necessary, it is guaranteed.

3.3 Setting the PI Level for the P-wave Alarm

The setting procedure for the P-wave alarm is described in Figure 7. This figure shows the relation between PI, DI_v and maximum acceleration. The horizontal axis is related to the detected S-wave; C represents the maximum acceleration or DI_v on this axis. The vertical axis represents the detected P-wave, and PI is the value calculated after P-wave detection as described in Figure 5. According to the distribution of the data, the upper limit of DI_v is named DIU, and the upper and lower limit of PI are named PIU and PIL, respectively. PIT is the trigger level for the detected P waves. Depending on the wrong alarm tolerance, this level can be shifted to PI1 or PI2. For high tolerance, the value can be set as PI1 and for low tolerance the setting value is PI2. CT is a trigger level for conventional alarm systems. $CT^{\bullet}$ is selected as the minimum trigger level for detecting destructive earthquakes. The CT level is lower than $CT^{\bullet}$, in order to be able to issue an alarm earlier. As mentioned above, an alarm is needed only for earthquakes above the $CT^{\bullet}$ level. Without considering PIT, setting the trigger level at CT (for issuing the alarm earlier) the

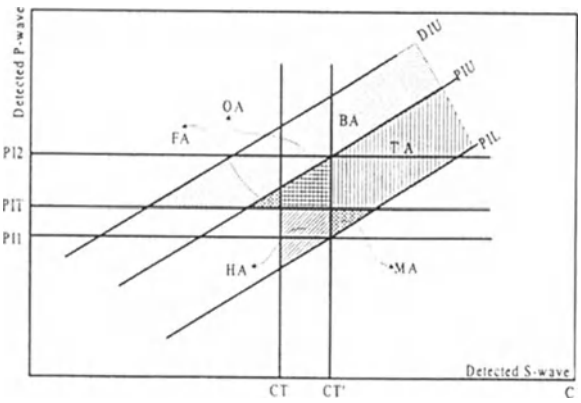


Fig. 7. Relation between PI, DI and maximum acceleration

total area of HA + OA becomes an "over-alarmed" area, comparing with the $CT^{\bullet}$ level. Taking into consideration PIT as well, the number of over alarms becomes OA + FA, and depending on the PIT value, some missing alarm may appear in the area of MA. To reduce the number of earthquakes in MA area, the PIT level can be set to a smaller value. The area of TA represents the number of earthquakes for which alarms will be issued for both these cases. Setting the trigger level at $CT^{\bullet}$, the issued alarm will be equal to TA + MA. Taking into consideration PIT as well, the alarm distribution will be TA, MA and OA + FA in which MA represents missing, and OA + FA represents over alarm. As explained above, this is equal to issuing an alarm based on S wave detection, but in the latter case the ability exists to issue an alarm earlier.

Detection of the P-wave is extremely important for making the system work properly. If the system fails for detecting P waves, then the number of the alarm may increase as the area of BA. The relation between the number of alarm issued and trigger level can be summarized as in equation (11),

$$\left.\begin{aligned} CT_{Alarm} &= TA + OA + HA + MA \\ PIT_{Alarm} &= TA + OA + FA \\ (PIT + CT')_{Alarm} &= OA + MA + FA + TA \\ CT_{Alarm} - PIT_{Alarm} &= Ha + MA - FA \\ CT_{Alarm} - (PIT + CT')_{Alarm} &= HA - FA \\ CT'_{Alarm} &= TA + MA \end{aligned}\right\} \quad (11)$$

If $(CT_{Alarm} - PIT_{Alarm})$ is greater than 0, and also if (HA - FA) is greater than 0, this means the number of alarms is lower than that issued

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by conventional alarm systems. FA and HA show increased and decreased number of alarms, respectively. For Japan Railways, the CT and CT$^{\bullet}$ levels for the alarm system are set to 40 and 80 Gals, respectively.

4 Application of the Method to Real Earthquake Records

Application of this method was made to the K-Net data recorded at Imaichi, Ito and Akune stations from 1996 to 1997. These stations were selected as example, as they include records with I_{JMA} up to VI. Distribution of the alarms with maximum acceleration set at 40 Gals and 80 Gals are shown in Figure 8. PIT values vary between 2–2.5 in the present study. As can be seen in the figure, the number of alarms issued where CT > 40 Gals is 16. For CT$^{\bullet}$ > 80 Gals together with PIT > 2.5 the number of alarms issued is 11, with the advantage of having earlier alarms and without having any missing alarm. It can be seen from these results that issuing PI together with the maximum acceleration CT$^{\bullet}$ results in a reduction of about 30% in the number of issued alarms.

In addition to this, if the areas are grouped based on the K-value method, then it is also possible to decide on other alarms needed in areas close to the observation point.

5 Concluding Remarks

The methodology whereby microtremor measurements of ground and structures are used to estimate vulnerability indices (K-values) is summarized. New characteristic parameters named PI (P-wave Index) and DI (Damage Intensity) are then proposed to define the destructiveness of the earthquake and effectively realize the P-wave alarm. The formulation and its relation to I_{JMA} is also introduced. It has been clearly shown that by using the P-wave alarm (PI-value) together with the maximum acceleration value (as CT ●), the number of alarms decreased by about 30%. Compared with I_{JMA}, it has been proven that the new DI value has the following advantages:

1. Its physical meaning is clear and it is easy to grasp its relation to another values;
2. Changes in DI function can be measured in real-time;
3. By correlating it with damage, an alarm can be issued immediately after the P-wave arrival.

Combining PI-, DI- and K-values shows promise for future early warning systems, since it has been clarified by both methods that it is possible to estimate the vulnerabilities of all ground and structures concerned and it is possible to issue an alarm before the real damage occurs.

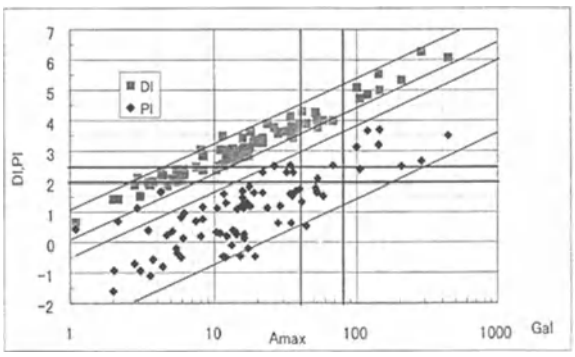


Fig. 8. Application of the method to the K-Net data

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Real-Time City Gas Network Damage Estimation System: SIGNAL

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Abstract

SIGNAL's main functions include the rapid monitoring, using a reliable radio network, of: SI and seismic acceleration at 331 locations, acceleration waves at 5 locations, and rising ground water levels at 20 locations considered most at risk from ground liquefaction. This real-time earthquake data is linked to GIS data bases of gas pipelines and ground conditions, to give an accurate damage estimation based on records of pipe damage suffered in previous earthquakes. The estimation of damage to the gas network is useful for the rapid implementation of emergency work, and in drawing up efficient and accurate restoration plans.

1 Introduction

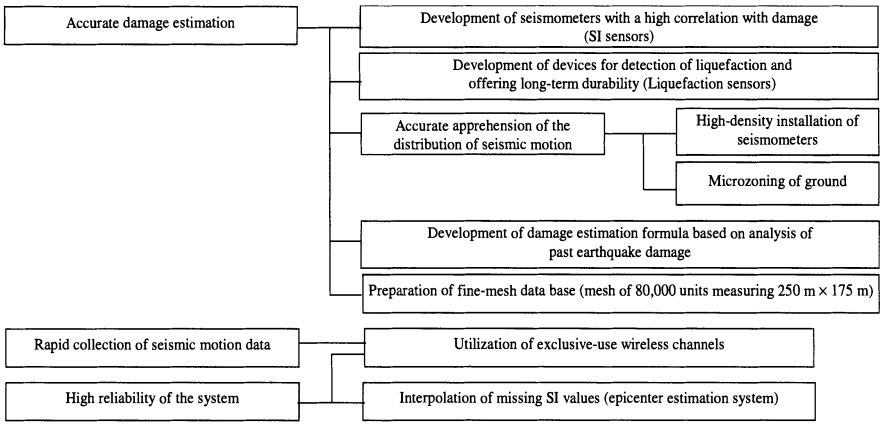
It is part of the social obligation of gas distributors to ensure safety, even in the event of a major earthquake. The sure prevention of secondary gas-related damage in the event of an earthquake requires the firm assessment of the extent of damage to pipeline networks in each area immediately after the earthquake, and the prompt shut-off of gas supplies in areas of serious damage. At the same time, in areas that have incurred little or no damage, gas supply services must be continued to support urban life. However, factors such as the severance and tying-up of telephone lines and roads make it extremely difficult to collect information on damage to gas facilities in the wake of a major earthquake. In the Great Hanshin Earthquake, for example, it was difficult to collect such information, and the shut-off of gas supplies to heavily damaged areas was only completed about 15 hours after the earthquake had occurred (Gas Earthquake Countermeasures Study Group Report, 1996). This situation underscored the need for a system capable of high-density measurement of seismic motion and high-accuracy estimation of the extent of damage in each area, to get a handle on the overall damage immediately after a major earthquake, without having to wait for first-hand collection of information. This kind of perspective motivated the development of the real-time city gas network damage estimation system "the Seismic Information Gathering & Network Alert System (SIGNAL)" in 1986. In June 1994, SIGNAL became the first system of its kind in the world to reach the level of practical utilization, and it is now in operation.

2 Development Targets

Under the prevailing guidelines, decisions on the implementation of emergency measures in the event of a major earthquake are to be made no later than one hour after the earthquake. SIGNAL was designed to provide information necessary for appropriate decision-making no

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Fig. 1. Development Target



later than 10 minutes after an earthquake. To this end, the development targets outlined in Figure 1 were set.

3 System Outline

3.1 SI Sensors

This section profiles the SI sensor (Katayama et al. 1988), which is a core SIGNAL seismic sensor. The impact exerted by seismic motion on structures depends on the degree of power of this motion to shake these structures. One indication of this power is the velocity response

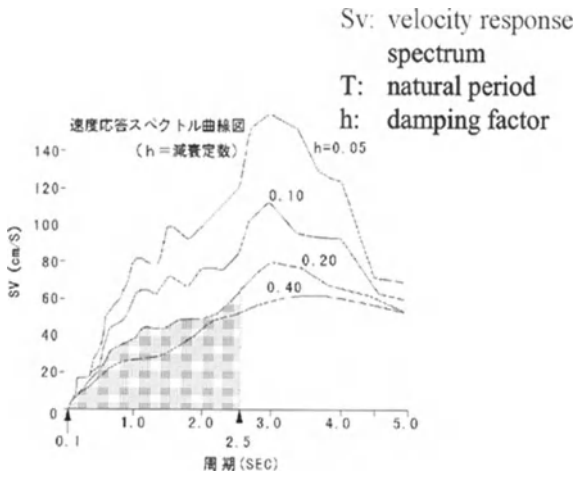
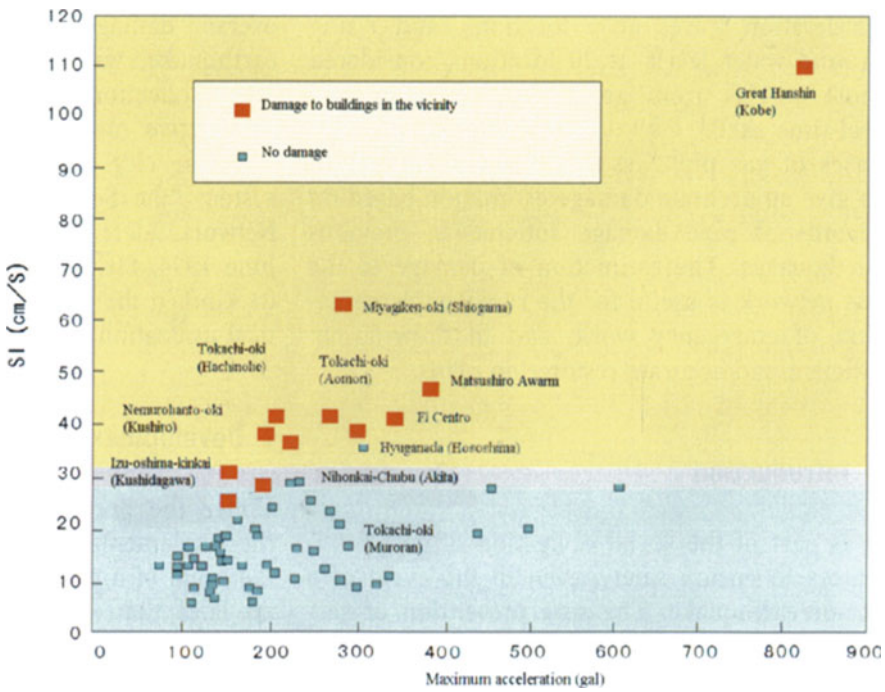


Fig. 2. Definition of SI value

Fig. 3. Relationship between earthquake damage, maximum acceleration, and the SI value



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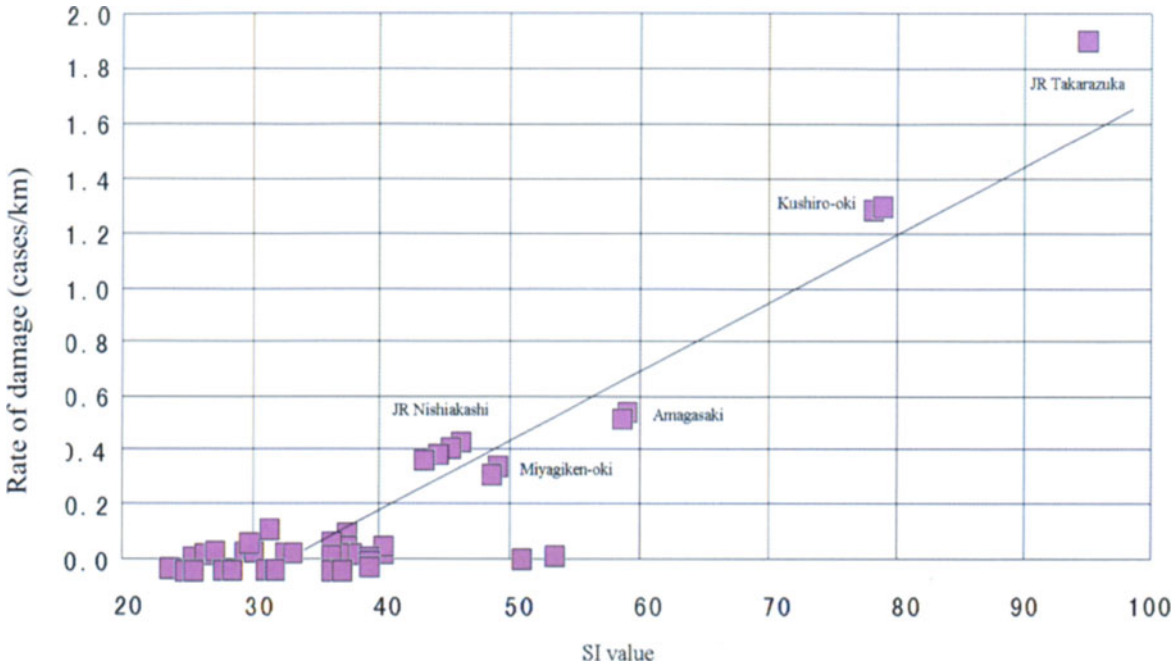


Fig. 4. Correlation between SI values and rate of damage to screwed joints

spectrum. In this respect, almost all structures exhibit a natural period in the range of 0.1–2.5 seconds. Prof. G. W. Housner defined the spectrum intensity (SI), i.e. is the mean value in this range, as an indicator of the intensity of seismic motion (see Fig. 2).

As shown in Figure 3, a fairly strong correlation between this SI value and the damage of houses appears in historical data for seismic motion. For this reason, efforts were made to develop sensors for this SI value (i.e. SI sensors). These sensors are now installed at 331 locations in the SI monitoring network of the SIGNAL system.

Figure 4 shows the relationship between the rate of damage to screwed joints of low-pressure gas pipelines and the SI value areas affected by the Great Hanshin and other earthquakes. It can be seen that the rate of damage increases as the SI value rises. This indicates that the measurement of SI value is important for damage estimation.

3.2 Liquefaction Sensors

Based on data from past earthquakes, it has been concluded that damage to buried facilities, such as water and gas pipes, in areas of liquefaction is from a few to ten times more extensive than in areas without liquefaction. It was



Fig. 5. Mechanism of the liquefaction sensor

therefore vital for SIGNAL to determine the occurrence and degree of liquefaction, in order to estimate damage to pipes just after an earthquake.

It is clear that the liquefaction phenomenon can be detected by a rise in water pressure between grains of sand (i.e. a rise in pore pressure). Sensors for the direct measurement of pore pressure are commercially available and have good measurement precision, but cannot stand up to long-term use upon burial and also are difficult to maintain. They are consequently not suited for burial to be thus in constant readiness for an earthquake. These circumstances compelled the development of the a sensor that is easily maintained and is of high durability. The resulting Liquefaction sensor (Shimizu et al. 1992) detects the change in pore pressure as indicated by the monitored change

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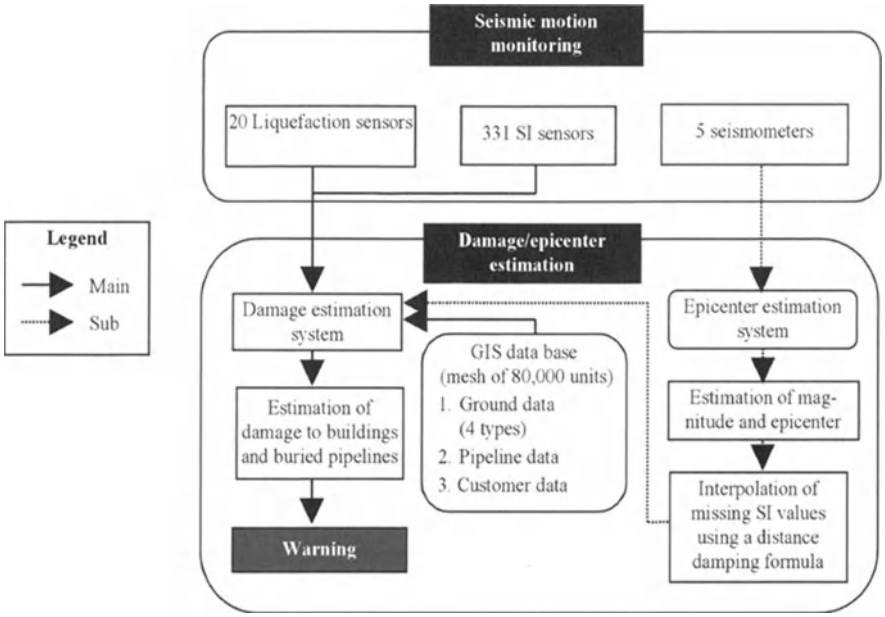


Fig. 6. Overall configuration of SIGNAL

in pressure and water level in an air chamber within a hollow pipe. This structure made it possible to install all instrumentation above ground, thereby making the maintenance work easier.

3.3 Configuration of SIGNAL

SIGNAL consists of three subsystems: a seismic motion monitoring system, an epicenter estimation system, and a damage estimation system. It is also equipped with a data base, prepared in advance, for the ground and pipe systems, and similar items. Figure 6 presents the overall configuration.

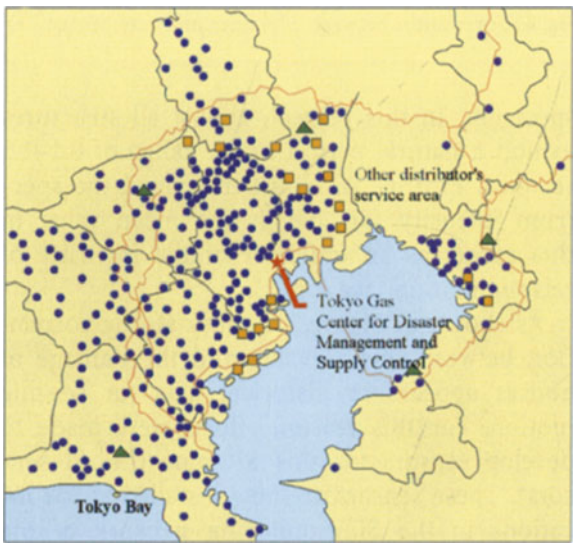


Fig. 7. ● 331 SI sensors ■ 20 Liquefaction sensors ▲ 5 ground seismometers. Distribution of seismic sensors and Tokyo Gas's supply area

3.3.1 Seismic Motion Monitoring System

SIGNAL uses seismic sensors installed in 356 locations in the Tokyo metropolitan area to monitor seismic motion. Figure 7 shows the distribution of these sensors. All sensor data are transmitted through exclusive-use wireless channels to avoid tie-ups and maintain high reliability even in the event of an earthquake. The key role is played by the SI sensors installed at 331 locations to measure the seismic motion SI value and maximum acceleration.

In order to estimate the earthquake epicenter and magnitude on our own, ground seismometers are installed at five locations on the periphery of the service area. These seismometers are set into place in the engineering bedrock layers from 20 to 40 meters below the surface, and continuously record and transmit waveform data for acceleration with three directional components. Furthermore, liquefaction sensors are installed at 20 locations in areas thought to be at high risk of liquefaction, in order to detect the occurrence and degree of liquefaction, which increases the rate of damage to buried pipes.

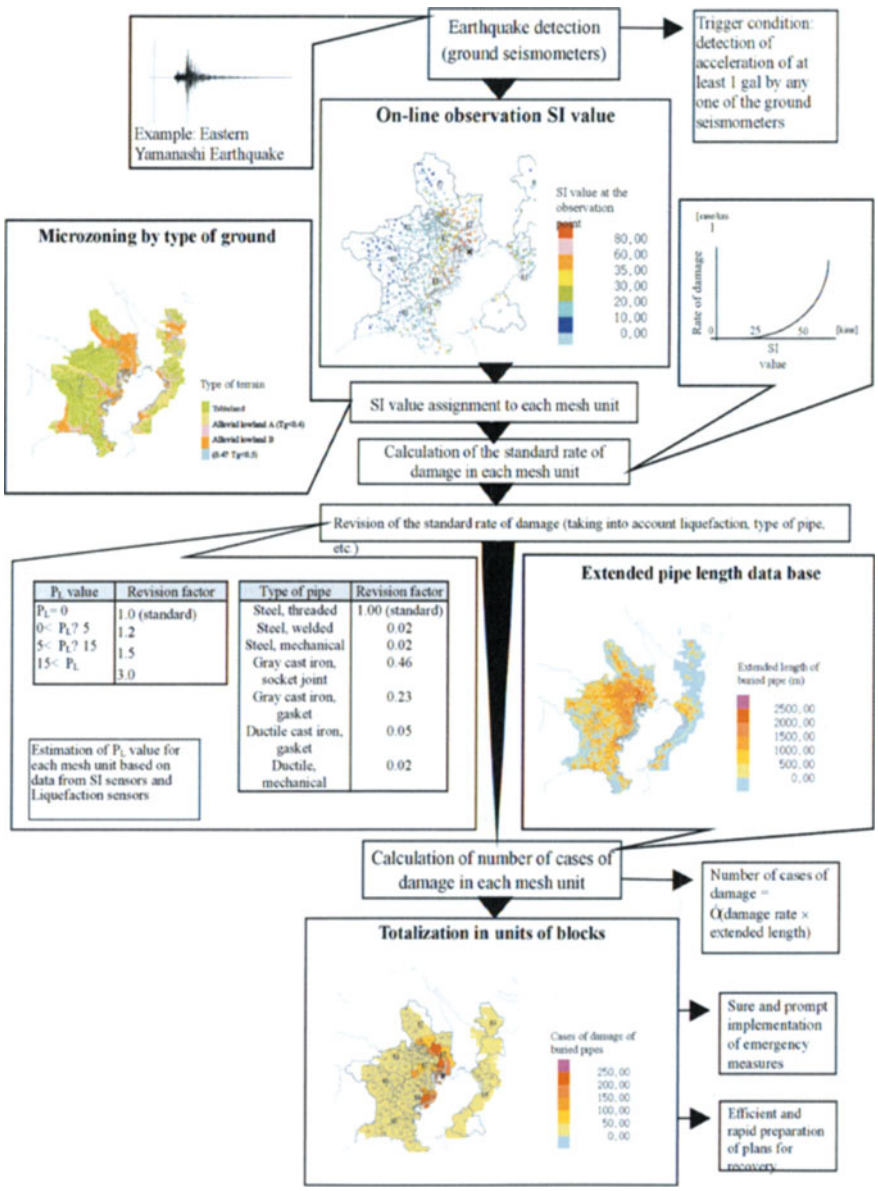
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3.3.2 Data base

For basic data on the surface ground, pipelines and customers, SIGNAL employs the data bases of a geographic information system (GIS) and mapping system. These data are managed in a mesh containing a total of about 80 000 units, each measuring 250 m in the east-west direction and 175 m in the north-south direction. Because the magnitude of seismic motion is heavily influenced by the surface ground, it may be assumed that the measured value from an SI sensor also indicates the magnitude of motion at areas with the same type of ground in the vicinity of the sensor. As such, it was decided to divide the entire service area into zones based on type of ground, as determined from data from 20 000 bore holes, and thereby to determine the area covered by each SI sensor. There are four types of surface ground, consisting of two types defined in terms of terrain (tableland and alluvial lowland) and three types of alluvial lowland based on differences in natural period. In addition, data for extended length of pipe of each type and diameter, number of customers, and other items are input for each mesh unit.

3.3.3 Damage Estimation System

Analysis of data relating to pipeline damage incurred during past earthquakes revealed a very



PL value	Revision factor
PL = 0	1.0 (standard)
0< PL? 5	1.2
5< PL? 15	1.5
15< PL	3.0

Type of pipe	Revision factor
Steel, threaded	1.00 (standard)
Steel, welded	0.02
Steel, mechanical	0.02
Gray cast iron, socket joint	0.46
Gray cast iron, gasket	0.23
Ductile cast iron, gasket	0.05
Ductile, mechanical	0.02

Fig. 8. Flow chart of the damage estimation system

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close correlation between the rate of damage and the SI value. This led to the use of SI sensor data for estimating damage to buried pipes within ten minutes of an earthquake (Yamazaki et al. 1994), as shown in Figure 8.

First, the standard rate of damage in each mesh unit is obtained based on SI values measured at the 331 locations. For mesh units without SI sensors implementation of ground zoning enables the use of the value from the nearest SI sensor installed in a mesh unit with the same type of surface ground. The standard rate of damage is calculated by means of an empirical formula using the SI values obtained from data for past earthquake damage as functions. In addition, to obtain the rate of damage in the event of liquefaction, the standard damage rate is multiplied by the rate of increase in damage corresponding to the degree of liquefaction. Finally, the number of cases of damage in each mesh unit is obtained by multiplying the extended length of buried pipe by the damage rate, upon revision of pipe type and diameter. This number of cases of damage in each mesh unit serves as the basis for calculation of the combined number in each block, and consequently for decisions on the need for supply interruption and other emergency measures, as shown in Table 1. Furthermore, an assessment of the efficiently and promptly overall damage to gas pipes immediately after occurrence of the earthquake makes it possible to prepare appropriate recovery plans (resumption of service).

3.4 Epicenter Estimation System

The location of the epicenter is estimated in real time using the wave-form data for acceleration continuously transmitted from the five ground seismometers (Noda et al. 1993). The determination of the time of initial motion for P- and S-waves is followed by the comparison of theoretical propagation time and measured propagation time, and the epicenter location is determined by minimizing the gap between these two. The magnitude is determined using the formula employed by the Meteorological Agency. The epicenter can be estimated if data can be collected from at least three of the five ground seismometers, and the process should therefore be possible in the event of any earthquake, however large. If collection of data from SI sensors in a certain area becomes impossible for some reason, SI values for the same area could be obtained through application of a damping formula based on distance from the estimated epicenter. In other words, damage in the area in question can be estimated by automatically interpolating missing SI data.

4 Record of SIGNAL Operation

SIGNAL began operation in June 1994, and has thus far detected numerous cases of seismic motion. A recent major case in point was the earthquake with an epicenter in the vicinity of Lake Kawaguchi that occurred in the eastern part of Yamanashi prefecture on the night of March 6, 1996. At the time of occurrence, SIGNAL recorded a maximum SI value of 9 kines and a maximum acceleration of 222 gals. Figure 9 shows the distribution of SI values and acceleration as measured by SIGNAL.

Data from the 31 major nodes on the SIGNAL seismic observation network have always been transmitted to the public broadcasting network NHK and other mass communications entities as well as to administrative organizations of the Tokyo Metropolitan Government and other local governments. Furthermore, effective from September 1996, it was decided to

Table 1. Decision-making guideline on emergency measures for low-pressure pipelines

Case No.	Area	Emergency measures	Basis of decision	Time of decision
1	Areas recording an SI value of 60 kines or more	Interruption of supply	SIGNAL and SI sensor monitoring data	Immediate decision
2	Other areas	Interruption of supply	Comprehensive judgement based on SIGNAL damage estimation data and other relevant data	Within one hour after the earthquake
		Continuation of supply		

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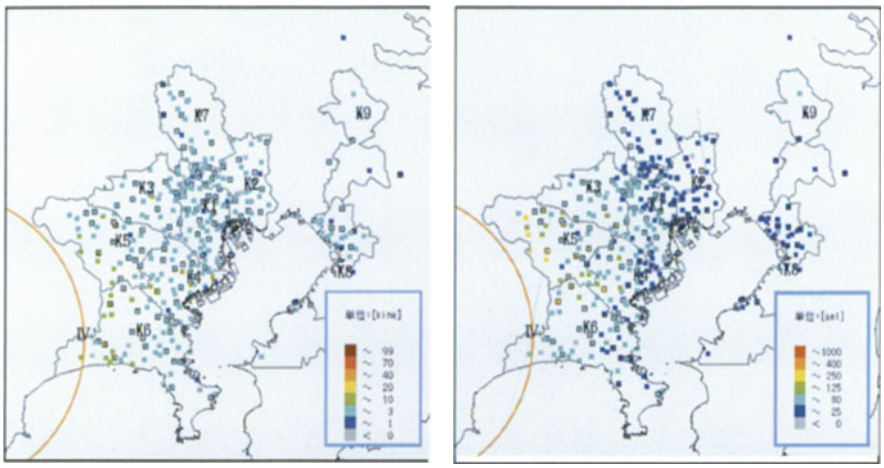


Fig. 9. Distribution of SI values and acceleration in the case of the Eastern Yamanashi Earthquake

release seismic data from all 331 nodes (i.e. SI sensors) through Internet (http://www.tokyo-gas.co.jp) within a very short time following earthquakes with the magnitude 3 or over on JMA's seismic scale, in order to assist prompt emergency response and related research carried out by a wider circle of institutions.

5 Conclusions

Rapid and accurate decision-making on shut-off of gas supplies after an earthquake is needed to prevent the occurrence of secondary damage. SIGNAL (Seismic Information Gathering & Network Alert system) was developed to assist in this decision-making. This system comprises 331 SI sensors, 20 ground liquefaction sensors, and 5 ground seismometers which provide data for monitoring of seismic motion after an earthquake. A detailed data base for ground conditions, buried pipes, buildings and structures, liquefaction risk, and damage ratios for buried pipes following earthquakes was prepared to estimate pipe damage based on the monitored SI values. The system has been running since June 1994.

Ever since the Great Hanshin Earthquake of January 1995, there has been great interest in real-time prevention of earthquake disasters. Numerous bodies, including the government of the city of Yokohama and the Keiyo Gas Co. are in the process of planning systems for monitoring seismic motion and estimating damage in real time. SIGNAL is a forerunner of such systems. One of the tasks for the future is to ensure increased exchange of information with other public institutions in the event of an earthquake in order to bolster efforts to prevent seismic disasters throughout the Tokyo metropolitan area.

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CHAPTER 7.5

GPS Monitoring of Structures: Recent Advances

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Abstract

Relative displacements used to assess stress and drift conditions of structures are difficult to measure directly. Accelerometers are the most common instruments used to monitor structural systems during earthquakes or strong winds, but to arrive at displacements requires processing including double integration. In most cases, such processing does not take place in real-time or near real-time because of requisite steps including choice of filters for signal processing. These choices could introduce errors at periods relevant to structural response.

However, recent advances in Global Positioning System (GPS) technology recording at 10 samples per second (sps) allows reliable monitoring of long-period structures such as suspension or cable-stayed bridges and tall buildings. GPS units with a capability of resolving motion at the centimeter level (±1 cm for horizontal, ±2 cm for vertical accuracy) with sampling rates of 10 sps are now available from several manufacturers. The majority of tall buildings (20–40 stories or more) are flexible steel framed structures whose fundamental period (T, in seconds) can be estimated with the empirical formula T = 0.1 N, where N is the number of stories of a building. Thus, the frequencies corresponding to the fundamental periods of most buildings over 20 stories are 10–20 times the Nyquist frequency of the sampling, which is sufficient to assess accurately its average drift ratio[1]. With this method, displacement is measured directly in real-time.

In this paper, we discuss the scientific justification and feasibility of using GPS technology to monitor long-period structures. We describe an experiment simulating the response of a tall building. The results indicate that sampling at 10 sps provides a clear and accurate response history from which drift ratios and dynamic characteristics of the specimen can be derived. The paper discusses in detail how data recorded from tall buildings monitored with GPS units can be used by engineers and building owners or managers to assess the building performance during extreme motions caused by earthquakes and strong winds, by establishing threshold displacements or drift ratios and identifying changing dynamic characteristics. Such information can then be used to secure public safety and/or take steps to improve the performance of the building.

1 Introduction

Seismic monitoring of structural systems constitutes an integral part of National Earthquake Hazard Reduction Program. In general, until recently, monitoring the response of structural systems for the purpose of assessment and mitigation of earthquakes (and also severe winds) has relied on measuring shaking response by deploying accelerometers throughout a particular structure of interest to the scientific and en-

[1] Drift ratio is the relative displacement of two consecutive floors divided by the height of the floor. In this case, we are defining average drift ratio between the roof level and the ground level as the relative displacement between those two levels divided by the height between the two levels.

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gineering community. In contrast, there are no efficient or feasible methods to measure displacements during an earthquake or severe wind. Recordings of the acceleration response of structures have served us well. Studies conducted on such records have been useful in assessing design/analysis procedures, improving code provisions and in correlating the response with damage.

Since the $M_s = 6.7$ Northridge (17 January 1994) and $M_s = 6.8$ Kobe (17 January 1995) earthquakes, drift studies and assessment of susceptibility to damage of tall buildings have become important issues – particularly because so many steel framed buildings were damaged, some severely and some lightly. In the Los Angeles area, for example, following the Northridge event, several hundred steel-framed buildings had to be examined, assessed, repaired and/or retrofitted. Only three of these buildings were instrumented prior to the event, providing some limited acceleration response data to be used for interpretation of the widespread damage. Additional data, if available in real-time or near real-time could have been very useful for studies and design of repair and retrofitting projects that followed. Therefore there is a great need for better monitoring of tall buildings.

Relative displacements, which are the key to assessing drift and stress conditions of structures, are difficult to measure directly. On the other hand, measuring acceleration response requires a double integration process to arrive at displacements. The integration process is not readily automated because of the nature of signal processing – which (1) requires selection of filters and baseline correction (the constants of integration), and (2) often requires substantial judgement when anomalies exist in the records. Consequently, this process can lead to errors in the calculation of velocities and displacements. This problem is more acute for permanent displacements. Accelerometer measurements cannot be used to recover the permanent displacements at the centimeter level; and even if they were, it is questionable whether it can be done so in real-time. To the authors' best knowledge, only a limited number of such comparisons have been made. That is, the level of accuracy of displacements calculated from accelerations has not been widely verified by observations. The issue is complicated by the fact that the majority of earthquake response records to date are from analog accelerographs. Iwan et al. (1985) found that for analog accelerographs, the comparison of integrated versus observed displacements are not good, but that there is hope for digital accelerographs. Some shake table tests performed to compare the performances of accelerometers and accelerographs have not been directed to check displacements.

As an alternative method of measuring relative displacements while monitoring structural systems, we introduce GPS technology. In general, GPS monitoring systems are used for other purposes because of the sampling rates used (e.g., 1 sample per hour, day etc.). However, the technology has advanced to such a stage whereby it is now possible to record at 10 sps and higher. This provides a great opportunity to monitor long-period structures reliably (e.g. tall buildings that are 20–40 stories or more). The majority of the tall buildings are flexible steel framed structures. The fundamental period of such a flexible framed building can be estimated with the empirical formula[2]: $T = 0.1\,N$, where N is the number of stories of the building. This means that at least 20–40 data points will be recorded for one cycle of motion of a 20–40 story building vibrating at the fundamental period. This provides sufficient accuracy to assess the average drift ratio of a building. Such information can be very useful in assessing the damage to a building. In addition, the main value in using GPS technology to assess the condition of a building is that the displacement measurements can be made directly in real-time and with sufficient precision. As discussed later, we have made preliminary tests to prove the technical feasibility of the application of GPS to monitoring structures.

There is great potential for the development of the application of GPS technology to monitor long-period structures during earthquakes. The application can also be extended to monitoring wind-induced deformation of tall build-

[2] For most flexible buildings, the fundamental period (T) is approximated by 0.1 N, where N is the number of floors of a building (even though the fundamental period can vary between [0.05–0.15] N depending on the flexibility of the building). Therefore, to simulate a 40-story building, we set the period (frequency) equal to 4 s (0.25 Hz) and proportioned the length, width and thickness of the cantilever.

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ings, long-span suspension and cable-stayed bridges and tall chimneys. Furthermore, with future advances in GPS technology and improvements in sampling capability (e.g., higher than 10 sps), it will be possible to monitor short-period structures as well. The current technologies do not readily lend themselves to automated, real-time applications. Additionally, direct measurements of displacements will enable us to reliably detect structural movement caused by failure of the ground under the structure (e.g., liquefaction).

In the last few years, there have been numerous studies related to the technical feasibility of using GPS units to measure displacements of civil structures. Most of the initial work was accomplished by aerospace atmospheric researchers. The number of studies related to the application of GPS for static or dynamic measurements of displacements of structural systems include, but are not limited to, those by Hyzak et al. (1997), Teague et al. (1995), Guo & Ge (1997), Kando & Cannon (1995) and Lovse et al. (1995). In our study, we have directed our efforts towards actual permanent deployment of GPS units alongside acceleometers, and towards using the displacement measurements from GPS as a structural health monitoring tool.

2 Model Tests Simulating a Tall Building

To investigate the feasibility of using GPS technology to monitor tall buildings (and other long-period structures), we conducted 2 experiments. Figure 1 depicts a photo and the overall set-up of a simple experiment designed by selecting a standard stock steel bar to simulate a 30–40 story flexible building. We selected the length, thickness and width of the two bar specimens to yield a fundamental period of approximately 4 seconds in the weak direction. To make things simple, we purposefully selected

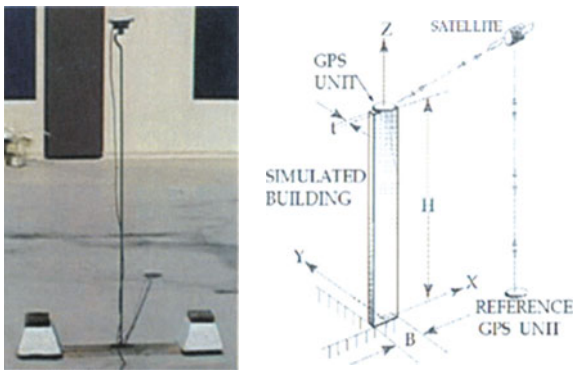


Fig. 1. Photo and Schematic of Test Set-up for using GPS for monitoring tall buildings

the width and thickness of each of the two bars such that there was a considerably weaker axis in one direction. The width was varied to show the sensitivity of measurements during vibration and at a 10 Hz sampling rate. Each bar was fixed at the base and the GPS unit was attached at its tip. By providing an initial displacement, each bar was set into free vibration and its motion was recorded. Results are summarized in Table 1. Figure 2 shows the particle motion and time-history of one of the tests performed. The axes of the bar were at an angle to the NS (and EW) direction. Therefore, the NS and EW components of displacements are identical in phase and proportional in amplitude. Also, since the GPS unit is not symmetrically and concentrically mounted in the weak direction (see photo in Fig. 1), the amplitudes of measured positive and negative displacements are not the same. The detection of the effect of the eccentric mass adds to the assurance that the measurements are accurate and sensitive.

Figure 3 is a plot of NS components of measured relative displacements and corresponding amplitude spectra of Bars A and B. The figure shows the accuracy and sensitivity of the GPS monitoring technology at 10 sps. The measurements differentiate between the frequency of the free-vibration response of the two bars with

Table 1. Results of tests using the GPS unit

Specimen	Length [H] ft (m)	Width [B] in. (cm)	Thickness [t] in. (cm)	Measured Frequency [f] (Hz)	Measured Period [T] (s)	Damping [ξ](%)
BAR A	6 (1.82)	1.5 (3.8)	1/8 (0.32)	0.245	4.08	~2.0
BAR B	6	2.0 (5.0)	1/8	0.296	3.38	~2.0

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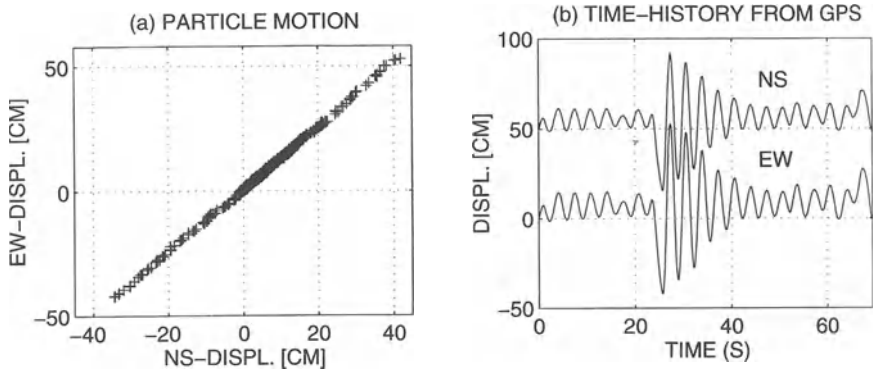


Fig. 2. Particle motion and time-history of relative displacements (NS and EW components) of simulated test specimen

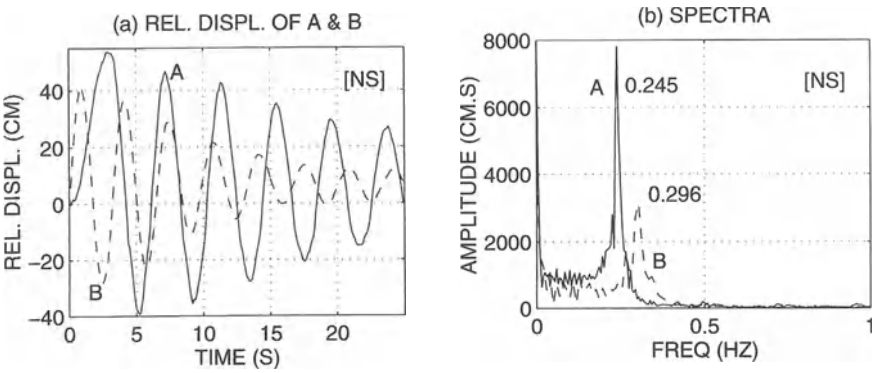


Fig. 3. Relative displacements of two test specimens (NS components only) in free-vibration and corresponding amplitude spectra identifying the fundamental frequencies of the test specimens

different dynamic characteristics. From the data, the fundamental frequencies (periods) of the two bars are identified to be 0.245 Hz (4.08 s) and 0.296 Hz (3.38 s) respectively. In addition, a damping percentage of approximately 2% is extracted. This simple test shows that sampling at 10 Hz with GPS units provides a clear and accurate displacement response history from which drift ratios and dynamic characteristics of the specimen can be derived (Çelebi et al. 1997; Çelebi 1998). The implications of this extend beyond the measurements themselves. It can be shown that identification of variation in dynamic characteristics can be used to identify not only different structural systems, but also the possible non-linearities that occur during vibration (e.g., due to damage and plastic behavior of the structural members, components and/or joints, or soil-structure interaction under varying amplitudes of input motions).

3 Looking to the Future: Real Time Monitoring

We are developing a real-time structural monitoring technique using GPS. Our approach in developing this application is as follows:

We are planning to deploy GPS units on one or more tall buildings that are already instrumented with accelerometers. This will facilitate comparison of absolute and relative displacements. The GPS units will be configured to provide data to indicate the real-time average drift ratio and changes in the dynamic characteristics of the tall building. This information can be made available to building managers (or interested parties) in real-time or whenever a predetermined displacement threshold is reached. The building managers can assess the response of the buildings according to (1) different threshold displacements (e.g., A, B and C as shown in Fig. 4), (2) drift ratios, or (3) changing dynamic characteristics. If a situation is serious, the management can make decisions to evacuate the building for additional inspection. Therefore, one by-product of the effort

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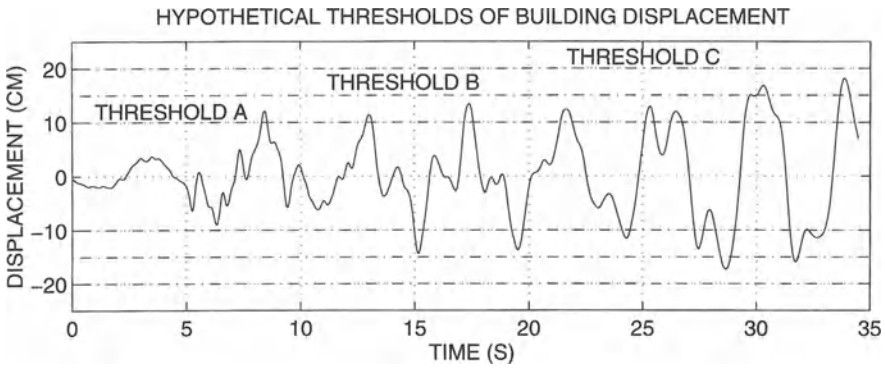


Fig. 4. Hypothetical thresholds of displacements. The time-history of displacements shown is actually integrated from accelerations recorded at the 38th floor (accepted in lieu of roof) of a 44-story building. The actual record is amplified by 20 times for illustration purposes

would be to secure the safety of the occupants and significant contents of the building. Thus, a real-time structural health monitoring environment will be created. At least 3 GPS units per building are required to monitor a tall building. Two of the units should be deployed on the roof to detect the translational and torsional response of the building. The third unit will serve as a reference ground station to evaluate relative displacement. This also needs a site with excellent sky visibility.

Similar deployments are being planned for other types of long-period structures. One project in development at this time is for deploying GPS units on one of the long-period suspension bridges such as the Golden Gate Bridge and Bay Bridge (San Francisco) or Vincent-Thomas Bridge (Los Angeles). As in the case of tall buildings, changes in dynamic characteristics of a bridge after the displacements at critical locations have exceeded predetermined thresholds can be calculated in near real-time. When warranted, the management can make decisions to inspect the bridge (e.g., decisions can be made to stop the traffic, thus securing the bridge safety, which is one of the objectives of lifeline earthquake engineering). With the GPS technology, we can furnish time-dependent displacements for the relative movements of structures at critical locations. For example, for bridges, GPS units placed at pre-selected locations of bridge elements can indicate, in real-time, the amplitude of the displacements of the decks and towers, as well as movements of key bridge elements relative to local bedrock reference points. Thus, movements of the piers relative to the abutments, the top of a tower with respect to its base, or the span with respect to the ground, can be made at a centimeter-level of precision, in real-time. We will recover both the dynamic motions that accompany the earthquake, as well as the static or permanent displacements experienced by the bridge once the shaking has stopped. Such permanent displacements affect the state of stress of a bridge, and provide evidence for distortion or failure of bridge elements or subsidence of piers due to ground compaction induced by earthquake shaking.

Requisite software is being developed to assess and mitigate the two natural hazards (earthquake and severe wind) affecting the structures by using the displacements measured by the GPS units.

The information collected regarding the response of the structure during strong motion events (or strong winds) can be used to make decisions for further evaluation of the susceptibility to damage of the structure and future repair/retrofit schemes may be developed.

The recorded data can be used to analyze the performance of the structure and such results can be used to improve future analyses/design procedures.

The data collected will also be used to assess long-term displacements of critical locations in structural systems (e.g., permanent displacements, settlement of foundations, long-term deformations due to change of temperature and the plate tectonic deformation spanning the San Francisco Bay and parts of the Los Angeles Basin) and to develop methodologies on how the findings can be incorporated into useful practical design procedures.

4 Conclusions

It is shown in this paper that recent advances in sampling rates of GPS technology allow real-time monitoring of long-period structures such

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as tall buildings and long-span bridges. The advantage is that relative displacements can be measured in real-time and with sufficient accuracy. The technical feasibility is illustrated through two tests conducted on two vertically cantilevered bars that simulated tall buildings and an ambient test of a 44-story building. Both approaches show that GPS monitoring of long-period structures provide sufficiently accurate measurements of relative displacements and that dynamic characteristics of the vibrating systems can be accurately identified. This capability can be very useful for structural health monitoring purposes. Procedures and software are being developed to permanently deploy GPS units on tall buildings and suspension bridges.

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The Earthquake Early Warning System of the Armenian Nuclear Power Plant

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The idea of increasing the operation reliability of the Armenian Nuclear Power Plant (ANPP) via the radio-seismic system of NPP initial shutdown (RSIS) is intended to ensure the initial shutdown of the NPP should a strong earthquake occur. This represents essentially an upgrade of the currently applied systems of industrial anti-seismic protection, with the additional use of radio-communication means.

It essentially involves the creation of a radio-seismic station (RSS) network around the NPP (or any other object to be protected) located at a certain distance from the plant, in order to transmit a signal regarding seismic hazard through radio channels. Activation of the system takes place when a threshold ground acceleration is exceeded at any RSS when this occurs a signal of first class emergency protection system activation (A3-I) is automatically transmitted to the plant. Thus, due to the difference between velocities of seismic and radio waves, an early warning on seismic hazard is given.

The main indicator of system effectiveness is the time of prior warning Δt, which arises from the distance from an RSS to the NPP travelled by the seismic wave, more precisely, the difference of the distances: hypocentre – NPP, and hypocentre – RSS. The time spent in radio-wave transfer and system activation can be neglected.

Figure 1 indicates the plan of epicentre location relative to RSS and NPP, and a simplified scheme of seismic wave passage from the source to NPP and RSS.

To calculate Δt from Fig. 1 the following formulas can be used:

$$\Delta t = h/V(1/\sin\alpha - 1/\sin\beta);\ \alpha \le \beta \qquad (1)$$

where V is seismic wave velocity, or

$$\Delta t = 1/V((L^2 + h^2)^{1/2} - (M^2 + h^2)^{1/2}),\quad M \le L \qquad (2)$$

The geometric location of points (epicentres) for which $M = L\ (\alpha = \beta)$, defines the edge of the so-called zero-zone. For epicentres in this domain $\Delta t = 0$, i.e. the RSIS system is not effective.

Figure 2 indicates RSS locations relative to the NPP.

The shaded zones on Fig. 2 represent zero-zones, indicated for systems with 6 symmetrically located RSSs and 12 RSSs.

The size of the zero-zone can be reduced by decreasing the distance N, but because $\Delta t = N/V$, in this event Δt_{max} will also decrease. The most effective way to reduce the zero-zone is the installation of additional RSSs, located as shown on Fig. 2b) (echelon option). In this case, the number of RSSs doubles, but the area of the zero-zone is drastically reduced, and the average value of Δt increases overall due to the expansion of the system's efficiency zone. The notion of an efficiency zone is understood as dangerous earthquake epicentres domain for which $\Delta t > 0$.

A quantitative example is described below. Let us assume that RSIS consists of 6 RSSs, symmetrically located at the distance of 60 km from NPP. In this instance the Δt_{max} for longitudinal and transverse seismic waves is 11.5 and 17.7 seconds, respectively. The area of the zero-zone for this case comprises 3121 km^2, whilst in the echelon option is reduced to a third of this. The most dangerous earthquakes for the NPP are local ones occurring within the closest epicentral zone (hereafter referred to as the control domain). A control domain with a radius of 150 km has an area of 70650 km^2, therefore the areas of the zero-zones of simpli-

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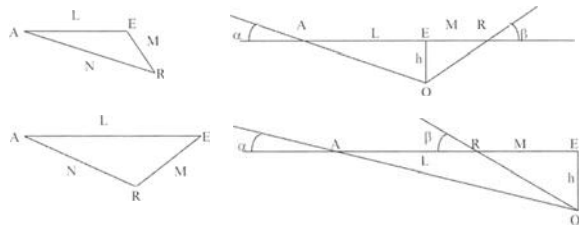


Fig. 1. The plan of epicentre location relative to RSS and NPP, and a simplified scheme of seismic wave passage from the source to NPP and RSS.
E – epicentre; R – RSS; A – NPP; N – distance from NPP to RSS; M – distance from epicentre to RSS; L – distance from epicentre to NPP; O – earthquake source; h – source depth; α and β – outcrop angles of seismic rays

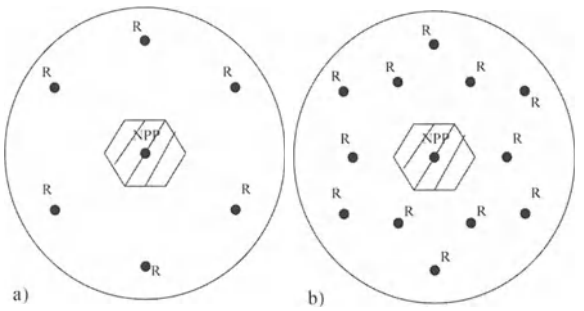


Fig. 2. Locations of RSS relative to the NPP: a) simplified option; b) echelon option

fied and echelon options comprise only 4.4 and 1.4% of the total volume, respectively.

Assuming an even distribution of epicentres, the probability of an earthquake occurrence in zero-zones equals 0.044 and 0.014 respectively. These values would be even lower if one takes into account that remoter earthquakes may also be hazardous, as well as the important fact that an NPP construction site is selected based on microseismic zonation results of a given region.

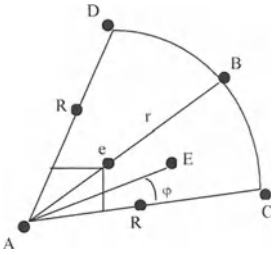
Thus, the vast majority of earthquakes that are dangerous for NPP fall into both options of the system efficiency zone.

In the efficiency zone, the system covers values from 0 to N/V seconds, but the best characterisation of its effectiveness is the average value of prior warning time – Δ_{tave} obtained within control domain.

The same value of Δ_{tave} can be calculated in anyone of the identical semi-sectors of the control domain (see Fig. 3).

Let us calculate Δ_{tave} for an earthquake with source on surface ($h \approx 0$). Then from formula (2) it is derived:

Fig. 3. A sector of the control domain: A – NPP; R – RSS; r – radius of the control domain; E – epicentre



$$\Delta_{tave} = 1/SV \iint (L - M)dS \qquad (3)$$

where S is the area of given semi-sector. For convenience we can present formula (3) in polar coordinates:

$$\Delta_{tave} = 1/SV \iint (\rho - \sqrt{N^2 + \rho^2 - 2N\rho\cos\varphi}) \times dS \qquad (4)$$

Let us present formula (4) in the form of binary integral:

$$\Delta_{tave} = 1/SV \int_0^a d\varphi \int_{N/2\cos\varphi}^r \times (\rho - \sqrt{N^2+\rho^2-2N\rho}\cos\varphi)\rho d\rho \qquad (5)$$

where r is the radius of the control domain, and a is the angle of the CAB sector.

Taking into consideration that the most hazardous seismic waves are those of type S, which bear most of the earthquake's energy, we take the velocity of these waves (V_S) as the basis for calculation of Δt.

It is known that for relatively shallow local earthquakes, S-wave velocity does not exceed 3.4 km/s. Applying the data from the above quantitative example, the following can be derived from formula (5):

$$\Delta_{tave} = 1/56833.4 \int_0^{\pi/2} d\varphi \int_{30/\cos\varphi}^{150} \times (\rho - \sqrt{3600 + \rho^2 - 120\rho\cos\varphi}) \times \rho d\rho = 14.86\,s$$

Δ_{tave} decreases when the depth of the source h is taken into account. For instance, if $0 \le h \le 50$ km, then $\Delta_{tave} = 10.1$ s.

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Table 1. Average values of prior warning time

No. of RSS (and angle ° at the top of the semisector)	Distance from NPP to RSS in km				
	30	40	50	60	80
4 (45°)	7.42	9.57	10.53	13.27	16.02
6 (30°)	8.08	10.53	12.80	14.86	18.26
8 (22.5°)	8.33	10.91	13.32	15.54	19.28
10 (18°)	8.40	11.10	13.59	15.90	19.83
12 (15°)	8.46	11.21	13.74	16.10	20.16

The biggest dependence of Δt on h is observed for values of L close to and less than N. With increasing of L, this dependence promptly shrinks: at places where relatively deep earthquakes prevail, it is therefore expedient to reduce the distance N, or apply the echelon option of the RSIS system.

Table 1 indicates Δ_{tave} values for certain distances and RSS numbers for the simplified option of the system ($h=0$).

As seen from the table, the Δ_{tave} values increase with increasing number of RSS, and this dependence is irregular.

It is clear that increasing the number of channels to over 8 slightly impacts on the Δ_{tave} value. Hence the eight-channel system of RSIS is considered to be optimal. The optimal distance for N depends on reactor type, or to be more precise: on the time needed for reactor shutdown. It is known that the time needed to move the components of protection system control (PSC) from the upper position to the lower one for reactor types WWER-440 and WWER-1000 is 9–12 s and 1.5–4 s, respectively. Hence for reactor type WWER-1000 the RSIS system ensures PSC component withdrawal from core, and reactor shutdown for any value of N under consideration, whereas for WWER-440 reactor types it ensures the above for values of $N>50$ km.

The aforementioned values apply to the systems with RSS asymmetric localities. In practice, when an actual RSIS system is emplaced, one has to take into consideration the most probable place of earthquake occurrence (seismogenic zones), as well as a range of other local factors when choosing the spots for RSS installation. Such symmetry is desirable, although not obligatory. In this respect, the number of RSS and their distance from NPP can also be modified significantly. An elaboration of the RSIS is described and tested in a case study of the Armenian NPP, where particular emphasis was placed on calculating Δ_{tave} for a system with RSS asymmetric configuration.

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Concept for Seismic Alarm and Monitoring of Soviet-Designed Nuclear Power Plants

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Abstract

A seismic pre-warning system for nuclear power plants is presented. In this system, a number of accelerometers are installed in seismic stations at a distance of approximately 50 km from the plant, providing a pre-warning time of 8 seconds. This is sufficient to initiate a fast reactor shutdown, SCRAM, before the arrival of the seismic shear waves at the plant. In this way, damage to the power plant is reduced. Due to the fact that the nuclear power plant is in a less vulnerable state after the SCRAM, the risk of radioactivity release to the environment is lowered by the seismic pre-warning system. In order to quantify the risk, the seismic pre-warning system should be included in the probabilistic risk assessment, PRA, of nuclear power plants.

This system is designed for installation in Soviet-designed nuclear power plants. The same concept can also be applied in plants to other parts of the world.

Accelerometers with digitizers are installed in the seismic stations. Special software differentiates seismic events from man-made vibrations. This software, together with redundant instrument installation and the local diversity of the instruments results in reliable detection of relevant earthquakes. Therefore, an automatic SCRAM by the system becomes feasible.

Seismic monitoring of the area by usual instrumentation (seismometers, recorders) is required to determine the correlation between the ground motion at the seismic stations and the accelerations at the reactor buildings. This must be carried out in cooperation with the national seismic service. A scheme for the integration of the seismic pre-warning system of the nuclear power plant in a national seismic network is presented.

1 Introduction

In the course of its operational life, a nuclear power plant can be affected by many internal and external events. Earthquakes and fires are the most important external events. With regard to fires, a broad spectrum of measures is applied including the application of fire-resistant materials, the installation of fire detection and fire fighting systems and the implementation of redundant installations. Earthquakes are different. There is no way to fight them. Their local extent cannot be confined and, therefore, redundant installations do not help against them. Designing the buildings and the components to withstand earthquakes is one method to cope with earthquake damage. Another method is described in the present paper. An instrumentation system detects an earthquake several seconds before its arrival at the nuclear power plant; the pre-warning time is used to initiate a reactor shut-down. In this way, the nuclear power plant is in a less vulnerable state when the earthquake arrives.

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According to western standards, as well as those of the former Soviet Union, nuclear power plants are designed for two levels of earthquakes. The operating basis earthquake, OBE, designated as the design earthquake in the Soviet Union, covers the seismic event which could reasonably be expected during the operating life of the plant. The nuclear power plant should be able to continue normal operation after an OBE. Usually, an earthquake having an average return period of 100 years is assumed. There is a general consensus that the buildings and components of nuclear power plants shall be fully designed against an OBE and, if during the lifetime of a nuclear power plant, buildings and components are found not to comply with this requirement, they should be seismically upgraded. Reasons for this non-compliance might be under-estimation of the OBE accelerations and loads at the design stage, or ageing of the materials.

After a safe shutdown earthquake, SSE, designated as the maximum design earthquake in the Soviet Union, the safety-relevant buildings and the systems required for the removal of the residual heat shall remain intact. Usually, an average return period of 10000 years is assumed for the SSE. As this far exceeds the time period during which measurements of earthquakes have been made, it is not easy to determine the relevant ground acceleration of the SSE. Even in the western world, many discussions have been held on this issue. What is under-designed for one party, may be regarded as well-designed for another party.

Meanwhile, with regard to the Soviet-designed nuclear power plants, it is internationally accepted that not all safety-relevant buildings have to be upgraded (Fraas 1997). The upgrading is to be based on alternative approaches applying the experience gained in recent years.

The seismic alarm system outlined in the present paper is to be considered as an alternative approach to the seismic upgrading of nuclear power plant buildings and components.

2 Seismic Instrumentation for Nuclear Power Plants

According to the American and German standards (American Nuclear Society ANSI/ANS-2.2-1988; German KTA 2201.5-1996), the following seismic instrumentation should be installed in nuclear power plants (see Fig. 1): triaxial accelerometers at the foundation of the reactor, on top of the reactor building and in an open field near safety-relevant buildings. An alarm is issued when 2 out of 3 instruments indicate a value exceeding the threshold.

Standard instrumentation used in western countries has the following disadvantages (Renard 1997):

- Due to the fact that the instrumentation is installed in the generally noisy environment of the power plant, the sensitivity to seismic events is reduced. For example, a seismic event of magnitude 5 in Belgium was not recorded by the instruments in the nuclear power plant at a distance of 70 km.
- In the standard configuration, a 2-out-of-3 logic of the alarm initiation is included. This merely provides a redundancy in the case of instrument failures but does not eliminate false alarms caused by vibrations of large components as these will influence more than one instrument due to the limited distance between them.
- The instruments issue an alarm irrespective of the frequency. In so doing, a seismic alarm is also given in response to vibration of large components, e.g. reactor primary circulation pumps and pipe. In order to reli-

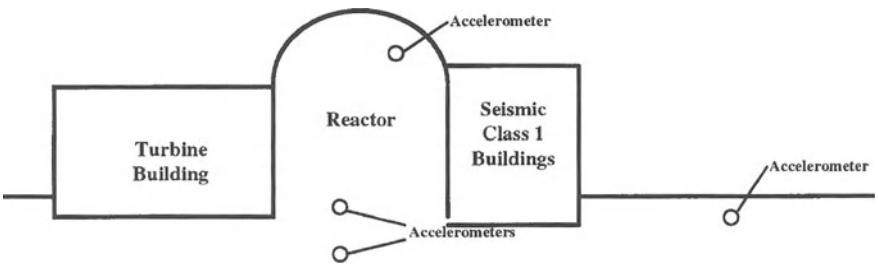


Fig. 1. Layout of earthquake early warning system and detail of field station of Ignalina Nuclear Power Plant (NPP) (YT: accelerometer; ST: bore hole seismometer; telemetry of data to NPP). Standard seismic instrumentation of nuclear power plants

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ably determine whether an earthquake has occurred, an in-depth analysis of the recorded time histories is required. This takes some hours, which exceeds the allowed time delay following a seismic event in which the decision must be made whether to continue operation or to shut-down the nuclear power plant. As a consequence, the plant must be stopped – unnecessarily in many cases.

3 New Seismic Alarm System

3.1 Concept

In the proposed system, a number of field stations are placed in a circular arrangement at a distance of 50 km from the power plant (see Fig. 2). This provides an improved sensitivity to seismic signals due to the fact that the field stations are not influenced by vibrations from the power plant.

The alarm is initiated if at least two of the field stations indicate that the present threshold has been exceeded. This provides the required redundancy in the case of instrument failures. In a set-up with eight stations, the distance between the field stations is approximately 40 km. The probability is extremely low that ground shakings from sources other than seismic events, e.g. from railway traffic, construction works or other man-made events, affect two stations at a distance of 40 km at the same time. By the diverse locations of the installations, an effective redundancy against false seismic alarms is achieved.

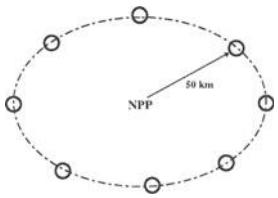


Fig. 2. Configuration of seismic alarm system

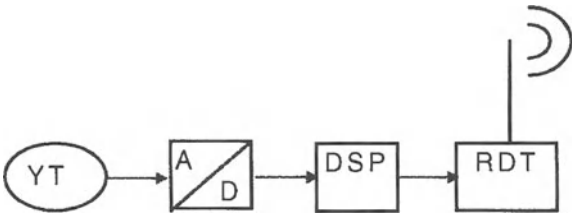


Fig. 3. Block diagram of seismic alarm system
YT = accelerometer; A/D = digitiser; DSP = differentiation software processor; RDT = radio data transmitter

Each field station includes an accelerometer and a digitiser as shown in Fig. 3. The digital signal is fed to the differentiation software processor. The software is "taught" by previously recorded signals to differentiate between seismic events and non-seismic events. One factor in this context is the frequency. Above 10 Hz, a "non-seismic" event is indicated, at lower frequencies it might be an earthquake. Seismic events with frequencies beyond 10 Hz are possible; however, these are minor events, which do not cause any problems for the nuclear power plant. The processing time required by the differentiation software is approximately 2 seconds. This is by far less than the time which would be required for the calculation of the complete set of earthquake parameters.

The signal is transmitted virtually instantaneously to the nuclear power plant by radio waves.

3.2 Pre-warning Function

Considering a velocity of seismic shear waves of roughly 5 km per second and a distance of 50 km between the field stations and the nuclear power plant, the earthquake is detected 10 seconds before the arrival at the plant. The evaluation at the field stations requires 2 seconds. What can be done with a pre-warning time of 8 seconds?

The pre-warning time can be used to initiate a reactor SCRAM by manual action. SCRAM inserts the control rods, starts the residual heat removal system and switches off the turbine-generator.

The control rod insertion stops the nuclear reaction. Instantaneously, the nuclear heat generation is reduced to the residual heat level. In detail, the control rod insertion takes place in several steps:

- Transmission of the respective command from the control room to the control rods. Control systems can be regarded as relatively susceptible to severe ground shaking due to the extended cabling required for signal transmission and because at the end of the control path there is an electrical/mechanical device, e.g. an electrical relay. Therefore, it is

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essential that this step is done before the arrival of the main earthquake waves at the power plant.

- In normal operation, the control rods are held in place by a mechanism, for example, by clutches. In order to drop them into the reactor core, the rods must be released from the clutches. Considering the fact that this procedure might be impaired by shakings, this is to be completed before the earthquake arrives at the reactor. The pre-warning time is sufficient for this purpose.
- Finally, the control rods drop into the reactor core by gravity. The core is provided with sleeves for this purpose. At the Soviet RBMK reactor, only 1 second is required for dropping down the control rods. The corresponding value at the WWER is about 12 seconds. With regard to the WWER, this exceeds the available pre-warning time. However, this can be disregarded since the nuclear heat generation is strongly reduced even in the case that the control rods are only partially inserted.

The control rod insertion might be obstructed by deformation of the control rod sleeves by seismic shaking; however, this can be excluded because the reactor core internal parts will not be affected in the first seconds of even a strong earthquake.

In conclusion, the critical steps of the control rod insertion, viz. the signal transmission and the release of the rods from the mechanical clutches, can be finalised before the arrival of the earthquake at the power plant.

Other functions of the SCRAM, the start of the residual heat removal and the shut-down of the turbine generator, will not be completed within the pre-warning time of 8 seconds. It should be noted in this context that the Soviet-designed reactors do not immediately require full operation of the residual heat removal systems due to the huge water inventory relative to western reactors. Regarding the diesel emergency power generators, which are switched on together with the residual heat removal system, the chance of a start failure is lower if they are started without ground shaking. With regard to the turbine generator, damage will be much lower if it is already in the run-down state, compared to the case where the earthquake hits the turbine generator under full load.

It is concluded that damage to the nuclear power plant in case of a strong earthquake is reduced, by means of the new seismic alarm system because the SCRAM is initiated before the arrival of the seismic waves at the plant.

Another issue remains to be considered: will the operators trust the seismic alarm and push the SCRAM button in the case of a seismic alarm? This depends on their training. As with, for example, fire alarms, they must be trained to recognise and believe in the signals received. For training purposes, the alarm threshold of the proposed system can be adjusted from the control room of the nuclear power plant down to levels where microseismic events, which are always present, can issue an alarm. In this way, the operators can familiarise themselves with the seismic alarm.

3.3 Automatic SCRAM by Seismic Alarm System

As outlined above, the pre-warning time may be used to initiate a reactor SCRAM manually. An automatic SCRAM is also feasible. A similar system (see Fig. 4), which is being installed at the Ignalina Nuclear Power Plant by a joint venture of Electrowatt Engineering Ltd. and GeoSys Ltd., is designed for an automatic SCRAM. Several prerequisites are to be set for this (Wieland 1997):

- A thorough investigation of the seismic characteristics of the site must be carried out to determine the proper alarm level at the field stations. For this purpose, a seismic monitoring campaign of the area is required. This will be described in Section 5 of the paper. Considering the fact that the monitoring campaign will take about one year, the automatic SCRAM is recommended only after that time.
- A high reliability, i.e. a low number of spurious signals is mandatory. The reliability investigation of the system has shown that the number of spurious signals will be 1 in 10000 years. This is achieved by the redundancy of the instrumentation, by the diversity of the installation locations and by the application of proven components. According to our assessment, the extremely low number of spurious signals allows an automatic SCRAM.

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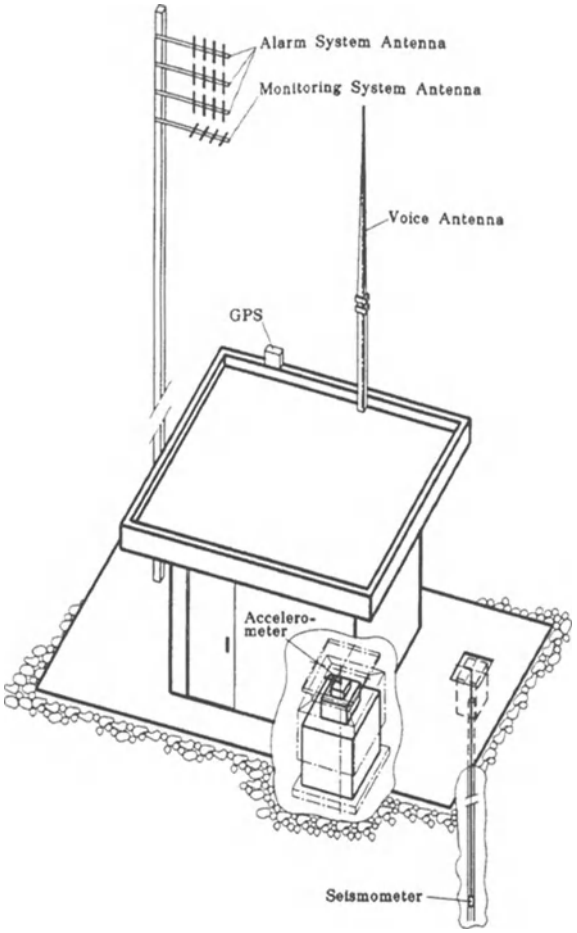


Fig. 4. Architectural view of field station

- In order to keep the high reliability, the seismic alarm system must be fully maintained and checked at regular intervals.

The radio signal transmission is often questioned in the context of reliability. In our system, the radio transmission has several features required for high reliability. For example, by means of the error correction, the received signal is checked to see whether it is identical to the sent signal. Only in the affirmative case, is the alarm issued. By these safety features, the spurious signals are kept at the low level indicated above. It should be noted, however, that radio transmission is in fact susceptible to atmospheric influences. For example, during a strong thunderstorm, a brief interruption may occur. This will not issue a seismic alarm, rather results in a short break in the operation of the seismic alarm system.

4 Reduction of Risk of Radioactivity Release

Although nuclear power plants are equipped with a series of safety systems, a very small risk of radioactivity release to the environment remains. As outlined in Section 3.2, the new seismic alarm system protects the safety systems in the case of a severe earthquake. The insertion of the control rods, the start of the residual heat removal systems with the diesel emergency power generators and the shut-down of the turbine generator are the most important issues to be mentioned in this context. In this way, the risk of radioactivity release is reduced.

The risk is determined in the probabilistic risk assessment (PRA). Figure 5 presents the risk distribution of a nuclear power plant in the U.S. and of a plant in Switzerland for several events including earthquakes. In the U.S. plant, the risk of radioactivity release by earthquakes is 6.3×10^{-5} per year, which contributes only 25% to the total risk. In the Swiss plant, the corresponding values are 3.0×10^{-5} per year, 40% of the total risk. With regard to the Swiss plant, a considerable reduction of the total risk can be achieved by the installation of the new seismic alarm system. It should be noted that the absolute value of the risk of radioactivity release by earthquakes in the U.S. plant is higher when compared to the Swiss plant. However, due to the small share of the risk caused by earthquakes in the U.S. plant, not much could

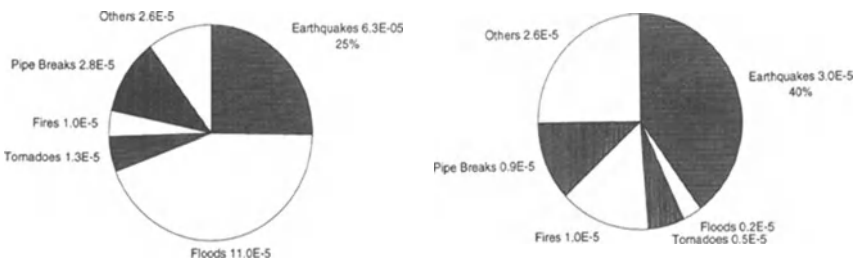


Fig. 5. Nuclear Power plants in U.S. (left) and Switzerland (right): Contribution of earthquakes and other events to risk of radioactivity release

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be gained by the seismic alarm system. A preliminary assessment would, therefore, be that the new seismic alarm system should be installed in the Swiss plant, but probably not in the U.S. plant.

The exact figure of risk reduction can only be determined by a plant-specific PRA and it is suggested that future PRAs include the new seismic alarm systems as an alternative.

5 Seismic Monitoring

It is essential to establish the correlation between the seismic accelerations at the field stations distant from the power plant, and at various levels of the power plant buildings. This will allow the determination of the alarm acceleration at the field stations corresponding to the SSE at the plant. For this purpose, seismic monitoring has to be used. Seismometers with recorders are to be placed at the field stations and at various levels of the power plant buildings. Very accurate time synchronisation is necessary, which is only feasible by GPS timing. Due to the fact that only small seismic events will probably be recorded, a high resolution of the seismic instruments is required. Portable instruments may be used at the field stations.

With regard to the monitoring of the power plant buildings, considering the fact that reactor and other safety-relevant buildings should be monitored permanently, fixed installation of accelerometers as part of the building monitoring system is recommended.

It is estimated that the seismic monitoring campaign will take one year at each nuclear power plant.

6 National Seismic Services

Several of the new countries of the former Soviet Union do not yet have a well-developed national seismic service. Considering the fact that seismic monitoring requires specific techniques, which are normally not available in nuclear power plants, the seismic monitoring campaign outlined in Section 5 above may well be carried out by the national seismic service. This could represent the origin of a permanent seismic network. Such a network consists of fixed installations of seismometers with wireless data transmission to a central data collection base. Here, the data collection and evaluation is carried out including the determination of hypocentre, epicentre and magnitude by means of well-known software such as IASPIE or SEISLOG/SEISAN of the Bergen University, Norway. This requires international cooperation with seismic services of other countries.

In the proposed seismic alarm system, the selection of the locations of the field stations is flexible. They can, for example, also be placed at a greater distance from the power plant. This provides the opportunity to combine the seismic alarm stations of the nuclear power plant with the stations of the national seismic network. In this way, the nuclear power plant owner does not have to install and maintain equipment which is located outside of the power plant premises.

7 Conclusions

The seismic alarm system developed by Electrowatt Engineering in cooperation with GeoSys represents an improved instrumentation system compared to the seismic instrumentation of nuclear power plants stipulated in the American and German standards. The improvements include:

- High sensitivity to seismic signals due to the placement of the sensors in quiet areas, distant from the power plant.
- Full redundancy is achieved by use of multiple instruments and diverse installation locations.
- Application of techniques to differentiate between man-made vibrations and earthquakes
- Pre-warning function to allow the nuclear reactor to be shut down before the arrival of an earthquake at the plant. This might be done manually or automatically. The system has an extremely low number of spurious signals per year, which is a prerequisite for the automatic SCRAM.
- Reduction of the risk of radioactivity release in case of a severe accident.

The system is to be considered as an alternative approach to the expensive seismic upgrading of nuclear power plant buildings and components for the safe shutdown earthquake.

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The system can be the origin, or a valuable extension, of a national seismic network and can, in this way, promote international cooperation which is mandatory for national seismic services.

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Optimizing the Seismic Early Warning System for the Tohoku Shinkansen

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Abstract

The Tohoku Shinkansen is a high-speed passenger train that connects Tokyo to the northern city of Morioka. The line is protected by a seismic early warning system, which includes two sets of accelerometers: one set is deployed along the line (wayside system), while the other comprises eight accelerometers placed along the eastern coast of Honshu (coastal system). The coastal system is designed to protect the train against earthquakes with origin in the highly active offshore subduction zone. It causes trains to automatically stop when the ground acceleration at one of the stations exceeds a preset limit. At the time of the study, the system was causing frequent train delays, while providing an unclear level of seismic protection. We have found that, with the current early warning system, the rate of earthquake-induced derailments along the entire 500 km line is about 2–3 per 100 years. By changing various system parameters, one can lower this rate to about 1.5 derailments per 100 years while reducing the rate of false alarms and unnecessary delays by a factor of about 40. These benefits arise mainly by operating the wayside system on spectral acceleration rather than peak ground acceleration.

1 Introduction

The Tohoku Shinkansen is a high-speed passenger train that links Tokyo to the city of Morioka, on Honshu, Japan's largest island; see Figure 1. The line, which is operated by Japanese Railways East (JREast), is about 496 km long and runs almost parallel to the eastern coast of Honshu, at a distance of about 60–70 km from the Pacific coast. Except for tunnels in mountainous areas, the train travels on a continuous reinforced concrete viaduct structure, with a double track. The typical viaduct span is 7 m and the average height above ground is 10 m. The natural period of the viaduct in the transversal direction is about 0.32 sec. Soil conditions along the line vary, with a dominance of diluvium and alluvium. Shinkansen trains have an average length of 250 m and travel at an operational speed of 245 km/h.

The Tohoku line is threatened by earthquakes from moderately active inland sources and, more importantly, from the subduction zone off the eastern coast of Honshu. A seismic early warning system (SEWS) comprising two sets of accelerometers has been in operation since 1978 to mitigate the consequences of destructive earthquakes on the Tohoku line. The most feared earthquake-induced accidents are derailments, which typically occur when a running train encounters damaged tracks. The SEWS triggers automatic braking of all trains in pre-assigned segments of the line when the recorded level of ground acceleration exceeds a

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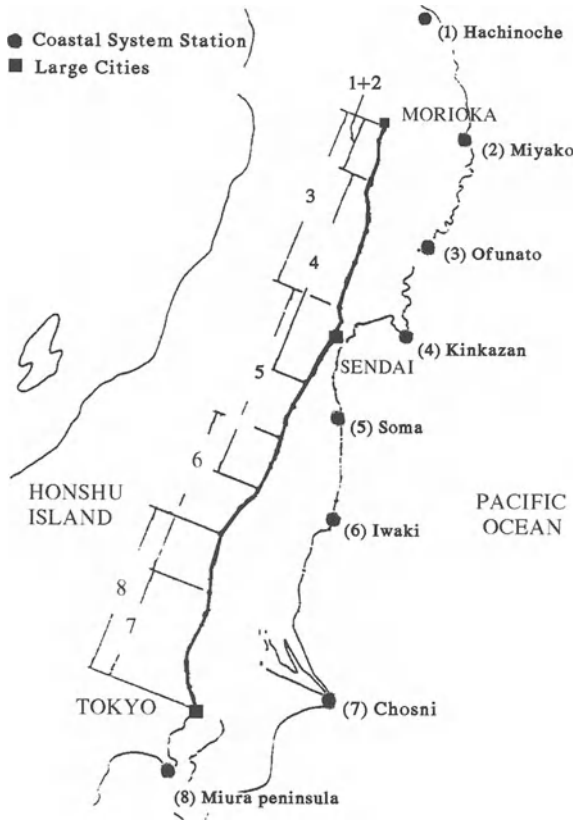


Fig. 1. Tohoku Shinkansen line. Location of coastal and wayside accelerometers in the seismic early warning system (JREast, personal comunication)

preset threshold. In so doing, the SEWS reduces the distance traveled by trains on potentially damaged tracks and reduces the risk of severe accidents.

The SEWS is causing frequent train delays and cancellations on the Tohoku line, while the level of earthquake protection it provides is unclear. JREast sponsored the present study to (a) quantify the current level of seismic risk, its variation along the line, and the degree to which the risk is abated by the current SEWS, and (b) improve the operation of the SEWS.

Assumptions, methodology and results of the study are summarized below. Further details can be found in Veneziano and Papadimitriou (1998) and Papadimitriou (1995).

2 The Current Early Warning System

Except for the area around Tokyo, inland seismicity along the Tohoku line has a low rate and consists of low to moderate magnitude events. By contrast, offshore seismicity is intense and has included large magnitude earthquakes in historic times. The rupture zones of these offshore earthquakes are at an average epicentral distance of 130 km from the line. These characteristics of regional seismicity have motivated the use of a double earthquake protection system for the Tohoku Shinkansen:

- Protection against offshore earthquakes is provided by a linear array of eight accelerometers along the eastern coast of Honshu, practically midway between the track and the offshore earthquake sources (coastal system; see Fig. 1). Each accelerometer controls a preset track segment. If a threshold ground acceleration A_{coast} is exceeded (currently, A_{coast} is set at 40 gals), emergency braking of the trains in the corresponding track segment takes place.
- Protection against inland earthquakes is provided by a system of accelerometers located along the tracks (wayside system). The wayside system consists of 26 accelerometers at almost regular intervals between Tokyo and Morioka. Each accelerometer controls the track segment on each side of its location. When ground acceleration at a wayside station exceeds a given threshold A_{loc} (currently also set at 40 gals), all trains in the corresponding segments are automatically stopped.

After a train has been stopped by either the coastal or wayside system, decisions about track inspection and resumption of service are based on the recorded peak ground acceleration a_{max} at the closest wayside station. The current policy is shown in Table 1.

Table 1. Current post-braking operational policy for the wayside system

Recorded Seismic Intensity	Operational Policy	Type of Train Delay
$a_{max} < A_{insp1}$ (currently, 80 gals)	No track inspection; resumption of operation	Short
$A_{insp1} < a_{max} < A_{insp2}$	On-train track inspection; operation at low train speed	Medium
A_{insp2} (currently, 120 gals) $< a_{max}$	On-foot track inspection; no resumption of operation	Long

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Over a period of eleven years (1982–1993), the early warning system has induced an average combined rate of 2.8 medium or long delays per year and an average rate of 72.4 short delays per year. During the same period, there have been no earthquake-induced derailments.

3 Alternative Early Warning Systems

We have compared three alternative types of coastal early warning systems:

System A. This is the present SEWS system, except that the threshold acceleration A_{coast} is treated as a variable (for uniformity with subsequent notation, we denote this threshold by a_t), with values that may differ from the present setting $A_{coast} = a_t = 40$ gals.

System B. This system differs from the current SEWS in that there is no preset shutdown section assigned to each coastal accelerometer. Rather, for each accelerometer, the length of the shutdown segment increases as the recorded seismic acceleration increases. Another new feature of this system is that the epicentral location of the earthquake is roughly estimated by determining its 'sector of origin'. The sector of origin includes all geographical locations that have the first triggered coastal station as their nearest station. System B operates with an array of trigger acceleration thresholds $A_{coast}(i, s, R)$, one for each combination of coastal station i, track segment s, and sector of origin R. These thresholds consider the expected spectral acceleration levels along the track and are calculated as:

$$A_{coast}(i, s, R) = b_t\, g(i, s, R) = b_t \frac{\int_R d\underline{x} \int_6^{M_{max}} \frac{a_{max}(M, \Delta(\underline{x}, i))}{s_a(M, \Delta(\underline{x}, s)} 10^{-bM} dM}{\int_r d\underline{x} \int_6^{M_{max}} 10^{-bm} dM} \quad (1)$$

where b_t is a scaling factor with units of acceleration, $g(i, s, R)$ is the expected ratio between the peak ground acceleration at coastal station i and the spectral acceleration (at the frequency and damping of the viaduct structure) at track segment s for earthquakes that occur within the sector of origin R, and Δ is the epicentral distance of interest.

System C. The main conceptual difference between this and the other two systems is that System C determines which segments of the line should be shut down based on real-time estimates of the magnitude M and epicentral location $\underline{x}$ of the earthquake. Another difference is that System C uses P waves to infer M and $\underline{x}$ rather than S waves. Due to their higher speed, P waves give System C about 15 additional seconds of warning time. The initial estimates of M and $\underline{x}$ based on P waves may be revised and made more accurate at the time of S waves arrival. System C triggers emergency braking when

$$0.7\,\mathrm{lM} - \log_{10}[\Delta(\underline{x}, s)] \geq c_t \quad (2)$$

where c_t is a scaling parameter that controls the conservatism of the system and $\Delta(\underline{x}, s)$ is the distance between the epicenter $\underline{x}$ and track segment s. The expression in the left hand side of Eq. 2 is an empirical measure of the destructiveness of the earthquake at track segment s (Nakamura 1989). The effectiveness of System C depends on the accuracy with which M and $\underline{x}$ (or Δ) are estimated. Table 2 gives the standard deviation of the estimation errors used in the analysis (from Nakamura 1988 and JREast personal communication).

The only variant of the current wayside system we have considered is one that replaces peak ground acceleration a_{max} with response spectrum acceleration S_a as the seismic intensity parameter used to trigger braking of the trains and to decide upon post-earthquake inspection of the tracks and resumption of service. S_a is evaluated at the natural period of the viaduct and for 5% critical damping.

Table 2. Standard deviations of single-point estimates of M and Δ

Estimation using	Magnitude, M (JMA)	Epicentral Distance, Δ (km)
P-waves	1.0	0.75 Δ (Δ = median value)
S-waves	0.5	25 km

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4 Risk Analysis

One way to rationally choose among alternative early warning systems is to compare their annual rate of earthquake-induced derailments (λ_{DE}) and the annual rates of various types of delays (λ_{SD}, λ_{MD}, λ_{LD} for short, medium and long delays, respectively). An important first step to obtain such rates is the assessment of seismic risk for the viaduct structure, which combines earthquake recurrence, ground motion attenuation, and seismic fragility information for the viaduct structure.

The region of interest has been divided into 15 seismic sources and each source has been assumed to produce spatially uniform Poisson earthquakes, with Gutenberg-Richter parameters a and b based on historical seismicity and the analysis by Utsu (1974). For ground motion, we have used a modified version of the attenuation law proposed by Kawashima et al. (1984). The modification affects the median values associated with large-magnitude events, which were found unrealistically low compared to other Japanese studies; for details see Papadimitriou (1995).

We have considered response spectrum acceleration S_a at the transversal natural period for 5% damping as a measure of the damage potential of an earthquake on the viaduct structure. Therefore, we have expressed the probability of different damage states for track segment s as a function of the value of S_a experienced by that segment. More specifically, the state of damage of segment s given S_a has been calculated in two steps: first we have assessed the damage probability for a single viaduct span, and then we have considered dependence among the damage states of different spans.

4.1 Probability of Damage of a Single Viaduct Span, $P_1(S_a)$

Following the NIBS Technical Manual (1994), we have assumed that the reinforced concrete (R/C) viaduct has resistance R (expressed in terms of S_a) with lognormal distribution, median value R_m and logarithmic standard deviation λ_{lnR}. The median value R_m depends on structural and geotechnical parameters, in particular the ductility of the viaduct frame and the local soil conditions. Given the Japanese code that was in effect when the viaduct was constructed, the estimated median resistance of the viaduct structure is 1.48 g, 1.85 g and 2.22 g for rock, normal soil and soft soil conditions, respectively.

Based on data from the NIBS Technical Manual (1994) on railway bridges and other studies on the seismic fragility of framed R/C structures, the logarithmic standard deviation has been set to $\sigma_{lnR}=0.40$. From this information, one can calculate the probability of damage of a single viaduct span, $P_1(S_a)$.

4.2 Spatial Dependence of Damage

For simplicity, the sequence of damaged/non-damaged spans has been modeled as a Markov chain with binary 0–1 state (1 denoted damage, 0 denotes no damage). Then, for a given spectral acceleration S_a, the mean number of spans in a continuously undamaged viaduct segment, $n_o(S_a)$, and the mean number of spans in a continuously damaged viaduct segment, $n_1(S_a)$, are functions of two probabilities: the aforementioned $P_1(S_a)$ and $P_{1/1}(S_a)$. The latter is the probability that span i+1 is damaged, given that the viaduct experiences a spectral acceleration S_a and given that span i is damaged. This conditional probabililty $P_{1/1}(S_a)$ is an increasing function of $P_1(S_a)$.

4.3 Annual Rates of Derailments and Delays

The general procedure to calculate the rate of derailments and the rates of short, medium and long delays caused by earthquakes is as follows. Let F be the event of interest (F may be Derailment or Short, Medium or Long Delay). For a given seismic early warning system (SEWS), the annual rate $_{F|SEWS}$ is given by:

$$\lambda_{F|SEWS} = \int_M \int_{\underline{x}} \times \left(\sum_s R(M,\underline{x}) E(N_S) P[F|M,\underline{x},s,SEWS] \right) d\underline{x}\, dM \quad (3)$$

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where $R(M,\underline{x})$ is the rate (actually, rate density) per year of earthquakes of magnitude M with epicentral location $\underline{x}$, $E(N_s)$ is the expected number of trains at a random point in time in operational segment s, and $P[F|M,\underline{x},s,SEWS]$ is the probability of F for a train running in operational segment s, when an earthquake of magnitude M and epicentral location $\underline{x}$ occurs and the early seismic warning system SEWS is in operation. The latter probability may in turn be written as:

$$P[F|M,\underline{x},s,SEWS] = \sum_T (P[T|M,\underline{x},s,SEWS]P[F|M,\underline{x},s,T]) \quad (4)$$

where T is the generic trigger/no-trigger status of the early warning system. T has the following logical values: $T=T_{coast}$ for braking triggered by the coastal system, $T=T_{loc}$ for braking caused by the local system and T='No Trigger' in case of no triggering.

A key quantity in the risk analysis is the probability of derailment of a train running in operational segment s, given the occurrence of an earthquake of magnitude M at epicentral location $\underline{x}$, if the SEWS is not triggered. This probability, denoted by $P[DE|M,\underline{x},s,\text{'No Trigger'}]$, is also the probability that a train meets damaged track. Taking into account that a portion of the track is in tunnels, which are considered as not subject to seismic damage, we obtain

$$P[DE|M,\underline{x},s,\text{'NoTrigger'}] = \left(1 - E_{S_a|M,\underline{x},s}\left[\exp\left(-\frac{(L+L_1)/S_1}{n_0(S_a)}\right)\right]\right) \times \left(1 - \frac{tun(s)}{seg(s)}\right) \quad (5)$$

where L is the average length of the train, L_1 is the length traveled by the train after the arrival of the strong phase of the S waves, S_1 is the average length of a single viaduct span, tun(s) is the total length of tunnels in segment s, and seg(s) is the total length of that segment. For the estimation of other probabilities $P[F|M,\underline{x},s,T]$, see Papadimitriou (1995).

5 Annual Risk Results

Figure 2 compares the performance of the three coastal systems in terms of the rates of derailments and of delays with different durations. In all cases shown, the wayside system operates on peak ground acceleration with parameters (A_{loc}, A_{insp1}, A_{insp2}) = (40, 80, 120 gals). The rate of short delays is linked to the rate of derailments through trade-off curves. Also shown in the figure are the annual rates of medium and long delays, which depend only on the operating parameters of the wayside system and therefore are fixed numbers for all three coastal systems.

The annual rates for the current SEWS (System A with $a_t = 40$ gals) are marked as dots in Figure 2 and given numerically in Table 3. The range of values for the rate of derailments refers to ignoring or including the risk of derailment when traffic is resumed following short delays, without inspection of potentially damaged tracks. The estimated rates for the current SEWS system agree well with the average rates during the period (1982–1993), which were previously quoted.

From Figure 2, it may be concluded that, on the whole, differences in the performance under alternative coastal systems are small. The main reason is that, even when a train brakes

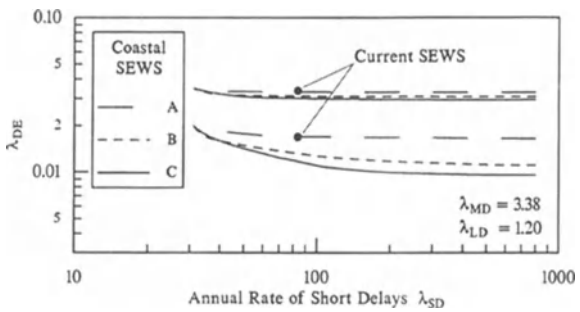


Fig. 2. Performance of three SEWS systems for the case of wayside settings (A_{loc}, A_{insp1}, A_{insp2}) = (40, 80, 120 gals). Derailment rates are shown for the cases when derailment risk following resumption of operation is included (upper curves) or excluded (lower curves)

Table 3. Annual rate of derailments and train delays for the current coastal system

Annual rates	λ_{DE}	λ_{SD}	λ_{MD}	λ_{LD}
Trains/year	0.017–0.033 [a]	82.6	3.38	1.20

[a] Range: min = before; max = after resumption of service following short delays

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due to early triggering of a coastal station, it still covers a large fraction of its braking distance after the arrival of the strong ground motion phase at the track. Therefore, it is mostly the wayside system that reduces the risk on the Tohoku line. Although this system triggers on S-waves, the distance trains must cover while braking (about 3 km for the operating speed of 245 km/h) is a small fraction of the expected distance to the next station, which is the distance trains would ordinarily have to cover if no early warning system were in place.

5.1 Risk decomposition

Analyses of how annual rates are contributed by earthquakes of different magnitudes and of how these rates are distributed along the track are presented in Figure 3. One may see that derailments are caused primarily by earthquakes with magnitudes in the range 7 to 8, whereas long, medium and short delays are caused mainly by earthquakes with magnitudes 7±0.5, 6.5±0.5, 5.5±0.5 respectively. A similar decomposition in distance (not shown here) indicates that all types of events (derailments or delays) are due to earthquakes at distances between 100 and 250 km from the track, with a maximum around 130 km. Figure 3 also shows that risk is not uniform along the line. Variability is due to changes in the distance and activity of the closest seismic sources, traffic load, presence of tunnels and local soil conditions.

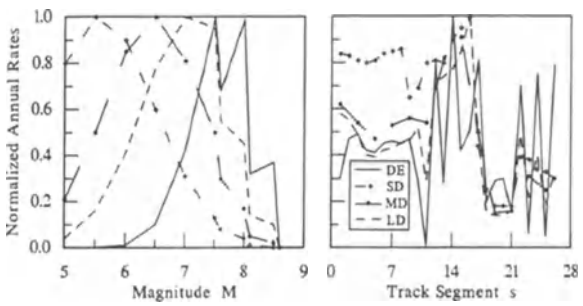


Fig. 3. Normalized risk decomposition for the current SEWS. (a) Decomposition by earthquake magnitude and (b) variation of risk along the track

5.2 Sensitivity analyses

The previous results have been obtained by fixing seismicity, attenuation and fragility parameters to values that we regard as best estimates. Some of these parameters are however affected by large uncertainties. In order to evaluate the effect of plausible alternatives to models and parameters, we have repeated the analysis after changing the values of the parameters one at a time. We have found that seismic risk is highly sensitive to the attenuation model, the soil conditions along the track, and the fragility model of the viaduct. On the other hand, varying the seismicity parameters a and b and the speed of the trains within reasonable ranges does not significantly alter the results.

6 Optimization of the Seismic Early Warning System

By choosing the most appropriate system and adjusting its operating parameters, the performance of the SEWS can be improved relative to the current delay rates, derailment rate, or both. From extensive comparisons, we have reached the following conclusions:

Alternative SEWS Systems. The three coastal systems considered reduce the rate of derailments by comparable amounts. The reason is that the SEWS share the same wayside sub-system, which is the one mostly responsible for avoiding derailments. The coastal system has no effects on the rates of medium and long delays, which are entirely controlled by the wayside system. On the other hand, the coastal system is the primary cause of short delays, which depend on the level of ground motion A_{coast} at which automatic train braking is initiated.

Alternative Measures of Seismic Intensity. Coastal Systems A and B require specification of the parameter (e.g. a_{max}, or S_a) that measures earthquake intensity and causes trains to stop (System C does not, since it uses an empirical correlation with earthquake magnitude and epicentral distance). In addition, for all systems, one needs to specify the measure of earthquake intensity to be used by the wayside stations. At present, both the wayside and coastal stations operate on a_{max}. We have found that there is little benefit from changing the intensity measure for the coastal stations, which

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therefore may be kept as a_{max} for Systems A and B. By contrast, there is great advantage in changing the intensity parameter of the wayside stations from a_{max} to S_a, as the latter parameter is much better correlated with damage to the viaduct.

Setting of Trigger Levels. We have made extensive analyses of the derailment and delay rates under different trigger levels of a_{max} at the coastal stations and S_a at the wayside stations. Of course, an increase in the trigger level produces an increase in the rate of derailment and a decrease in the delay rates. We have found that the rate of short delays can be reduced very significantly by: a) increasing the trigger level of the coastal system, and b) setting the train-brake level at the wayside stations equal to the level for on-train track inspection. The other two trigger levels at the wayside, which are associated with on-train and on-foot inspection, can be further varied to control the rate of medium and long delays. If S_a is used, then increasing these inspection thresholds does not significantly affect the rate of derailment.

Table 4a gives the derailment and delay rates for selected 'optimal' settings of Systems A, B and C, when the wayside stations operate on a_{max}. Similar results when the wayside stations operate on S_a are shown in Table 4b.

Comparing the current SEWS performance (see Table 3) to that of the above alternatives, one concludes that an S_a-based system with optimally chosen parameters can decrease the rate of delays by a factor of about 40 and reduce the rate of derailment by about 50%.

7 Conclusions

From studying the effectiveness of the current Seismic Early Warning System for the Tohoku Shinkansen and comparying it with alternatives, we have reached the following main conclusions:

- The risk of derailments under the current system is 2–3 earthquake-induced derailments per 100 years.
- Risk varies along the Tohoku line, depending on the local soil conditions, the location and length of tunnels, the traffic load and the proximity to the main seismic sources.
- The risk of derailment is sensitive to local soil conditions, the attenuation model and the seismic fragility of the viaduct structure; it is less sensitive to the seismicity parameters and the train speed.
- By changing the way in which the early warning system operates, one can reduce the number of delays by about 40 times, while

Table 4a. Alternative systems (A1, B1, C1), using a_{max} as the intensity parameter at the wayside system

Annual Rates	System A1: $a_t = 60$ gals (100, 100, 140 gals)[b]	System B1: $b_t = 60$ gals (100, 100, 140 gals)[b]	System C1: $c_t = 3.2$ (100, 100, 140 gals)[b]
λ_{DE}[a]	0.029–0.038	0.023–0.037	0.021–0.036
λ_{SD}	24.1	20.4	19.3
λ_{MD}	1.51	1.51	1.51
λ_{LD}	0.69	0.69	0.69

Table 4b. Alternative systems (A2, B2, C2), using S_a as the intensity parameter at the wayside system

Annual Rates	System A2: $a_t = 80$ gals (280, 280, 360 gals)[c]	System B2: $b_t = 120$ gals (280, 280, 360 gals)[c]	System C2: $c_t = 4.0$ (280, 280, 360 gals)[c]
λ_{DE}[a]	0.015–0.015	0.015–0.015	0.015–0.015
λ_{SD}	12.4	1.2	1.7
λ_{MD}	0.18	0.18	0.18
λ_{LD}	0.16	0.16	0.16

[a] Range: min = before; max = after resumption of trains following short delays
[b] (A_{loc}, A_{insp1}, A_{insp2})
[c] ($S_{a,loc}$, $S_{a,insp1}$, $S_{a,insp2}$); used when S_a is used at the wayside system, instead of a_{max}

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limiting the rate of earthquake-induced derailments to 1.5 per 100 years. These benefits can be obtained by changing the measure of seismic intensity at the wayside system from peak ground acceleration a_{max} to response spectrum acceleration S_a and by setting the wayside trigger level equal to the first inspection level. Changing the way the coastal system operates would not be equally beneficial.

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VIII The Role of Satellite Techniques in Early Warning Systems: State-of-the-art and Perspectives

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CHAPTER 8.1

Toward an Integrated Space Strategy for Disaster Management

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1 Introduction

The world community could better mitigate the human and economic losses caused by disasters if data from current and planned Earth Observation (EO) satellites were employed more effectively in disaster management support. Satellites have long been used to support forecasting of intensive weather hazards such as tropical cyclones, severe storms and flash flooding. However, although there have been numerous research and operational demonstrations that illustrate the potential usefulness of EO satellite data for a broader range of hazards, the operational application of these data to other hazards is rare. To address this opportunity, the Committee on Earth Observation Satellites (CEOS) has initiated a project on disaster management support. Within that project, several hazard teams have been formed. These teams are charged with compiling user requirements; identifying shortcomings and gaps in the provision of required satellite data; and developing recommendations for alleviating them. This paper describes that project – its objectives, approach, and structure.

2 Background

The International Federation of Red Cross and Red Crescent Societies estimates that the annual global economic costs related to disaster events average over USD 440 billion per year. Over a three-year period from 1992 to 1995 the United States alone experienced losses amounting to, on average, approximately one billion dollars per week due to natural hazards. While natural and, to some extent, technological hazards are inevitable, the impacts of hazards can be mitigated and in some cases even prevented.

Today, meteorological satellites are widely used to detect and track severe storms and other weather-driven events. However, while there have been a great many research and operational demonstrations that illustrate the potential usefulness of EO satellite data for other hazards, the operational application of these data to a broader range of hazards is rare. Recognizing the potential benefits that could be gained from better application of satellite data to natural and technological hazards, CEOS formed a Disaster Management Support Project and charged it to explore ways to achieve this aim. This project is one of a family of projects that were initiated by CEOS and supported by other partner organizations to improve the planning for future satellite missions and the use of EO satellite data across a broad spectrum of application areas.

CEOS was formed in 1984, in response to recommendations from the Economic Summit of Industrialized Nations Working Group on Growth, Technology, and Employment's Panel of Experts on Satellite Remote Sensing. This group recognized the multidisciplinary nature of satellite-based EO and the value of coordination across all proposed missions. In CEOS, providers and users of EO satellite data also

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work together to promote the effective use of data from such satellites.

3 Uses of EO Satellites

Today, several countries operate what are termed "operational environmental" satellites to support weather and climate forecasting. Those that operate in geostationary orbits are noted for their contribution to severe weather monitoring and forecasting, including tropical cyclone tracking and prediction. A key capability of the geostationary satellites is their ability to view (or "revisit") fast developing weather systems frequently (e.g., every few minutes to every 1–3 hours, depending on the satellite system). Polar-orbiting environmental satellites provide global coverage, supporting less frequent but worldwide observations.

Both classes of satellites have shown benefits for volcanic ash cloud detection in support of aviation safety. Since the high altitude ash plumes from volcanoes can be transported over long distances, the problem of monitoring them is a global one. Satellites provide a valuable complement to ground-based and airborne sightings (e.g., airline pilot reports).

Many countries have signed agreements forbidding the dumping of waste materials in the marine environment. Much of the public concern behind these agreements arose from incidents in which tons of oil were released into coastal ocean regions from oil tanker accidents. However, the total spillage from such incidents in terms of volume of oil released is less than that released as illegal discharges due to tank cleaning activities. Using satellite-based sensors (notably Synthetic Aperture RADAR), it is possible to detect oil slicks from tank dumping or accidents in a wide range of environmental conditions, day and night. However, mission constraints such as the frequency of revisit of a site and spatial coverage capability of the satellite exist to varying degrees with current satellite systems.

According to the International Federation of Red Cross and Red Crescent Societies, over 46% of annual, worldwide disaster costs between 1990 and 1994 were due to flooding. Satellite data are used today in the prediction of flood events, including flash flooding. Opportunities exist for improvements in preparedness, response and recovery activities through expanded use of EO satellite data.

In the current decade, large-scale, intensive droughts have been observed on all continents leading to huge economic losses, destruction of ecological resources, food shortages, and starvation of millions of people. In the past eight years, satellite data have become an important drought monitoring and forecasting tool, especially over large regions.

The capabilities and limitations of EO satellite data for a variety of hazard types, phases, and users are being considered by the CEOS Disaster Management Support Project.

4 Project Overview

The specific foci of the Disaster Management Support Project are:

1. To identify ways to provide improved information services, derived from EO satellites and other sources, for use by disaster management organizations;
2. To facilitate the operational use of such services;
3. To identify the need for changes in the space segment to meet user requirements including, for example:
   - Faster collection of remotely sensed information (e.g., using more satellites with requisite capacity; different orbits; or more frequent data transmission);
   - New or improved sensors for hazard detection;
4. To foster the creation of more effective disaster information systems to support disaster management activities.

Project participants recognize that the project needs to leverage off of work already underway around the world, including numerous national and regional research programs, demonstration projects, and fully operational systems where they exist. Therefore, the first few project meetings focused on an extensive review of related activities. During 1997, project meetings were held in Europe (Belgium and England), Asia (Japan and India), and a related meeting was held in the United States.

A good understanding of the requirements of the diverse range of users is needed as an early step toward planning for improved support services derived from EO satellite data. To accomplish this, the project needed information from

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emergency management authorities and other users and data providers to develop and refine a set of profiles of user requirements for this application area. But due to the large numbers and variety of types of users, such interactions are most effectively established and maintained at a local or regional level. Therefore the approach of this project has been to work with organizations that have broad geographic responsibilities, in order to benefit from their experience and to effectively communicate with a broad range of users around the world.

Today, project participation is strong and growing. Participating organizations include space agencies (all are members of CEOS), national and regional agencies responsible for disaster reduction and response programs, as well as a number of international organizations and research programs. For example, the United Nations International Decade for Natural Disaster Reduction involves disaster management authorities from more than 140 countries.

Other participating organizations include: the European Commission (EC) DG XI Civil Protection Unit, that works with civil protection departments of EU member states; Japan's National Research Institute for Earth Science and Disaster Prevention; the Council of Europe; and the US Subcommittee on Natural Disaster Reduction, made up of 19 member agencies and departments.

5 Hazard Teams

The utility of EO satellite data may vary greatly according to the type of hazard (e.g., flooding, earthquake), disaster phase (e.g., preparedness, mitigation, response and recovery), user level (e.g., international, national, regional, or local) and operational status (e.g., research vs. operational).

Several hazard teams have been formed to address information requirements for specific hazard areas: drought, earthquakes, fire, flooding, oil spills, tropical cyclones and volcanic ash. These teams are charged with progressively reviewing existing documentation and current practices for handling their respective hazard types; compiling user requirements; identifying shortcomings and gaps in the provision of required information; and presenting recommendations to CEOS for rectifying deficiencies and improving capabilities. These recommendations should not only address the space segment (e.g., satellites and sensors), but also any areas that need improvement in the information delivery and utilization area (e.g., timely information delivery, easier data access, improved sensor validation).

During the week of March 30, 1998, the project held a workshop in Silver Spring, Maryland (US) hosted by the US National Oceanic and Atmospheric Administration (NOAA). Nearly 100 participants from North America, Europe, and Asia attended. Each of the hazard teams and the information server team held working sessions at the meeting. The hazard teams have prepared interim reports on their work. More comprehensive reports are expected over the next year.

6 Information Server

In general, real time information on the development of hazards, as well as general information on risks, hazards, and opportunities remains fragmented and difficult to access. To begin to address these and other gaps, prototype tools are being developed. NOAA is sponsoring a prototype information server for the project. This server is intended to demonstrate timely access to satellite-derived data and information products (i.e., "one stop shopping") to support various facets of disaster management. A number of agencies are participating in the development of this service, providing links to their data and information services, and developing additional support tools for the project. These efforts are coordinated via a project information server team.

7 Project Information

Current information for the project, its hazards and information server teams, and current and retrospective examples of satellite data and information related to selected hazards may be obtained at *http://www.ceos.noaa.gov.* For more information contact: Helen M. Wood (Chair), NOAA, Tel: 1-301-457-5120, Fax: 1-301-457-5184, E-mail: Helen.Wood@noaa.gov, or Kenneth Inglis (Vice Chair), EC/KEMSAT, Telephone: 32.2.345.7190, E-mail: ken.inglis@club.innet.be

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CHAPTER 8.2

The Satellite Techniques in Early Warning Systems for Large Towns and Megacities

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Abstract

The problem under consideration here is Russian operational practice concerning the use of remote sensing, access to satellite date and global communications technologies (especially the World Wide Web) for the environmental management of the megapolis Moscow and other large cities. Environmental space monitoring and global communications technologies are vital for early warning systems and pollution mitigation. Earth observation by remote sensing from space should be considered an essential part of the early warning systems for megapolises like Moscow. The Space Research Institute of the Russian Academy of Science, has developed megacity environmental monitoring based on space data.

1 Ecological Problems of Moscow

Three main ecological problems of Moscow megapolis are as follows: pollution due to automobile use, purity of water resources and preservation of woodland parks and zones.

In 1994–1995 the amount of cars in Moscow increased by more than 700 000 units, so that at present more than 2 000 000 cars are utilised in the city (area of Moscow $\sim 1000\,km^2$, population about 10 million). Car speed in the inner city often does not exceed 12–15 km/h, and 9000 tons of fuel are consumed per day. The total amount of pollution in the air reaches 1.7 tons per year (97% of air pollution). Air pollution is the reason for 25–30% of all deaths. Transport air pollutants also manifest themselves in waters, in soils, as well as in plant degradation.

Ensuring purity and rational use of water resources implies monitoring river and water reservoir quality on the basis of spectral remote observations and comparison with in-situ data.

The preservation of park zones and water resources requires monitoring the state of woodland parks and protective forest areas around Moscow, and monitoring of forests surrounding the sources of drinking water (the basins of the Moscow and upper Volga rivers).

2 Satellite Data

Ecological monitoring of the Moscow megapolis is based on information from U.S. meteorological satellites of the NOAA series and from Russian meteorological satellites of the RESURS series.

American meteorological NOAA-series satellites are supplied with optical observation system AVHHR: Advanced Very High Resolution Radiometer. NOAA satellites have polar orbits with inclination 98.89° and altitude 830–870 km. Spectral devices AVHHR observe the Earth in 5 spectral bands: 580–680; 725–1100; 3350–3930, 10 500–11 500; and 11 500–12 500 nm. Spatial resolution is about 1.1 km, the swath width is 2700 km. The images from NOAA satellites are being transmitted to the Earth in real time by the HRPT (High Resolution Transmission) regime. Ground sta-

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tions receive the images within a circle of 4000 km in diameter with radiometric resolution of 10 bits, which provides transmission of 1,024 levels of brightness in every spectral band. Information is renewed on average every 6 hours.

Russian meteorological satellites RESURS (helio-synchronous orbit, altitude 678 km) are supplied with opto-electronical scanners of two types. The scanner of high-resolution MSU-E has a spatial resolution of 35×45 m, swath width is 45 km, spectral bands are 500–600, 600–700, and 800–900 nm. The scanner of moderate resolution MSU-SK has a spatial resolution of 150×250 m, swath width is 60 km, spectral bands are 500–600, 600–700, 800–900, and 10 400–12 600 nm.

At the present time satellite information is used in the Space Research Institute for the following purposes: supplying meteorological data; providing measurements of land temperature; providing observations of atmospheric fronts dynamics; the detection of hurricanes; providing spectral measurements to reveal technogenic influences on the state of vegetation in the city and in suburban forest areas; to recognise interseasonal changes along highways in suburban areas; detection of strong fires in forests around the city; to recognise smoke traces from industrial plants; observing snow cover dynamics and forecasting flood danger; the detection and estimation of large floods. All these data are supplied by optical and IR observations.

3 Ground Stations

Ground stations for receiving satellite information carry out the demodulation of satellite signals and the primary processing, and prepare the information for further processing. The stations work continuously. Images of the Earth from NOAA satellites contain information on cloudiness and on the Earth's surface in visible and IR-bands. Digital information from NOAA satellites is being obtained on frequency 1.7 GHz (S-band, regime HRTP) at a rate of 100 Kbit/s. Following minor modernisation the above mentioned ground stations are now able to receive data from Russian RESURS satellites. Software provides complete processing of data, including satellite orbit calculations; data receiving; archiving of data; and topical processing within a few hours of receiving the signal.

Every station possesses a program for automatic observation of a satellite. Other functions of the software are to receive and decipher data; carry out primary processing and fragmentation of data; matching data to the geographic map; meteorological analysis of AVHRR data; spectral and correlation analysis of data; classification of multiband data; processing of images. Besides Moscow, regional centers of space monitoring were also established in Irkutsk, Vladivistok, Yakutsk, Krasnoyarsk, Dnepropetrovsk (Ukraina), Alma-Ata (Kazakhstan). These stations provide data processing and transfer to users both from NOAA satellites, able to receive space information, and from Russian meteorological satellites RESURS. Satellite information processed by such stations may form a basis for operative environmental monitoring of large territories in Russia.

Implementation of early warning systems is best done by exploiting the network of small ground-based regional stations and through the open system for on-line access to NOAA meteorological satellites. The Space Research Institute (IKI RAN) station installed in Moscow covers entire European Russia and Western Syberia. Two stations in Moscow and Irkutsk cover more than 70% of all Russian territory. Satellite data might also help local authorities solve environmental problems.

4 Information Support for Monitoring

The remote access system is based on the Internet's Word Wide Web information service, using the computer hypertext concept. WWW-technologies of Internet networks allow the presentation and exchange of data for space environmental monitoring. Computer networks and remote sensing technologies will play a major role in improving hazard identification and risk assessment, disaster preparedness, and monitoring for early warning.

The Russian Space Science Internet (RSSI) was established in 1994 as result of cooperation between NASA and IKI (Space Research Institute). NASA provides network routing equipment and the telecommunication infrastructure from NASA to IKI. RSSI operated by IKI provides network support and management within Russia. The satellite 256 Kbit/s link connects RSSI with the Goddard Space Flight Center

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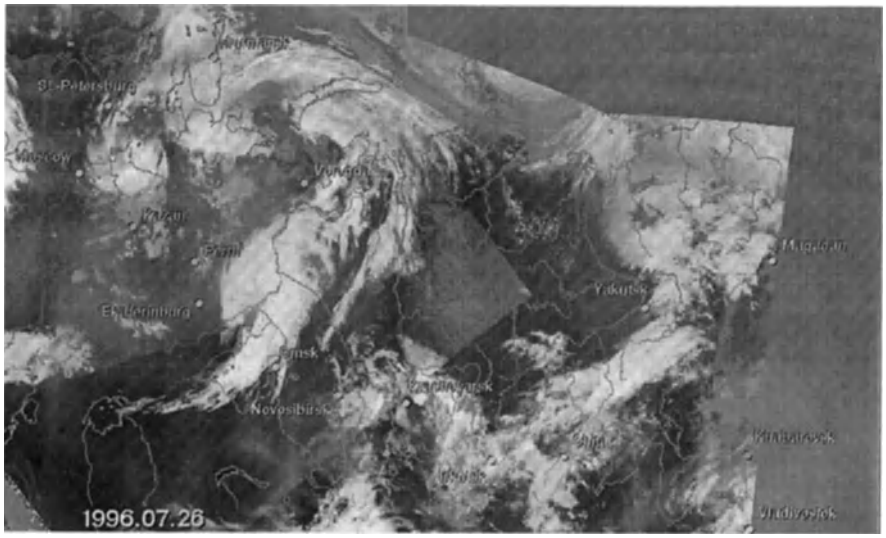


Fig. 1. Example of the cloudiness image, obtained over all Russia. This image, obtained by NOAA satellites, combines data from Moscow and Irkutsk ground stations and covers near 70% of the Russian territory

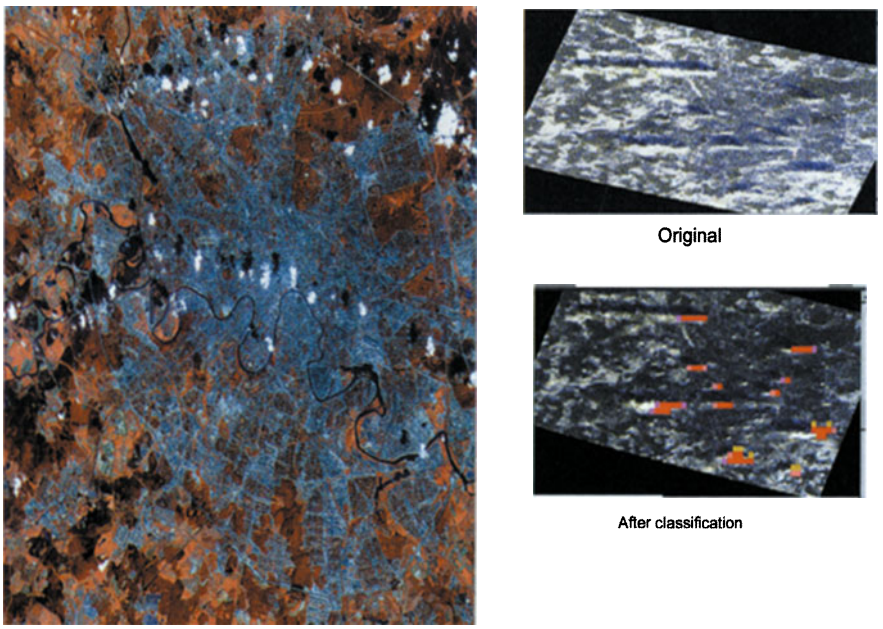


Fig. 2. Optical image of Moscow from RESURS satellite (Fig. 2 a) IR-image (Fig. 2 b) demonstrating thermal anomalies connected with power plants

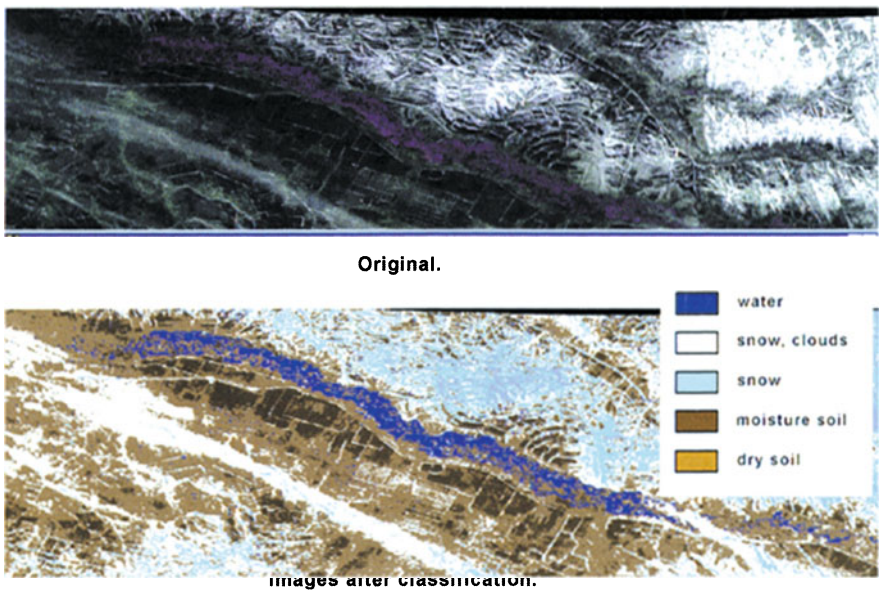


Fig. 3. Image of the Ural river flood near Orenburg (South Ural)

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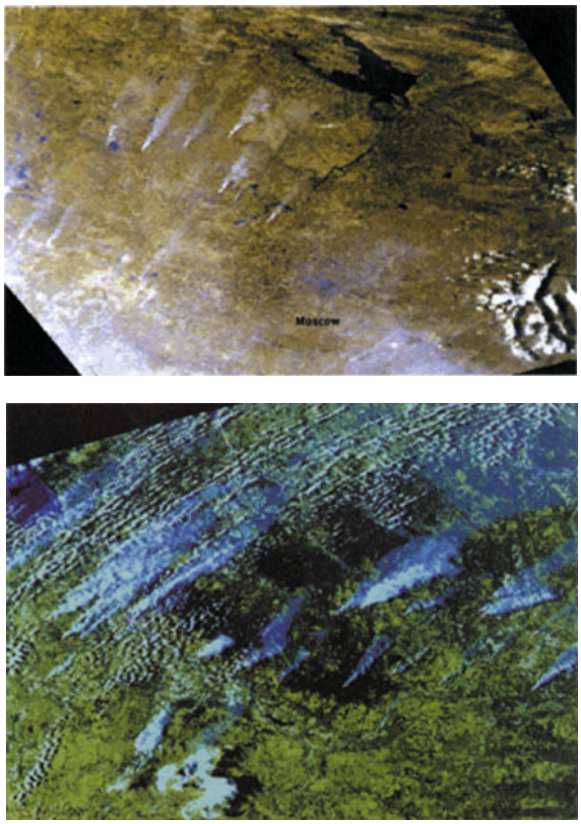


Fig. 4. Forest fire in Moscow suborn

(NASA). Since 1995 IKI is an IP-node Southern Moscow Fiber Optic Backbone (10 Mb/s) founded by the International Science Foundation. This allows RSSI to integrate the main Russian scientific and educational network resources and optimize network traffic using high speed FDDI media. NASA Internet provides connection to the global Internet for IKI and Russian users.

IKI put into operation an environmental server with information resources for the analysis of natural and technogenic disasters.

5 Illustrations

The following figures provide a few examples of early warning system options for large cities in Russia. Figure 1 represents an image of cloudiness over all Russia, obtained by Moscow and Irkutsk (East Siberia) ground receiving stations. Figure 2 shows an optical image of Moscow from RESURS satellite (Fig. 2a) and thermal IR anomalies, relating to power plants (Fig. 2b). Image of the Ural river flood near the large Orenburg city is presented in Fig. 3. Finally, Fig. 4 demonstrates an image of forest fires in Moscow suborn.

Acknowledgements

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Monitoring Fires with European Remote Sensing Satellite, ERS-2: The "Rush ATSR Fire Product" Demonstration

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1 Introduction

Every year land fires burn millions of hectares. Besides natural phenomena, which are actually responsible for the minority of fire events, human activities are causing most of world's land fires. Fires associated with particular climatic conditions such as drought and wind, when combined with a consistent vegetation "fuel", can easily degenerate into exceptional fire events like those that occurred in South East Asia in '97–'98 and in South America in the Spring of '98.

These fires burn for many days and can that evolve from agricultural clearing into large forest fires, thus generating an environmental disaster damaging the whole ecosystem: land, air, humans and animals.

Such dramatic evolution has captured world's attention, but land fires are not exceptional events. They occur daily and extensively in many parts of world, according to seasonal burning activity. Evidence of this can be derived from historical FIRE ATLAS (Arino et al. 1997) data sets. Constant fire activity is estimated by Levine et al. (1996) to be responsible for a massive injection of chemical particles into the atmosphere with consequent climate changes. Satellite remote sensing data providing systematic Earth observations, are the best source of long-term monitoring of land parameters to be integrated in Early Warning and Global Change analysis.

2 Rationale of Rush ATSR Fire Demonstration Activity

In September 1997, whilst promoting space technology to support the management of natural disasters, ESA began a demonstration activity by prototyping the "Rush ATSR (Along Track Scanning Radiometer) fire product" derived from ERS-2/ATSR-2 instrument data. The "Rush ATSR fire" activity is aimed at demonstrating the feasibility of a fast user-oriented service using the existing infrastructure for acquiring, processing and distributing ERS data. In this way, a consistent set of information regarding active fires is generated, managed and presented to users. The purpose is to promote the use of the ATSR data and get feedback and suggested requirements for improving future products, thus making them more suitable for community needs. The "Rush ATSR Fire" activity has provided an important opportunity to combine ERS/ATSR and ERS/GOME instruments in preparation for the ESA future missions ENVISAT and Earth Watch. With its high spectral resolution, GOME is able to detect atmospheric trace gases, in particular it can measure the concentration and spatial distribution of nitrogen dioxide (NO_2) correlated in time with the hot spots detected from the ATSR instrument.

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3 The Rush ATSR Fire Product

The Rush ATSR fire product (Fig. 1) uses data derived from the ATSR-2 instrument, currently flying on board the ERS-2 satellite (Stricker et al. 1995). The instrument raw data collected during a whole orbit are recorded on-board and dumped at ESA ground stations during the satellite overpass (ESA 1991). In this way, it is possible to collect global world coverage at 1-km resolution at few stations. To extract fire information, ATSR nadir view data are first processed into standard Gridded Brightness Temperature (GBT) products (RAL 1995), in order to get calibrated infrared measurements (Multlow et al. 1994).

Hot spot detection within the Rush ATSR fire processing is carried out for night-time data only (Buongiorno et al. 1997). During the night, the area sensed by the instrument is not affected by reflected solar radiation and an increase in 3.7 mm brightness by temperature above the background temperature indicates the presence of an hot area according to the Plank Function. As the ATSR instrument saturates in channel 3.7 μm at 312 K (Mason 1991), it has been decided to geo-localise and mark as a "hot spot" all pixels saturated in this channel. It is important to say that the detection of a hot feature, whether it produces a saturation or not, can also occur if the fire is occupying a sub-pixel fraction (Dozier 1981; Robinson 1991). This means that a fire smaller in extent than the instrument spatial resolution can produce a signal detectable at pixel level.

To give users the possibility of a more accurate inspection of hot features, a colour composite image is also provided within the Rush fire product, representing the combination of 11 μm and 3.7 μm Brightness Temperatures (Fig. 2).

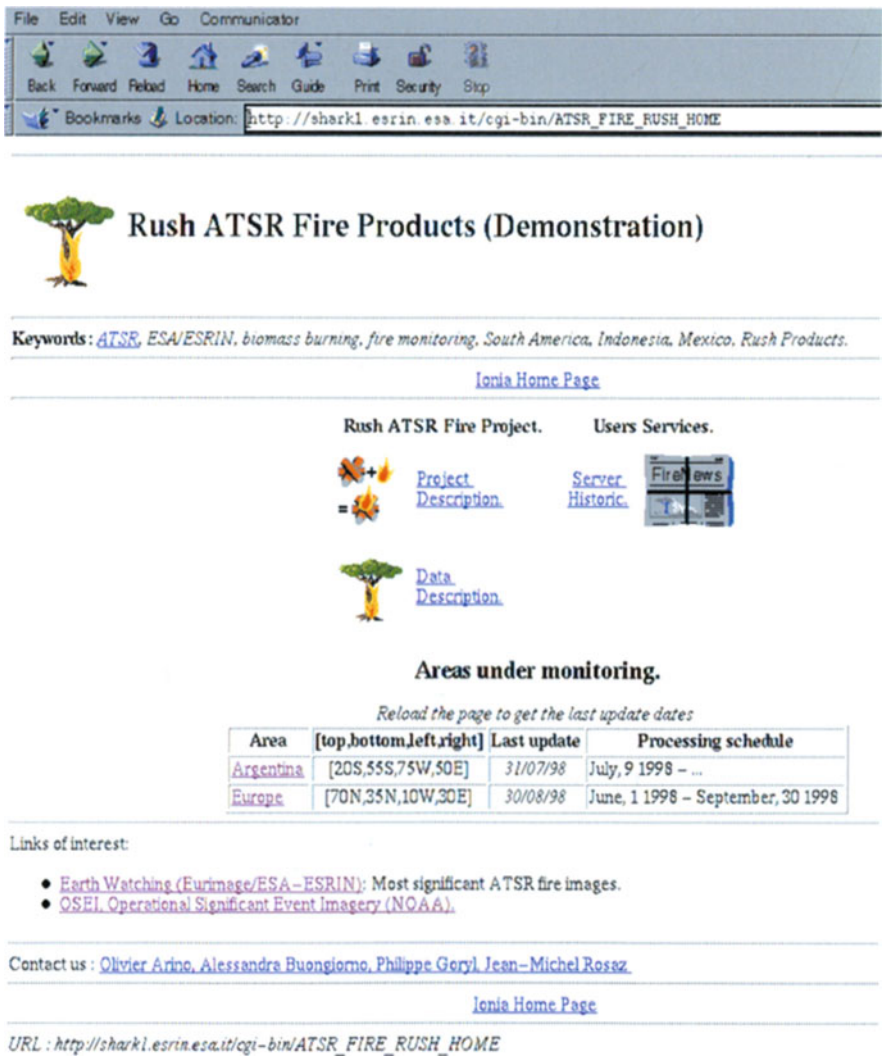


Fig. 1. The Rush ATSR fire product – a demonstration in the Internet

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Fig. 2. Colour composite image provided by the Rush ATSR fire product (explanation see text)

When the surface temperature increases, the contribution in red (3.7 μm BT) and in green channels ((3.7 μm+11 μm)/2 BT) become stronger than the blue one (11 μm), resulting in a visible creamy yellow colour on the grey background. Saturated pixels are marked in red. The hot features detected by ATSR are highly likely to exist, but some fires can be missed or partially underestimated due to clouds, atmospheric effects and the bi-directionality of emissivity.

4 Rush ATSR Product Availability

To make the information collected during the demonstration activity, widely available a dedicated web page has been developed for the Rush ATSR fire product, and has been accessible since April 1998 from ESA WWW services (*http://shark1.esrin.esa.it/FIRE/*). The Rush ATSR WWW page shows, according to monitored area, the daily processed ATSR data. When one or more hot spots are detected within an ATSR frame, the corresponding Rush Fire Product files are linked and accessible from the page. The Rush fire information is maintained on-line for 30 days and after this period the most significant events remain on-line on the Earth Watching page (*http://earth1.esrin.esa.it:8080/ew*). Currently, for the purpose of this demonstration activity, new information is available within 2–4 days of the acquisition of ERS low bit rate instrument data at the ESA Ground Stations in Kiruna (Sweden) and Gatineau (Canada). A demonstrative, near-real-time availability of Rush ATSR fire products is planned with the forthcoming ATSR Real Time processing facility installed at the Tromsoe Satellite Station (Norway). With the near-real-time processing capacity, ATSR fire information can be provided on-line a few hours after sensing.

Due to the global availability of ERS/ATSR data, users can request, through the WWW

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page, a specific area to be put under monitoring as has been done for Mexico, Malacca, China and Argentina. Seasonal monitoring over large tropical area like Brazil, Indonesia and Central Africa can be determined from the historical fire atlas information. The spatial and temporal correlation of fire distribution is evident from the comparison between fire events detected with ATSR in 1997–1998 and those from AVHRR in 1993 (Fig. 3a–d).

As part of a specific demonstration, Europe was monitored from June to August 1998. The amount and spatial distribution of detected hot spots is visible in Figure 4.

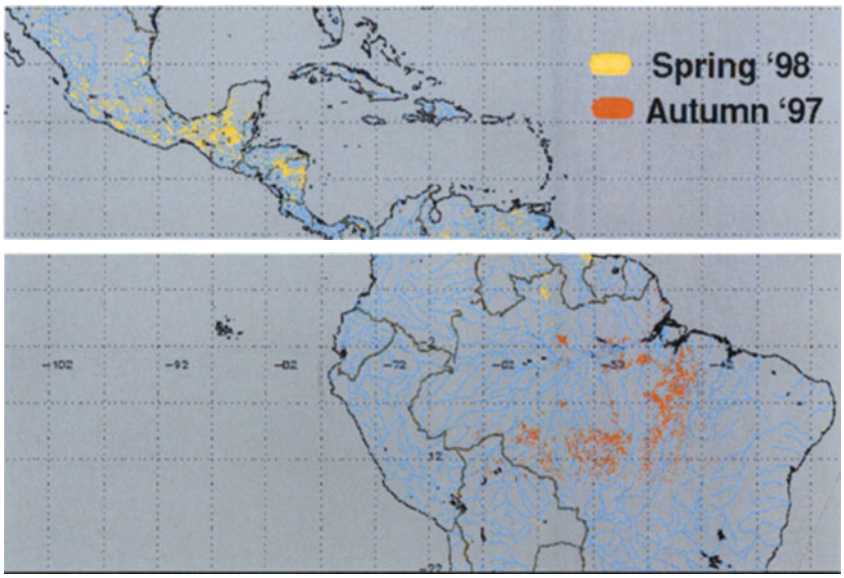


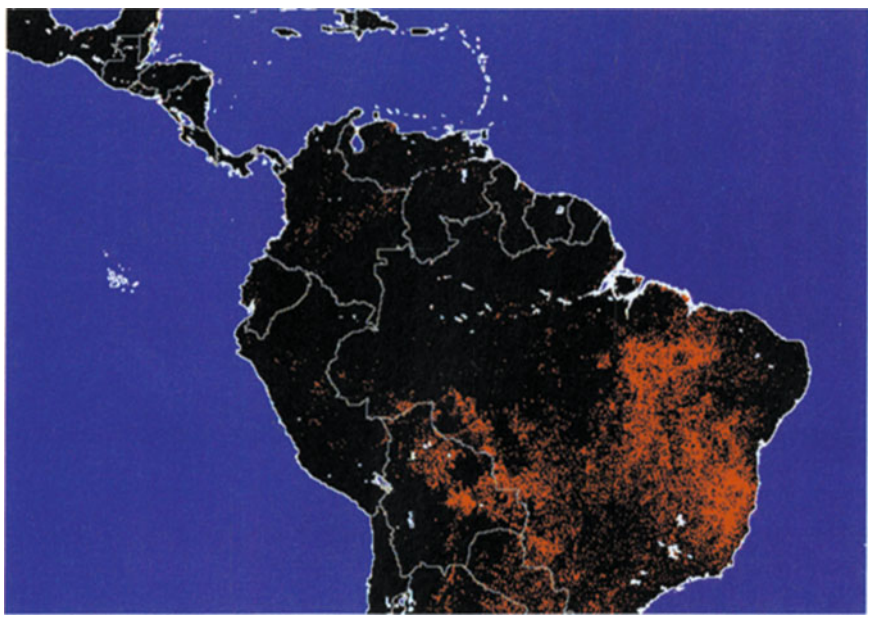
Fig. 3a. Fire events detected with ATSR in autumn 1997 and spring 1998: Mexico and Brazil

5939 Hot Spots in 119/380 ATSR night time frames **Aug '97-Nov '97**
7721 Hot Spots in 266/2436 ATSR night time frames **Mar '98-May '98**

Fig. 3b. Fire events detected with AVHRR in September 1993

South American continent : September 1993

57673 fires detected. **108** images used (108 HRPT.).
September 1993 Fire location file (499 Kbytes)



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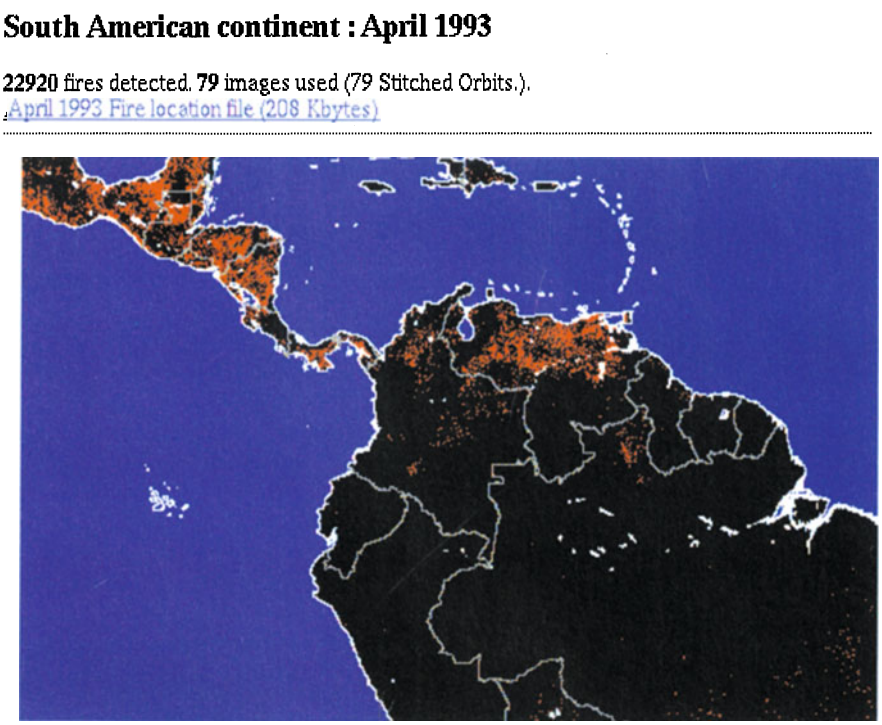
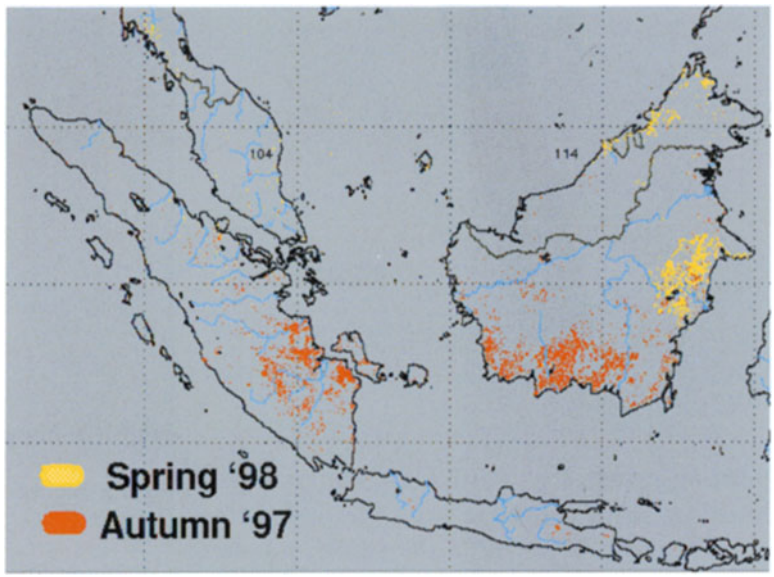


Fig. 3c. Fire events detected with AVHRR in April 1993



13484 Hot Spots in 102/1097 ATSR night time frames **Aug '97-Nov '97**
4896 Hot Spots in 103/487 ATSR night time frames **Mar '98-May '98**

Fig. 3d. Fire events detected with ATSR in autumn 1997 and spring 1998: Indonesia

5 Synergy with GOME and ATSR

Whether land fires require warning or not, they do introduce a significant amount of gases and aerosols into the atmosphere, which contribute to global warming, acid precipitation and changes in Earth's radiation budget. The long-term effect on the Earth's climate involves the whole planet's ecosystem. To quantify the effect of biomass burning as a source of gases and particles in the atmosphere, the recent experience gained by combined use of GOME and ATRS appears promising, and it should be more carefully investigated and validated. The Global Ozone Monitoring Experiment (ESA 1995) is a spectrometer which measures solar

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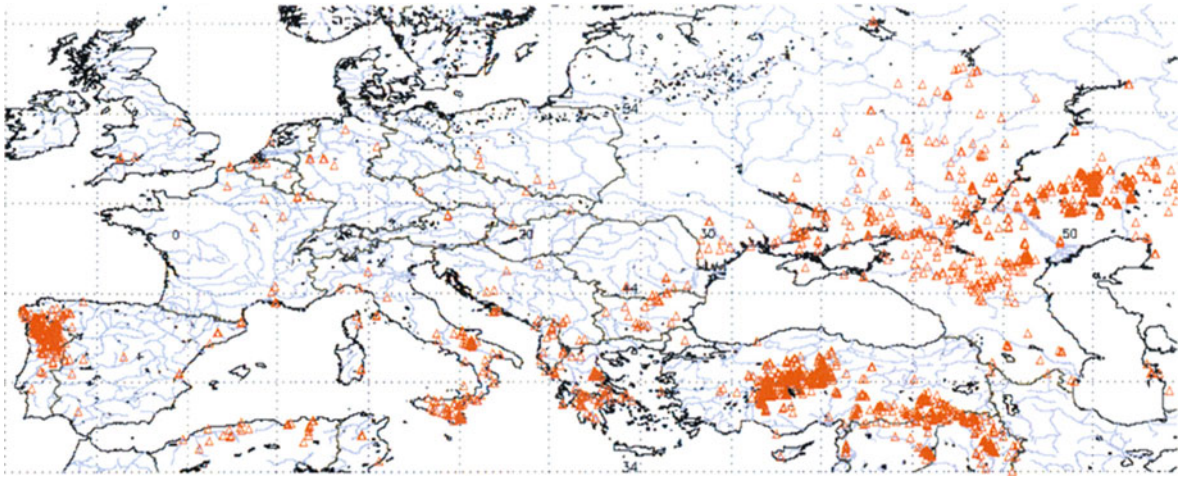


Fig. 4. The amount and spatial distribution of detected hot spots in Europe. Monitored from June to August 1998

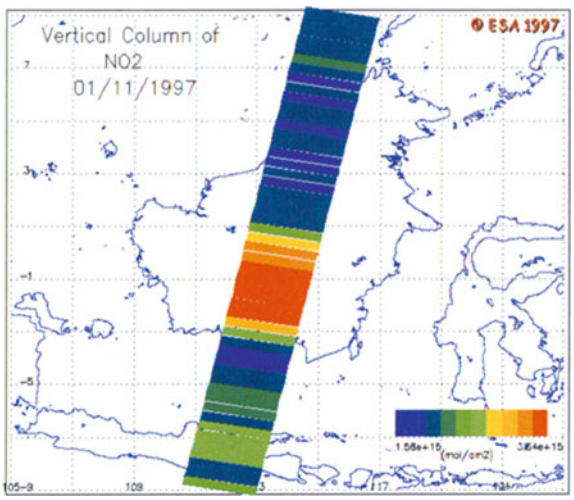


Fig. 5a. The NO_2 total column amount extracted from GOME central pixel

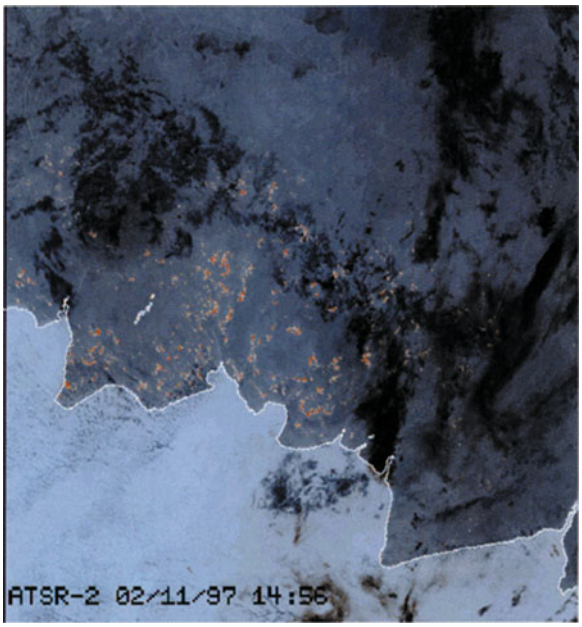


Fig. 5b. Night-time ATSR fire image over the same area as Figure 3a

radiation scattered by Earth's atmosphere or reflected by Earth' surface in nadir viewing geometry. The main objective of the GOME mission is the monitoring of total ozone distribution, its spectral range and high spectral resolution, however also allows the retrieval of other important trace gases (ESA 1996). The GOME level 2 product, generated at the German Processing and Archive Facility (D-PAF) contains in addition to ozone, the trace gas NO_2. The NO_2 total column amount has been extracted from GOME central pixel and compared with the night-time rush ATSR fire image over the same area (Fig. 5a and 5b). The results clearly indicate the correlation of the two events, and from the GOME data is it possible to quantify the amount of NO_2 detected.

6 Conclusion

At the request of the user community, the feasibility of a Rush Fire service from satellite sensing to the end-user has been fully demonstrated and dimensioned: more than 100 Gigabytes of data from over different parts of the world were processed in one year. Satellite missions dedicated to fire monitoring (FUEGO, FireSat) are planned for the near future, but to benefit from this enhanced monitoring capacity, practical experience is important to understand community needs and to

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prepare future products and infrastructures to prevent and react quickly to fire disasters. Remote Sensing data provide a valuable amount of information for preventing and detecting fires. Multispectral data analysis allows us to compute consistent sets of land parameters which are needed to determine, in advance, the potential evolution and risk associated with land fires. Long term fire observations together with land parameters are necessary for improving fire early warning capacity. Global mapping of land fires combined with atmospheric instrument data can quantify the environmental impact caused by fires, thus providing a significant contribution to global change analysis.

Acknowledgments

P. Goryl, J. Rosaz and P. Colagrande for their support in data processing and the setting up and maintenance of the Rush ATSR Fire WWW page.

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CHAPTER 8.4

Remote Sensing and GIS for Warning of Geological Hazards: Application in Vietnam

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Abstract

Satellite imaging has enabled us to make great progress in Earth observation and geological mapping. It also provides us with a very powerful tool for the prediction and warning of geological hazards. We deal with three applications in Vietnam: seismic hazard assessment, landslide hazard and coastal zone erosion. The most important application is the estimation of seismic risk. We use LANDSAT/TM, SPOT/HRV, radar and airborne images to determine active fault length, fault characteristics (normal, reverse or strike-slip; slip rate) and horizontal displacement accumulated during the Holocene. Directional filtering of SPOT/HRV and LANDSAT/TM images combined with Digital Elevation Modelling (DEM) from topographic data and radar images can detect active fault segments. The parameters are used to estimate the maximum credible earthquake magnitude. The results of satellite analysis are combined with other data such as geomorphology, topographic DEM, earthquake epicentre, radon distribution, stress field, using a Geographical Information System (GIS). It can be combined with an intermediate method of earthquake prediction, such as M8, for precisely locating a major event. Remote sensing has provided evidence for a weak dyke zone in the Red River delta. This weak dyke segment results from active faulting in the delta.

High resolution SPOT panchromatic and airborne images are useful for the identification and observation of large landslides. We combined this data with a topographic DEM and recognised a large landslide circle. GIS modelling can estimate the different levels of landslide hazards in the region. With the very high resolution of satellite imaging and radar interferometry in the next future, we can expect high precision warnings for this phenomenon.

By comparison of satellite images made at different times and using various topographic maps, we can calculate the rate of erosion in coastal zones. The erosion of coastal zones is a general problem in Vietnam. In some areas, the rate of erosion is 5–10 cm/y. Coastal erosion is associated with the rise of sea water level.

1 Introduction

The study of geological and geophysical processes demands a diversity of accurate investigations. Observation of processes at Earth's surface such as desertification, erosion, sea level change, crustal movement, earthquakes, and landslides play a key role in predicting geological hazards in reducing their negative effects. Remote sensing application is at a very young stage but its results in the geological sciences have been quite considerable. For decades, geologists have used satellite images to identify rocks and geological structures. Satellite images such as LANDSAT and SPOT, radar and aircraft imagery are commonly used in geological mapping and exploration. The progress of advanced techniques in remote sensing permits one to study not only global geological processes, but

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also the mechanism of geological phenomena in detail. The higher spatial spectral resolution and stereo capabilities provide quantitative measurement of the surface or near surface regions. Thanks to the progress of remote sensing on high resolution, stereoscopic satellite images, radar and infrared images, one can apply these successfully in the investigation of geological hazards.

The study of volcanic eruptions is improved by the use of airborne and NOAA images. The evolution of lava flows and their thermal characteristics can be studied over a period of time. Volcanic mapping is also supplemented by infrared images.

Landslide studies have improved using a combination of aerial photographic and SPOT images and the digital elevation model. The interpretation of aerial photographs combined with field observations is a fundamental tool for the study of landslides. The high spatial resolution and stereoscopic characteristics of aerial photographs demonstrate their advantages for landslide observation. The disadvantages of aerial photographs are that they do not exist for all areas, that they are sometimes old and that they are ineffective for the observation of large regions. That is why SPOT panchromatic and multispectral images are used in combination with the information from thematic maps on the geology, land use, geomorphology, topography and drainage network of studied regions.

Information regarding active faulting, recent tectonic movements and earthquake hazards can be derived from satellite image analysis. Important progress in the application of remote sensing has been achieved in the observation of crustal displacements. We can note three main approaches in using satellite images for the determination of tectonic displacement or offset associated with earthquakes. The first is the technique of image geodesy for measuring subresolution terrain displacement developed by a JPL group (Crippen 1992). This technique allows one to recognise the subresolution displacement associated with an earthquake event. The maximum fault offset is normally below the resolution of the satellite image (10 m of resolution). The image geodesy technique is based on the fundamental statistical concept of a normal distribution. Each pixel value is a measure of radiance weighted at subresolution scales by the point spread function. The image geodesy technique compares thousands of pixels in the 'before' image to thousands of pixels in the 'after' image to determine each displacement vector.

The second approach involves the outstanding results in the application of radar interferometry in the observation of earthquake deformation in Landers, California. Synthetic Aperture Radar (SAR) interferometry is used to determine the change in the ground surface resulting from an earthquake at a very high precision of 3 cm (Massonnet et al. 1993). An interferogram was constructed by combining topographic information with SAR images obtained by the ERS-1 satellite before and after the earthquake. The co-seismic displacement of active faults associated with the Landers earthquake agrees well with the slip measurements made in the field, and with the results of an elastic haft-space dislocation model. Right lateral movement on the fault can be estimated from the interferogram by assuming that the observed change in range is only due to horizontal right-lateral strike-slip on a plane with known trend. Compared with geodetic surveying techniques, the SAR interferogram provides a denser spatial sampling and higher precision. It does not require the installation of ground stations before an earthquake. For shallow events like the Landers earthquake, the change in range measured by radar agrees extremely well with both field observations and the dislocation model in the intermediate and far fields. For deeper earthquakes with small or no associated surface rupture, SAR interferometry will be a very powerful tool for measuring surface displacement in the intermediate and far fields (Massonnet et al. 1993).

The third approach is the thematic study of SPOT panchromatic and multispectral images that allows precise mapping of fault traces and estimates of fault displacement. The offset of landforms such as river and drainage patterns, moraines, glacial valleys, alluvial fans and terraces can be observed and measured from SPOT and Sojus images. If the age of the landforms is reasonably estimated, a fault slip rate can be calculated. The satellite image analysis is combined with field studies and other measurements such as classic geodesy, Global Positioning System (GPS) and analysis of earthquake focal mechanisms. Our study in Vietnam illus-

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trates the applications of thematic studies of remote sensing. We demonstrate in this paper that if remote sensing techniques are combined with other studies of geology, geophysics and geomorphology, it will prove a powerful tool for the study of active faulting and for seismic hazard assessment. If combined with other results deduced from other studies of intermediate earthquake prediction, this technique will be useful for the early warning of seismic hazards. The study of active faulting by remote sensing has also proven a good tool for the identification of a weak zone in a dyke in the Red River delta. It is expected to play a key role for the warning of natural hazards during flood time in this area.

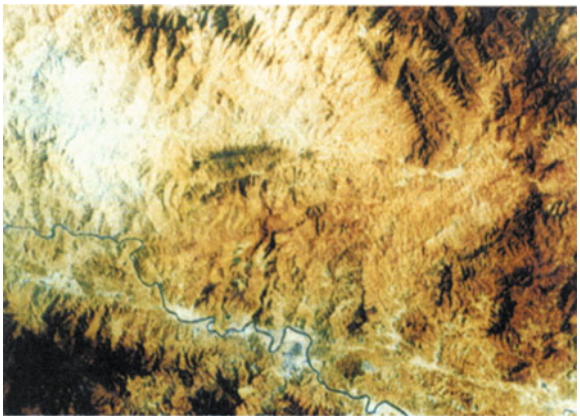


Fig. 1. Active faults in the Song Ca hydropower dam area. Two active fault systems are observed on LANDSAT images. The first system is located 10 km to the North of the Ban Mai hydropower dam, and is a right lateral strike-slip fault. Fault offset is recognised from the offset of hydraulic drainage. The second system comprises various normal fault segments located 4 km to the south of the Ban Mai dam

2 Active Faulting and Seismic Hazard

The collision of India and Asia is perhaps the most important event with respect to the change of the Asian tectonic framework during the Tertiary. Systematic studies along the Red River fault zone from Yunnan to Vietnam have proved that almost the whole gneiss structure along the Red River metamorphic zone was formed during the Cenozoic (Tapponnier et al. 1990; Leloup et al. 1995; Trinh et al. 1997). Tertiary deformation and relief development in the northwest region of Vietnam have been clarified thanks to analyses of deformation history of the Red River fault zone. Tectonic activity in the Northwest is expressed by left lateral strike-slip of the Red River fault zone and a series of fault zones in the same northwest–southeast direction.

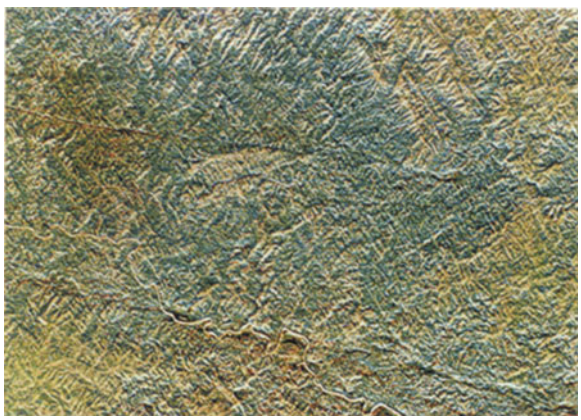


Fig. 2. Gradient filter of a LANDSAT image of the Song Ca hydropower dam area. Two active fault systems are evident. We can see different deformation levels along the first fault system

For the purpose of assessing geological hazard potential in connection with the construction of the Son La hydropower dam, the tectonic framework of the whole northwest region of Vietnam was analysed, incorporating remote sensing and geophysical measurements such as seismic sections, electricity, mercury vapour, detecting nuclear traces and a series of observations of geology, geomorphology, tectonophysics. The latest techniques in seismotectonic analysis have been applied in order to assess geodynamic hazard in the hydropower zone to optimally design the Son La hydropower dam Figs. 1, 2. The structure, more than 200 m high, will be built in an area of complex geological structure which has undergone different stages of tectonic development and has experienced strong tectonic deformation in the Cenozoic.

Brittle microtectonic analysis (Trinh 1993) indicates that, since the Miocene, two main tectonic phases have affected Northwest Vietnam. For each of these two phases, the state of stress was transpressive in the Northwest and extensive in the Hanoi basin with σ_3 remaining constant but σ_2 permuting with σ_1 (Phan Trong Trinh et al. 1994). The stress field of phase 1 is compatible with Miocene left-lateral shear along the Red River fault zone and with sea floor spreading in the South China Sea between 35 and 16 Ma.

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Phase 2, along with the associated active tectonic features of North Vietnam (right-lateral strike-slip along the Red River, N–S compression, E–W extension), probably began in the Pliocene. This involved a state of stress with σ_1 approximately N–S and σ_3 E–W. Several active faults associated with phase 2 are recognised in North Vietnam from analysis of TM and SPOT satellite images. Among these, two main zones exhibit a relatively fast movement: the Red River fault zone and the Dien Bien Phu fault. In North Vietnam, the Red River fault zone splays into two major active fault branches. The Red River branch, that represents the limit of SW the metamorphic massif of Day Nui Con Voi, follows the Red River valley. The Song Chay River branch, very clear on LANDSAT and SPOT images and in its geomorphology, is located NE of Day Nui Con Voi. Towards the SE, the Red River itself splays into several faults. The two major ones are located NE and SW of the Red River. Right lateral strike-slip offsets of these faults are determined by analysing tributaries, stream channels, Quaternary alluvial fans and river valleys on LANDSAT and SPOT images, on detail topographical maps, and by field observations. The fresh geomorphological appearance of the faults under these intensely erosive conditions demonstrates that these faults are very active. Along the SW fault of the Red River, right lateral offsets of stream channels range between 220 and 700 m (mean offset 313 m). Drainage offsets (358±109 m) are found on the NE branch. Geomorphology and topographical offset suggest that these strike-slip movements are combined with normal slip. Along the Song Chay branch, right lateral offsets of rivers range between 250 and 1000 m (mean value 566 m). Towards the Southeast, the Red River fault branch splits up into several faults. One of them bends towards Hoa Binh, striking N–S. The kinematics of this fault change from right lateral strike-slip to normal dip slip to form the Quaternary Hoa Binh graben (Trinh 1995). Clear evidence of the active strike-slip movement is also found on the conjugate Dien Bien Phu fault. The measured left lateral offsets of tributaries, river and drainage channels range between 270 and 790 m. The actual uplift of the Fanxipang massif, that towers to more than 3000 m, may have resulted from movements on two great strike-slip fault zones. The rapid uplift of the Fanxipang massif can explain the displacement of some normal fault segments striking NW–SE and NNW–SSE. On the side of the Red River fault zone, a SW dipping normal fault striking NW–SE (parallel to the Red River fault zone) is clearly observed in TM and SPOT images. In the field, triangular facets of the escarpment following the SW Tam Dao massif indicate typical dip slip displacement. In Northeastern Vietnam, the Cao Bang-Tien Yen fault is recognised as a right lateral strike-slip fault. This fault terminates in the Bac Bo gulf. The islands to the NE side of the fault can be considered as the recent anticline resulted from the termination of the right lateral fault. The Mau Son massif, more than 2000 m high, located beside the Cao Bang-Tien Yen fault may be considered a Quaternary anticline, striking E–W. The uplift of the Yen Tu massif, striking E–W and bounded by two faults, results from the N–S compression.

The Northwest region was affected by intensive deformation in the Tertiary. Overthrusting was widely developed in regions of Hoabinh arc, Sapa marble and Phong Tho Limestone. It should be noted that Triassic limestone overthrusts Yen Chau strata. This can be observed indirectly at Moc Chau plateau (Findlay & Trinh 1997). 10 km to the North of Yen Chau, on the way from Ban Dan to Ban Ngop, one can directly observe Triassic limestone overthrusting upper Yen Chau strata with inverse bedding observed at Yen Chau. The overthrusted contact can be mapped in detail from SPOT multispectral images (Fig. 3).



Fig. 3. Active and old faults deduced from SPOT multispectral images of the Son La hydropower dam area. Active faults are recognised from differences in landforms and geomorphological features

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Within the Son La hydropower dam, the Phong Tho-Nam Pia fault is bounded regionally by the tule volcanic zone and the Da river zone. This fault is developed as an active normal fault. Triangular facets dipping towards the southwest are recognised clearly in SPOT images and digital elevation models (Figs. 4, 5). On the topographic map, the height of the triangle reaches 300–500 m. The fault changes direction from NW–SE to a sub-meridian direction on the western side of the Tule volcano zone. The slip rate of sub-meridian trending fault is not clearly manifested. In the segment from Muong La to Bac Yen, the fault changes again, to trend NW–SE. Extensional activity on the fault is manifested in this segment: the fault is divided into two segments, called segments Muong La 1 and Muong La 2 (see Fig. 6). From Bac Yen to Phu Yen, the fault changes its direction. The nature of this fault segment changes mainly into right lateral strike-slip.



Fig. 4. Triangular facets can be clearly recognised from multispectral SPOT images of the Son La hydropower dam area. This indicates that the fault segment of Muong La 1 is a normal fault, dipping to the SW

Thermodynamic analysis of P-T conditions shows that up until 15 million years ago, temperature decreased gradually to 300° over a period of 10 million years (Leloup & Kienast 1993). Metamorphic and slip-shear zones in the Ye Yen Sun granite have ages of 23 million years, and a formation depth of at least 4–10 km. In order to reach the present day topographic height (3 km) it must have been uplifted 7–13 km, and the present surface is not a trace of a Palaeocene surface, but only one of a late Miocene surface.

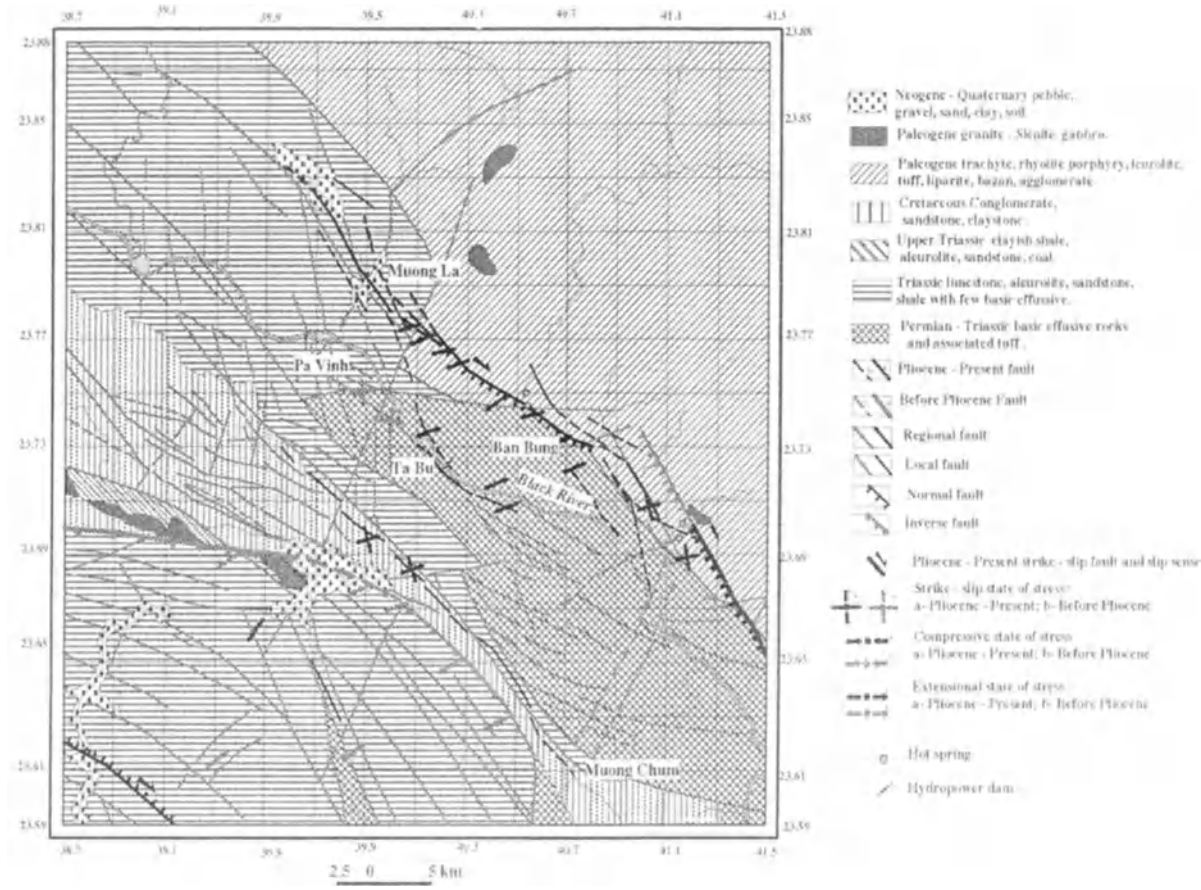


Fig. 5. Seismotectonic map of the Son La Hydropower dam area

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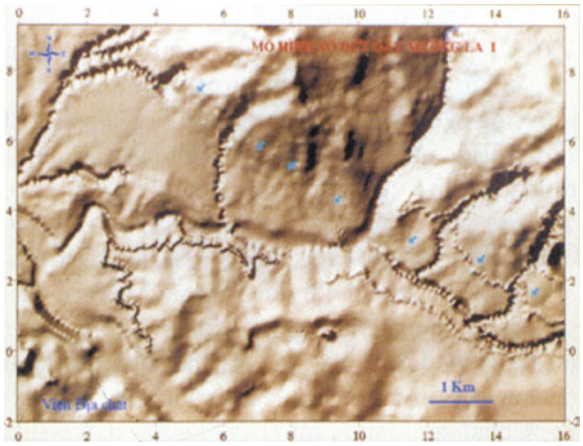


Fig. 6. The fault segment Muong La 1 is evident in the digital elevation model based on topographic maps of the Son La hydropower dam area

The time interval from 15 to 5 million years can be seen as sufficient to allow the formation of a relatively smooth surface due to accumulation of fine material containing coal in Hang Mon. The highest peaks on the present topographical surface are traces of surfaces existing just before the Pliocene. The Red River metamorphic zone, Hoang Lien Son zone and Tule volcano zone showed strong uplift from Pliocene to present. The Da river zone was also uplifted, but at a lower rate. The strongest uplift is represented by the Fanxipang mountain region, with average uplift rates of about 1.4–2.6 mm/year from the Pliocene up to now (uplift amplitude is 7–13 km within 5 million years). In a similar way, the average height of 2000 m reached in the Tu Le zone was also caused by uplift during this time with a rate of 0.93–1.73 mm/year, with the peak of average height of 900 m in the Da River zone showing an average uplift rate of 0.4–0.8 mm/year. From this, the relative displacement rate between the Da river zone and Tule volcano block can be calculated with 0.53–0.93 mm/year. In order to determine the relative displacement rate of both the Tu Le and Da River zones through the Phong Tho fault, attention should be paid to the block displacement of the two main zones through the main Phong Tho-Nam Pia fault zone. Rectifying vaulted displacement and that caused by other small faults in the zone with 1/3 of total displacement amplitude, we can estimate the average uplift rate of the northwest part relative to the southwest wing as 0.35–0.62 mm/year for the Phong Tho–Nam Pia fault from the Pliocene up to now.

In order to estimate the slip rate of the Phong Tho-Nam Pia fault for a shorter time interval, we have used two other approaches. The first uses SPOT images, geomorphologic and geological documents, and the second is based on geodetic measuring data over 20 years. The triangle facets are clearly observed on SPOT images (Fig. 4). The difference in amplitude between two fault sites is 300 m (for the clearest triangular facets) and 500 m (for less clear triangular facets). If we assume that the present surface is of early Quaternary age (1 million years), we can estimate the displacement as 0.3–0.5 mm/year. If this surface is related to the process of forming the present topographical surface, related to the Würm glacial cycle of 100 000 years age, we estimate the rate at 3–5 mm/year. It may be more reasonable to assume that the surface difference of 500 m corresponds to the early Quartenary, in which case we can estimate the rate as 0.5 mm/year, and the surface difference of 300 corresponds to the surface 100 000 years ago, in which case slip rate is estimated at 3 mm/year. Therefore, the average displacement rate of the Phong Tho-Nam Pia fault estimated on the base of geomorphology is about 0.5–3 mm/year.

To evaluate seismic hazard in the Son La hydropower dam area, we focused on the fault systems with considerable size and closeness to the dam. The fault length is measured from SPOT images, and controlled by geophysical and geomorphologic measurements in the field. The Phong Tho-Nam Pia slip fault – right lateral trust stretches from Phong Tho in the west, to Phu Yen in the northwest. This fault zone is divided into many fault segments with different activity levels. In the Son La hydropower dam area, the fault segment Muong La 1 stretches 10–12 km, and the fault segment Muong La 2 stretches 30 km. The shortest distance from section Muong La 1 to Pa Vinh dam is 4.4 km, and to the Ta Bu dam is 4.2 km. The fault dip is determined as 75°, thanks to observations of schistosity surfaces related to the fault. The fault depth cannot be determined correctly. To calculate a maximum credible earthquake magnitude, the fault depth can be estimated in 2 ways. The first is based on seismic characteristics in the area and along the fault zone. In general, the depths of seismic foci in the area vary between 10 and 20 km. The second is based on the change in mechanical characteristics of Earth's crust with

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depth. Normally, the focal depth does not exceed 2/3 of the length of the fault on the surface. Therefore, it is assumed that the maximum depth of a possible earthquake for section Muong La 1 is 10 km. The segment Muong La 2, belonging to the Phong Tho-Nam Pia fault, is of 30 km in length, the depth is estimated at 15 km, its dip is 75° to the southwest. The shortest distance from this fault segment to Pa Vinh is 17 km, and to Ta Bu 10 km. Because the fault segment Muong La 1 is very close to the Pa Vinh and Ta Bu dams, the exact determination of its size is very important in forecasting earthquake intensities to be expected. Therefore a series of specialised measurements involving seismology, electricity and nuclear trace detectors have been carried out near the end of the fault segment. This should be helpful to determine the exact extent of the fault segment Muong La 1. The location of the cross-section for this investigation is decided on the base of SPOT image analysis. Fault length, fault dip and nature of displacement are the main parameters used for the estimation of the maximum earthquake magnitude.

The International Committee for Large Dams recommended that three different magnitude models for earthquakes should be used when designing a dam: Maximum Credible Earthquake (MCE); Maximum Design Earthquake (MDE) and Operation Basis Earthquake (OBE). MDE and OBE can be determined from the maximum credible earthquake combined with the recurrence period of earthquakes in the specific region. Coefficient b of 0.814 used here is that from Nguyen Dinh Xuyen (1985) for the entire northwest region. The method used in this study is that of Slemmons (1977), while Coppersmith & Slemmons' method was used for the first time in Vietnam in UNDP's Project for assessment of earthquake hazard for the Hoa Binh dam (Winter et al. 1994). In our study, the methods used to calculate maximum magnitude based on the fault surface area are from Coppersmith, Wyss, Woodward-Clyde and especially by calculating a maximum credible earthquake from the earthquake moment.

To combine the various methods, we take the average value by weight number, whereby the method based on earthquake moment applies coefficient 3, the method based on fault surface area uses coefficient 2, and methods based on destroyed fault length employ coefficient 1. In order to get an average value, the method based on earthquake moment is used (coefficient 3), due to its highest confidence.

As there is a lack of specific laws in Vietnam regarding values for the Peak Ground Acceleration (PGA), we use models 1, 2 and 3 of Campbell and formulas of Idriss, Xiang and Gao, Woodward-Clyde as well as Ambraseys to calculate the PGA. Models 1, 2 and 3 of Campbell are based on global data of vibration near the source, so it is assumed here that they have sufficiently high reliability in assessing earthquakes at a distance of 50 km or less. The above formulas can use coefficient 2 for calculating a weight average. The formula of Xiang and Gao can also use coefficient 2, as it is set up based on data from earthquakes in Yunnan, similar in geological setting and structure to Vietnam.

Formulas of Woodward & Rosenblueth, Idriss and Ambraseys can be used with coefficient 1, because they are based on data from different sources with distances from 0 to more than 400 km. Peak Ground acceleration is calculated as g with 1 g $\sim$ 1000 cm/s^2. For the Son La and Quynh Nhai, Thuan Chau faults, the distance to the dam is 30 and 20 km respectively; and we rectify the model of near earthquakes by reducing the coefficient of Campbell's model and increasing the coefficient of Ambraseys' and of Idriss' methods. Table 1 represents the estimation of PGA corresponding to MCE, MDE and OBE at two sites chosen for the planned hydropower dams of Pavinh and Tabu.

The above application of remote sensing is used for estimating long term seismic hazard. If we calculate seismic hazard for a shorter period, such as 25 or 50 years, we can use satellite images for earthquake warning. We can also expand the capacities of remote sensing techniques for the early warning of seismic hazard. The scientific world is interested in intermediate methods for the prediction of earthquakes of magnitude-class 8. It may be possible to pre-

Table 1. Magnitude MCE, MDE, OBE and Peak Ground Acceleration at Pa Vinh and Ta Bu provoked by Phong Tho-Nam Pia, fault, segment Muong La 1

Magnitude	Peak ground acceleration PGA (g)	
	Pa Vinh	Ta Bu
MCE 6.1	0.20 ± 0.03	0.2 ± 0.03
MDE 5.9	0.18 ± 0.02	0.18 ± 0.03
OBE 5.2	0.12 ± 0.02	0.13 ± 0.03

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dict a class 8 earthquake in the Pacific rim with a probability greater than 80% in the determined error radius of an area. However, this determined error radius is too large (668 km for magnitude 8, 221 km for magnitude 7 and 192 km for magnitude 6.5). The error radius can be shortened if details of active faulting in the investigated area are known. This explains the important role of remote sensing to precisely locate the earthquake to be predicted.

Remote sensing has permitted the recognition of a weak dyke zone in the Red River delta. This weak dyke segment is a result of active faulting in the delta. The Red River fault system splits up into many small branches in the Red River delta. The active faults cut the dyke construction on both sides of the river. These fractured dyke segments may be destroyed by floods. Using SPOT multispectral images, we can recognise different weak segments along the dykes. The recognition of weak dyke segments is important for the prevention of a flood catastrophe. Considerable attention is now paid to this zone which is examined regularly by means of geophysical surveys and field investigations. Every year, before the flood season, much work is carried out to repair these dyke segments to ensure that they are safe during flood periods.

3 Landslides, Coastal Erosion

As in almost any region of the Earth, landslides in Vietnam occur in the rainy season in mountainous areas. They appear in the Northwest region and in some areas in the Northeast region such as Cao Bang, Ha Giang Province. We are particularly interested in the potential of large landslides in the vicinity of the hydropower reservoir, as large landslides occurring adjacent to the reservoir and next to the dam may produce great waves that may threaten or even destroy the dams. Hence we pay great attention to landslides situated within a 30–40 km radius of the dam. On SPOT images, we can observe some traces of old landslides along the border of the Hoa Binh reservoirs. Common landslide arc lengths are 500–1500 m. Geologically, they develop at the contact between Triassic limestones and Cretaceous red sediments. Field work has confirmed the observations from the SPOT images. The same observations have been made in the Son La hydropower region. Remote sensing gives us a large scale but nevertheless sufficient set of information to recognise or predict large landslides. Fortunately for all hydropower dams in Vietnam, no potential large landslides in the areas next to these dams have been detected.

The erosion of coastal zones is a crucial phenomenon in Vietnam. The loss of land from coastal erosion is in fact very significant. Many road segments are threatened with destruction, some fishing ports must be repaired or changed and terrain is salted. The system of sea dykes is threatened not only by tidal waves during storms, but also by erosion. A comparison of satellite images made at different times and covering different topographic regions permits us to calculate the rate of erosion in the coastal zones. In some areas, the rate of erosion is 5–10 cm/y. We can illustrate one of the applications of remote sensing in the Hai Hau district. This area is critically affected by coastal erosion. A sea dyke was constructed to protect the area, but it was destroyed during storms. A large new dyke was built. The sea side of the dyke is covered by rocks. Much discussion exists regarding the cause of coastal erosion. Some workers believe there is an active fault along the coast. Others think erosion is caused by tidal currents. Using SPOT multispectral images compared with LANDSAT images and topographic maps, we estimated the erosion rate to be 8 cm ± 3/year prior to the construction of the dyke. SPOT images revealed no evidence for an active fault. One must therefore look to an external source for the erosion process. Interpretations of SPOT images indicate that turbidites are almost absent in the coastal zone, although it is next to Ba Lat coastal estuary Fig. 7. This indicates indirectly the influence of a coastal current. Combined with field measurements, we can recognise that the coastal erosion in this area is a complex result of coastal currents, tidal waves, sea level rise and subsidence. In general, the coastal erosion in Vietnam is associated with the rise in sea level. Vietnam and other countries are influenced by complex global change. We expect that in the near future, as a result of sea level rise, coastal erosion in Vietnam will increase and threaten the lowlands in the delta. The erosion along the river border directly affects the river dyke system. The government has to pay more attention

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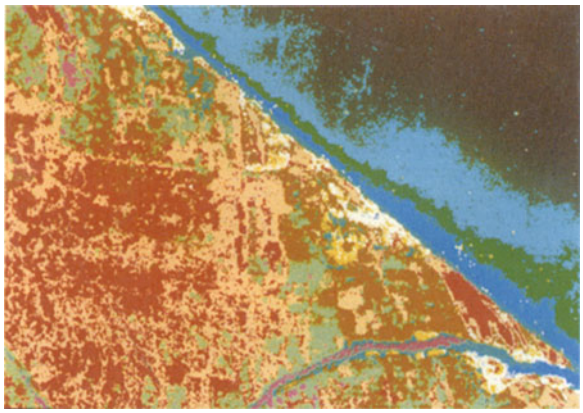


Fig. 7. Interpretation of the SPOT multispectral image of the Ha Hau area shows that turbidites are almost absent in the coastal zone, despite the fact that it is next to the Ba Lat coastal estuary

to this phenomenon when making strategic plans for development, particularly when related to construction, transport, agriculture and hydrology services.

4 Future Work

We are witnessing the rapid progress of remote sensing with higher spatial and spectral resolution. In the near future, satellite images with 1–2 m resolution will be commercially available. They will form a powerful tool for monitoring landslides and volcanic activity. The combination of SAR interferometry, GIS techniques and high precision GPS will increase the precision of measurements of tectonic slip movement and deformation associated with earthquakes. Some scientists are testing interferometry of shorter waves than radar. If they are successful, they will compare two images with the precision of half wavelengths. The high resolution of infrared images will make important contributions to the study of active tectonics, earthquakes and volcanic hazards. Nevertheless, we expect that the combination of information deduced from remote sensing and GIS techniques will be the most important achievement for the near future.

5 Conclusion

In this paper, we outline the main progress of remote sensing in geological hazard research, dealing especially with tectonic and gravitational movements. The mapping of the displacement field of the Landers earthquake based on SAR interferometry has been one of the greatest events in remote sensing. This achievement is an important victory not only for technology but also for science because since then we have an image of earthquakes and in this application, the deformation field measured by radar agrees extremely well with both field observations and dislocation model in the intermediate and far fields. From examples of active faulting, seismic hazard, landslides and coastal erosion in Vietnam we illustrate that although the application of remote sensing in Vietnam is limited thematically, when combined with other data from geology, geomorphology, geophysics and geochemistry, we can estimate fault slip rate, make evaluations of future earthquakes, and provide warnings of possible seismic hazards as well as other natural hazards such as landslides, floods and coastal erosion. We expect that the combination of high resolution images with thematic studies in connection with multisource GIS and GPS data will provide a very high precision toolbox for measuring and monitoring natural hazards in the near future.

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The SAF Concept: European Networked Approach for Organising the Generation of Products Based on Satellite Data

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Abstract

Several natural disasters are caused by particular meteorological conditions or phenomena, for example, by cyclones or heavy thunderstorms, hurricanes, floods, severe snow storms, icing and droughts. Meteorological disasters can be predicted, monitored and assessed by either applying nowcasting techniques, or by using Numerical Weather Prediction (NWP) models which provide forecasts of meteorological parameters and preconditions for meteorological disasters. Satellite data are indispensable in both approaches. The member states of EUMETSAT have developed a networked concept for the exploitation of satellite data: The SAFs (Satellite Application Facilities) to be implemented, for example, for nowcasting, for ocean and sea ice, for NWP, for land surface analysis and climate monitoring. With the support of EUMETSAT, the member states bring together their experiences and capacities to develop methods for extracting the relevant information from satellite data, and make this information available to interested users. The SAF concept will be explained in the presentation, with specific emphasis on activities supporting disaster detection, monitoring, forecasting and assessment.

1 Introduction

At the 50th anniversary of the United Nations in 1995, a sampling of what the United Nations organisations have accomplished since the foundation of the world organisation in 1945 was published. Under the 50 items of this sampling were at least 5 of meteorological concern. Item 24 has direct reference to this conference: Reducing the effects of natural disasters.

The aims of IDNDR concerning disasters of meteorological and hydrological origin are coincident with the programmes of the WMO. To coordinate efforts in this area, the WMO Congress adopted the WMO Plan of Action for the IDNDR in 1991. As part of the IDNDR Forum to be held in summer 1999 in Geneva, the WMO plans to convene a special conference on 'Science and Technology in Support of Natural Disaster Reduction'. The conference will cover nearly the same hazards contained in chapter 2 of this paper.

In spite of the progress reached in this field to date, there is still an urgent need for persistent and expanded activities in meteorology.

To fulfil this task, new perspectives were opened, on the one hand, by the COST-78 (European COoperation in the field of Scientific and Technical research) action of the European Commission concerning some significant meteorological matters in the context of nowcasting, and on the other hand, by initiatives of EUMETSAT (The European Organisation for the Exploitation of Meteorological Satellites) for nationally and internationally coordinated concerted efforts to utilise meteorological satellite data in fields of special importance.

Such activities came to synergy in December 1996 in the first pilot SAF (Satellite Application Facility) in support to nowcasting and very short-range forecasting. This includes severe

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and hazardous weather situations and phenomena. Further SAFs in several other application areas followed. The concept of the SAFs is the main topic of this paper.

2 Meteorology and Disasters

The most dangerous meteorological phenomena are related to thunderstorms, tropical cyclones, deep depressions and frontal zones.

The first include mainly extreme wind storms (tornadoes, downbursts, downdraughts and straight line winds), hail, lightning and flash floods caused by heavy (torrential) precipitation. Flash floods are floods that last up to 6 hours.

Tropical cyclones are responsible mainly for violent (wind)storms up to "hurricane intensity", coastal and river floods.

Mid and high-latitude depressions, fronts and certain meteorological conditions cause extensive (wind)storms, floods (including coastal floods), snow storms, thaw (leading to snowmelt), severe icing and fog.

In this regard one major problem in forecasting dangerous meteorological conditions and dangerous phenomena is their time-space dependence. Different disasters are connected with different sizes and lifetimes (Fig. 1). Surprisingly some dangerous or hazardous phenomena become more destructive and occur more frequently the smaller they are. As an example, with respect to maximum wind speed, mid-latitude storms are weaker than the smaller tropical cyclones (hurricane, typhoons etc.) and the latter are weaker than tornadoes, which are much smaller, appear and disappear more suddenly. The crux is that in the same succession of size order the predictability decreases. This is also valid for forecasts based on numerical weather prediction models. Annotation: Given a particular phenomenon, for example, tornadoes, the intensity naturally increases with the size.

Other disastrous or catastrophic events such as droughts or desertification are caused by certain persistent meteorological conditions. These events seem to be more easily recognised than above mentioned events, but the impact on long-term living conditions causes other very difficult problems. Further phenomena develop and/or spread out under certain meteorological conditions, i.e. avalanches, forest and wild fires, desert locust infestations or clouds from volcanoes.

In order to tackle all the problems connected with disasters a new concept of coordinated and concerted action (as mentioned above) is needed. As a starting point it has to take into account – as far as possible and as far as relevant – all existing knowledge. But that is not enough. New observational and processing techniques are needed to obtain necessary results. This will allow more comprehensive detection and representation of the phenomena themselves, or at least of their environmental conditions.

3 The Role of Meteorological Satellites for Disaster Prediction and Monitoring

Meteorological satellites have become an essential and indispensable part of the world weather and climate monitoring and prediction systems. Monitoring also includes analysis and diagnosis of the state of the atmosphere and the climate system. Therefore, it is a necessary precondition for the extrapolation and prediction of weather events and their impact on the environment.

Meteorological satellites supply us with information from areas in which data are sparse especially from the oceans and sparsely populated land areas. Such data fill gaps in the conventional observational network, not just in case of transmission problems, strikes etc. Further advantages are the nearly continuous (frequent) observations of clouds and cloudless areas in different scales. Meteorological satellites supply us – along with weather radars and lightning detection systems – with area-covering observations, which have the advantage of being really global-covering and more homogeneous than radar observations. Satellite data complement surface observations and measurements. High-speed transmission and processing of data guarantee their quasi real-time availability, i.e. a very short lead time between the time of data acquisition (observation) and their operational availability or the availability of derived products.

There are two primary methods which are used to apply data from meteorological satellites for the prediction of disastrous events:

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1. *The assimilation of data into numerical weather prediction (NWP) models* for early prediction and warning of severe weather events. The incorporated data have been up to now mainly wind vectors for different atmospheric levels derived from different spectral imaging channels (extracted from cloud and water vapour displacement, about 20 000 vectors every 6 hours), and data on the vertical distribution of temperature and humidity derived from special sounding channels. The latter are available world-wide, the former for the globe excluding the polar regions. The forecasts of meteorological parameters by means of mathematical-physical computer models cover a time period of up to about one week.
2. *Nowcasting and Very Short-range Forecasting techniques* are used for detailed forecasts of the precise site, time and intensity of phenomena up to 12 hours in advance. They partially fill the existing gap between the latest state of the atmosphere and model outputs, which are at present only available every 12 hours. Therefore, interpreted original and derived satellite image products are of special importance, along with specific nowcasting techniques under development, and the growing importance of NWP-products, for very short-range forecasts in the future.

For both the long-term monitoring of seasonal fluctuations and real climatological and environmental changes, the statistical evaluation of parameters such as vegetation indices, Sea Surface Temperatures (SSTs) and others are indispensable for obtaining results concerning dry periods, desertification, El Niño-teleconnections and others.

4 The SAF Concept

As can be seen from the explanations above, meteorological satellites have the potential to play a significant role in disaster prediction and monitoring. With regard to future satellite systems, the methods for the generation of appropriate products have, however, still to be developed. In order to be able to perform the necessary activities in the most efficient manner, the EUMETSAT member states developed the concept of Satellite Application Facilities, the SAFs, which is based on a network approach making use of existing experiences and capacities. The principles of the SAF concept are described in the following paragraphs.

EUMETSAT is the meteorological satellite organisation of Europe, the headquarters being located in Darmstadt, Germany. EUMETSAT has presently 17 member states which are represented by their National Meteorological Services. The SAF concept is based on the idea that institutions from member states bring together their experiences and capacities and make the results available to users. This means that each SAF is borne by some specialised partners, but the results are available to all member states. This approach results in a networked system with distributed activities and responsibilities.

The overall objective of a SAF is to undertake activities aimed at providing operational services which will become an integral part of the overall EUMETSAT operational service. In this context, the establishment of a SAF will be to undertake on a distributed basis such necessary research, development and operational activities not carried out by the EUMETSAT central facility.

SAFs will be located within the National Meteorological Service of a member state, or another agreed upon entity linked to a user community. Each SAF will have a lead organisation, the so-called host, responsible for the interface with EUMETSAT, and which maybe a consortium of other organisations and/or scientists from any member state.

The activities of each SAF are undertaken within the framework of agreements between EUMETSAT and the individual SAF. The agreements will preserve EUMETSAT control and responsibility and in particular will ensure that all the resulting products, intellectual property and proprietary technical data rights, including all algorithms and software will belong to EUMETSAT and be available at no cost to National Meteorological Services in member states and according to the agreed EUMETSAT data policy to other users.

All activities will be undertaken on a shared cost basis between EUMETSAT and the SAF with 50% borne by EUMETSAT and 50% by the partners of each SAF consortium.

The transition from research and development to operational activities will require a for-

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mal decision by the EUMETSAT council and new financial arrangements, and may or may not be undertaken in the same location or by the same entity that undertook the research and development. This decision will be made three years after the commencement of the development activities.

SAF deliverables will be either specific software packages for local implementation or, extracted products which will be transmitted to users and archived at the SAF. The products will be disseminated through both ground-based communication lines (including GTS, the Global Telecommunication System) and the Meteosat Second Generation (MSG) data dissemination system. Products generated with software for local implementation and relevant to disaster warning will be for example, an intensive rainfall rate product or a product on rapidly developing thunderstorms. Products to be extracted at still-to-be-defined sites and transmitted to the users are, for example, sea surface wind vectors or a sea ice edge product.

In summary, the key factors of the SAF concept are:

- to improve the ability of EUMETSAT member states to exploit the satellite data,
- to utilise the existing skills and infrastructure in member states in developing geophysical data products and services,
- to facilitate cost-effective exploitation by ensuring services are distributed in the most appropriate way,
- ensuring a balance between the EUMETSAT central services and distributed services provided through the National Meteorological Services.

In the first phase, the SAFs will perform research and development to exploit the data from the future EUMETSAT satellite systems. These will be the geostationary satellites of the MSG and the polar-orbiting METOP satellites of the EUMETSAT Polar System (EPS). MSG-1, the first satellite of the MSG-Programme will be launched at the end of the year 2000, and will have considerable improvements in comparison to the present METEOSAT system. This includes more frequent observations (30 min instead of 15 min) and higher geometrical resolution and more spectral channels (12 instead of 3). METOP-1 will be the first satellite of the Initial Joint Polar System, a cooperative project of NOAA (the National Oceanic and Atmospheric Administration of the USA) and EUMETSAT, with a planned launch date in the year 2003. The NOAA satellites and the METOP satellites will carry a common core payload.

There will be 7 SAFs, of which 3 have been firmly decided on, and have already started their activities, and 4 are under preparation and are close to formal approval. The SAFs are:

- SAF in support to Nowcasting and Very Short-range Forecasting
  (Host: Instituto Nacional de Meteorologia (INM), Spain)
- SAF on Ocean and Sea Ice
  (Host: Météo France, France)
- SAF on Ozone Monitoring
  (Host: Finnish Meteorological Institute (FMI), Finland)
- SAF on Climate Monitoring
  (Host: Deutscher Wetterdienst (DWD), Germany)
- SAF on Numerical Weather Predictio
  (Host: UK Meteorological Office (UK MO), United Kingdom)
- SAF on GRAS meteorology (GRAS = Global Navigation Satellite Systems (*G*NSS) *R*eceiver for *A*tmospheric *S*ounding)
  (Host: Danish Meteorological Institute (DMI), Denmark)
- SAF on Land Surface Analysis
  (Host: Instituto de Meteorologia (IM), Portugal).

5 SAF Activities with Benefits for Disaster Reduction

During the development phase the products at the different SAFs will be based above all on the data from GOES and from NOAA satellites (USA), and on simulated data from the SEVIRI imager of the planned METEOSAT Second Generation (MSG). Data from the 12-channel SEVIRI imager will be used upon the beginning of transmission from the first MSG satellite in the year 2000 or 2001.

The SAFs in support of nowcasting and very short-range forecasting and on numerical weather prediction will be the mainstays for disaster reduction in the field of meteorology. They will be particularly relevant for to suddenly emerging dangerous weather situations and phenomena.

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The following products developed at different SAFs are of special importance to disaster reduction:

1. SAF in support of nowcasting and very short-range forecasting
   - (convective) rainfall rate (especially torrential rain)
   - rapidly developing thunderstorms
   - (in)stability analysis imagery (as an indication for severe weather events)
   - automatic satellite image interpretation
   - air mass analysis (probability of severe weather events)
   - high-resolution winds (detection of gust lines)
2. SAF on Numerical Weather Prediction (NWP)
   - software packages for implementation at NWP centres and others
   - Remark: Satellite data is essential as an input into NWP models.
     Output from models give an indication as to the probability of meteorological events up to about one week
3. SAF on Ocean and Sea Ice
   - sea surface wind vectors
4. SAF on Ozone Monitoring
   - UV products and total ozone content (effects on health)
5. SAF on Climate Monitoring
   - long-term statistics on radiation, clouds, precipitation etc.
   - Remark: Such statistics will be useful for the assessment of effects from the climate system to the environment, especially concerning dryness and desertification
6. SAF on Land Surface Analysis
   - Several meteorological parameters are relevant to the assessment of droughts.

6 Conclusions

A concept has been introduced to undertake activities in the area of satellite meteorology aimed at providing operational services which will become part of a more general overall service. The concept is a distributive system, based on international cooperation and sharing of activities and funds to the benefit of a wide user community.

The key factors of the SAF concept are to improve the ability of EUMETSAT member states to exploit satellite data for dedicated purposes, in the context here for disaster early warning, to utilise the existing skills and infrastructure in member states for developing geophysical data products and services, to facilitate cost effective use by ensuring services are distributed in the most appropriate way and ensuring a balance between the EUMETSAT central services and distributed services provided through the National Meteorological Services.

The SAF concept is a possible tool for developing cooperation between non-member states and other organisations. It might also be regarded as a conceivable model for international cooperation and sharing of activities in other international organisations and enterprises.

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Use of Advanced Earth Observation Capabilities for Disaster Management – The Example of the Oder Flood 1997

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Abstract

From the Oder flood that hit the Czech Republic, Poland and Germany in July and August 1997, more than 30 satellite images were acquired and evaluated. The German Space Agency (DLR) has coordinated and contributed to the joint efforts made by the EU (European Union), ESA and national agencies in this respect. During and after the disaster, close contact with users in GO and NGO aid organisations was maintained, and the benefits and limitations of this kind of information were worked out, as well as requirements for future systems were formulated. Presently space-based information is dominantly used for prevention and post-crisis analysis, but satellite operators are striving – not least thanks to the lessons learned from the Oder case – to also better support crisis management itself.

1 Introduction

The recent increase in frequency, intensity and damage of flood disasters encourages the development of new technological solutions. Germany and its neighbour countries were struck by two Rhine floods of centenarian severity in two subsequent years (Dec./Jan. 93/94 and Jan. 95) causing 42 losses of life, 4.7 Billion USD damage (only 1.5 Billion of which was insured) and the greatest evacuation action (200 000) in the Netherlands since WW II.

In Summer 1997, the Oder rose to higher water levels than ever measured before (Fig. 1) affecting the Czech Republic, Poland and Germany with 74 losses of life (numbers diverging), 5.2 Billion USD damage (of which in Germany 0.45 Billion were insured) and 140 000 people were evacuated, most of them in Poland (United Nations-DHA 1997; Grünewald 1998).

It is now certain that man-made regulations regarding navigable rivers and land-use practices in Central Europe are responsible for only the last few decimetres of flood-wave height, but these are the ones that count, and make the difference compared with former times. To reverse the trend is a cumbersome process and requires extensive evidence and planning documentation.

The upper Rhine, for example, lost 870 of 1000 km^2 retention space during the industrialised era, and was shortened by 81 km, causing water to discharge in 23 hours rather than the 61 hours previously. The Oder lost 2850 of 3710 km^2 retention area, and was straightened by 160 km which corresponds to 20% of its former length (Grünewald 1998; Zunic 1998). Surface sealing in Germany is progressing at a rate of 70 hectares per day, equivalent to 100 soccer stadiums, and has increased from 6 (1950) to 13% (1998) (UBA 1998). To return only 47 km^2 of retention area in the state of Northrhine-Westfalia is connected with restriction to settlements (1.4 Million people are resident in endangered areas) and agricultural practices (some 20 farms are affected), and involves lengthy legal disputes before the dikes can be pulled back. Questions such as the following have to be dealt with:

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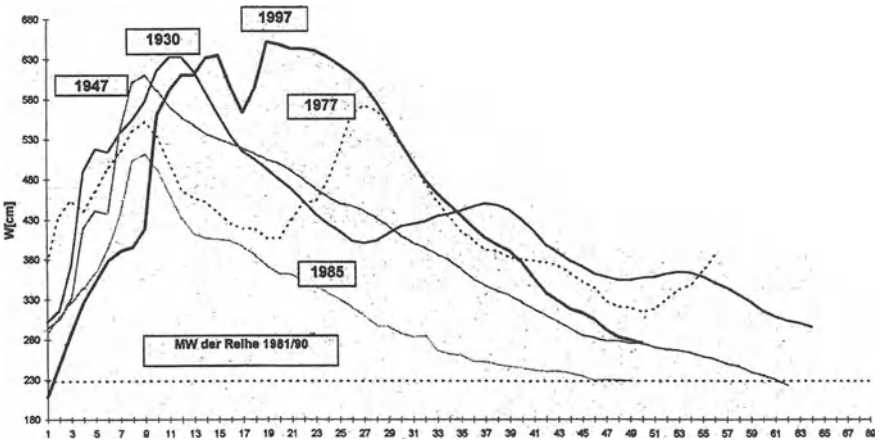


Fig. 1. Water marks versus flood event duration (in days) in 1997, and mean value for the 1981 through 1990 period for the Oder river, measured at the Frankfurt/O gauge. The relieving effect of the dike breaches at Ziltendorfer Niederung is clearly pronounced in the 1997 pattern (source: Federal Agency of Hydrology)

- why here, not elsewhere?
- what are the effects in peak level reduction?
- how much property will be saved?
- how will property losses in retention areas be compensated?
- how can restriction be controlled?
- where can new dikes be built?
- where is re-forestation or de-sealing of soils possible?

In this respect remote sensing and geo-information tools can make fundamental contributions (Steinborn 1997). In the Netherlands, during the 1995 Rhine flood, an "Aquagis" was developed to make rapid assessments on possible losses of human lives, livestock, property etc. in case of dike breaches, and to develop evacuation plans at the municipality level. Although the potential of this technology was clearly demonstrated, its efficiency was hampered due to lack of digital road maps and powerful hydrological models (Akkers et al. 1995).

In the timeframe between November 1996 and February 1998, German legislation has reacted to the increased flood hazard with one new law edition (on soil protection) and two amendments to existing laws (on water management and on land use and construction). These laws prescribe:

- restitution of former retention areas to the utmost extent,
- de-sealing of soils (e.g. a recent study for Munich has revealed that 70% of the sealed surface need not be sealed to retain its function),
- ground reserve for water infiltration in new building sites.

Moreover, France, Switzerland, Be-Ne-Lux and Germany have agreed on an action plan for the Rhine catchment involving 12.3 billion ECUs from different sources until the year 2020 (a similar plan for the Oder is in preparation) with the following goals (and cumulative spendings) (International Commission for the Protection of the Rhine 1998):

- Hazard minimisation (through dikes and other technical means) by 10% by the year 2005 (1090 MECU) and by 25% by 2020 (1418 MECU)
- Reduction of peak water marks by 30 cm by the year 2005 (3400 MECU) and by 70 cm by 2020 (10 810 MECU)
- Increased flood awareness through risk maps, covering the whole area under threat, by 2005 (38 MECU)
- prolongation of warning periods from the current 24 hours to 36 hours by 2000 (4 MECU) and to 48 hours by 2005 (12 MECU).

Envisaged measures include (selection with relevance to remote sensing):

- renaturalisation of 11 000 km of navigable rivers (adaptation of ships to rivers not rivers to ships)
- reactivation of 1200 km^2 of water interception areas
- extensivation of 3900 km^2 of agricultural land (to increase percolation)
- re-forestation of 3500 km^2
- de-sealing of 2500 km^2, new sealing only in compensation areas
- technical interception basins of 437 million m^3 volume

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- maintenance and new construction of dikes where indispensable (e.g. in communities), over 1115 km
- land use restrictions (e.g. reduction of pollution potential)
- vulnerability and risk maps, construction guidelines, evacuation plans
- improvement of early warning and rapid exchange of information.

2 Remote Sensing Projects During and After the Oder Flood

At the end of July 1997, when the flood wave reached Germany, the then German Space Agency DARA (now DLR) placed two contracts, one for satellite imagery acquisition and evaluation and one for supplementary airborne remote sensing, mostly using digital cameras derived from the German space programme. These projects were financed predominantly by DARA/DLR, and partly by the Federal Agency of Hydrology, to the order of 1 Million DM. Their goals were to:

- secure the maximum amount of current documentation on the event,
- develop evidence for the value of remote sensing in the context of traditional instruments used by the disaster management bodies, and requirements w.r.t. future missions,
- prepare, if useful, future prevention and warning scenarios including satellite remote sensing, in cooperation with the GOs and NGOs responsible,
- qualify and compare the different data sources (radar, optical stereo and multispectral scanning, space- and airborne methods) in actual crisis application.

Work on the project continued until the end of 1997, and involved cooperation of a total of 6 federal ministries, 13 other institutions on the federal level, 13 institutions on the level of the federal states of Brandenburg, Saxony and Mecklenburg-Vorpommern, ESA and 3 DGs of the European Commission, 6 institutions in Poland and the Czech Republic, 4 insurance companies, 11 other industrial partners, and 14 universities and research facilities.

During the Oder flood, more satellite images (30) were acquired and evaluated than during any other such event before. Preliminary experience had already been gained in earlier DARA projects analysing the 1993 and 1995 Rhine floods (plain floods) and the Saale-Werra-inundation in April 1994 (torrential flood) (Bach & Gebhardt 1997). The major improvement in satellite coverage in 1997 (Fig. 2, 3) consisted of:

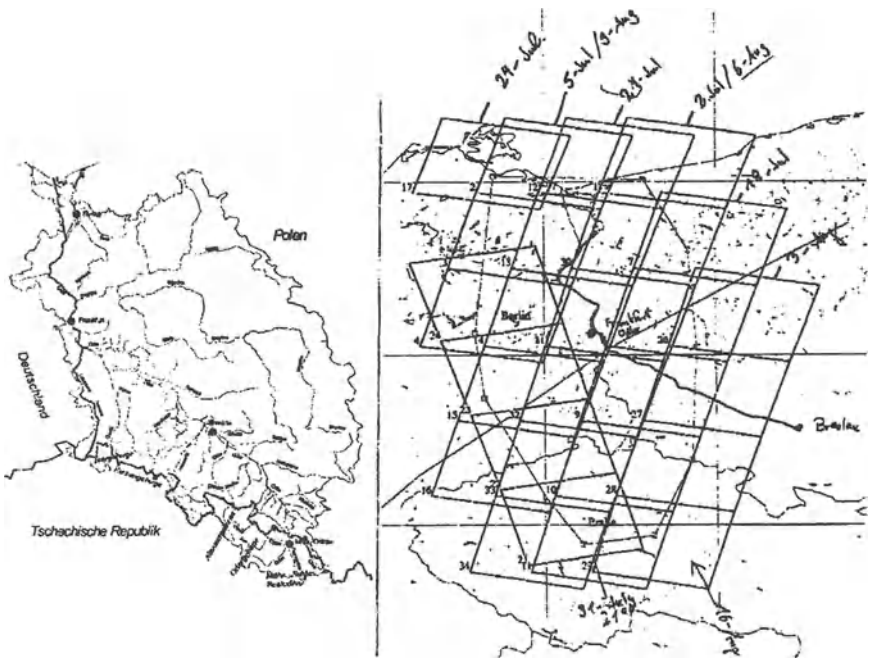


Fig. 2. Coverage of the Oder flood with satellite imagery was better than in any other such event before. The figure on the left shows the Oder catchment, the major part of which is in Poland, the figure on the right shows coverage and acquisition dates by the European Remote Sensing Satellite (ERS) which was only one of seven satellites used

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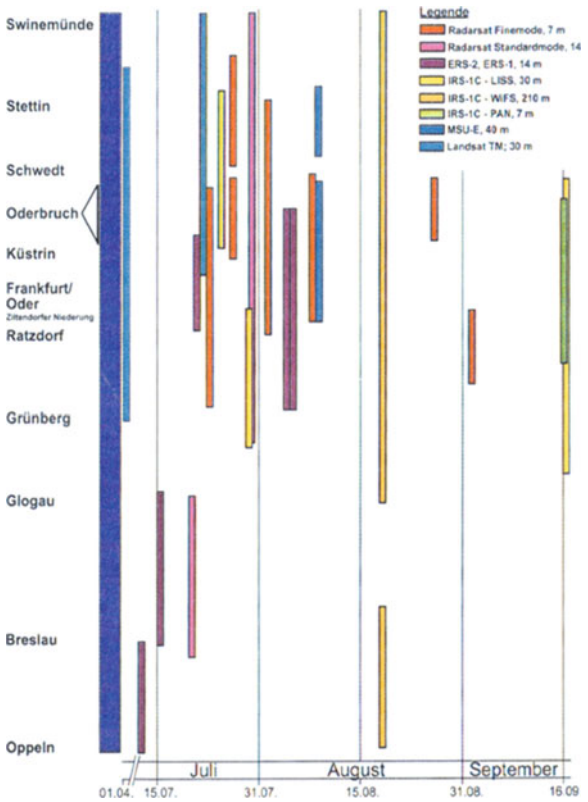


Fig. 3. Schematic diagram of the spatial and temporal coverage of the acquired scenes of the Oder flood from a total of seven satellites, working in different modes and ground resolutions (see legend)

- the availability of more satellites (in particular the Canadian Radarsat and the – optical – Indian Remote Sensing Satellite IRS-1C),
- the full availability of the Neustrelitz receiving station (NE-Germany).

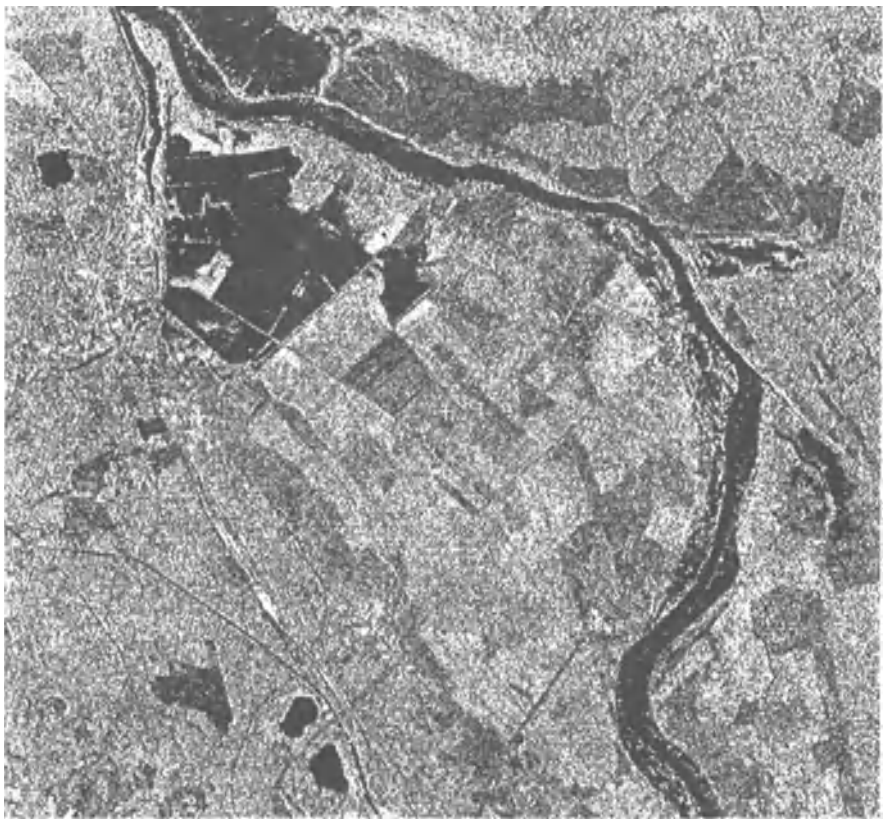
Figure 3 shows the spatial and temporal coverage of all acquired satellite scenes from a total of 7 satellites, working in different modes and ground resolutions, starting from 7 m. Whereas for the German part of the river there is an abundance of 14 images for the most critical period between 23. 7. 97 (first dike breaches at Ziltendorfer Niederung) and 9. 8. 97 (return of evacuated inhabitants to the Oderbruch), giving an almost daily coverage, data from the Polish part (the critical period for Wrocław/Breslau, for example, lasted from 12 to 29. 7. 97) are rather scarce. Had it been known at this time that information would be lacking, thus leading to limitations in the forecasts for Germany, more images could have been acquired.

SAR (Synthetic Aperture Radar) as an active sensor has the advantage of being not impeded by night or cloud cover – qualifying it especially for weather-induced catastrophes. Yet, it has only one wavelength (equivalent to black and white pictures) which makes evaluation sometimes difficult. However, distinguishing water from dry soil is straightforward. Figure 4, for example, shows a sequence of three images at weekly intervals. They document the inundation of the ca. 60 km^2-sized Ziltendorfer Niederung after the first dike breach occurred near Brieskow-Finkenherd (north-west) on 23. 7. 97 and the second near Aurith (south-east) on 24. 7. 97. The image from 9. 8. 97 already falls in the phase of initial water withdrawal. From such documentation the variable geographic extent of the water and the duration of water coverage for distinct locations can be easily derived, information which is useful for later modelling and damage regulation by insurance or aid organisations (Fig. 5).

In spite of the promising overall potential of Radar satellites for this kind of disaster, some minor technical disturbances were encountered which require further attention: The first resulted from an over-radiation by a broadcast transmitting station in the C-band where the sensor is sensitive (5.3 GHz frequency with 30 MHz bandwidth) and the other from a possible mis-interpretation of water as dry soil in fields where tall crops, e.g. corn, were protruding from the underlying water. Figure 6 shows an image of an optical sensor for comparison acquired in visible light at fair weather conditions on 40. 7. 97, 10:30 hrs by the Indian IRS-1C satellite. The gap in the dike near Aurith can be clearly seen, as well as the inward stream of sediment charged water, while the texture of the individual fields beneath water level is not very pronounced. To study also the after-effects of the event, the image in Figure 7 was taken using the same satellite 7 weeks later.

In addition, in order to assess possible gains in information when new generations of satellites with higher resolution and stereo scanning capability become available (highly desirable for disaster applications), three campaigns with airborne cameras were arranged (Fig. 8). The complementary character of the information is exemplified at the camera with the highest resolution of 13 cm and stereo in three pictures. Figure 9 shows the ongoing reinforcement work on the dikes (with synthetic sheets, see magnified inserts) and could, in its stereographic version, also be used to control weather height

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a



b

Fig. 4. Reliable image acquisition at predetermined times is only possible with Radar satellites, because of their cloud penetration capability. This sequence at weekly intervals (**a** 23. 7. 97, **b** 2. 8. 97, **c** 9. 8. 97) documents the dynamics of water coverage in the Ziltendorfer Niederung (South of Frankfurt/O, appox. 60 km^2 in geographic extension) with a ground resolution of 7 m. (Copyright: Radarsat Inc. and GAF mbH)

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Fig. 4c

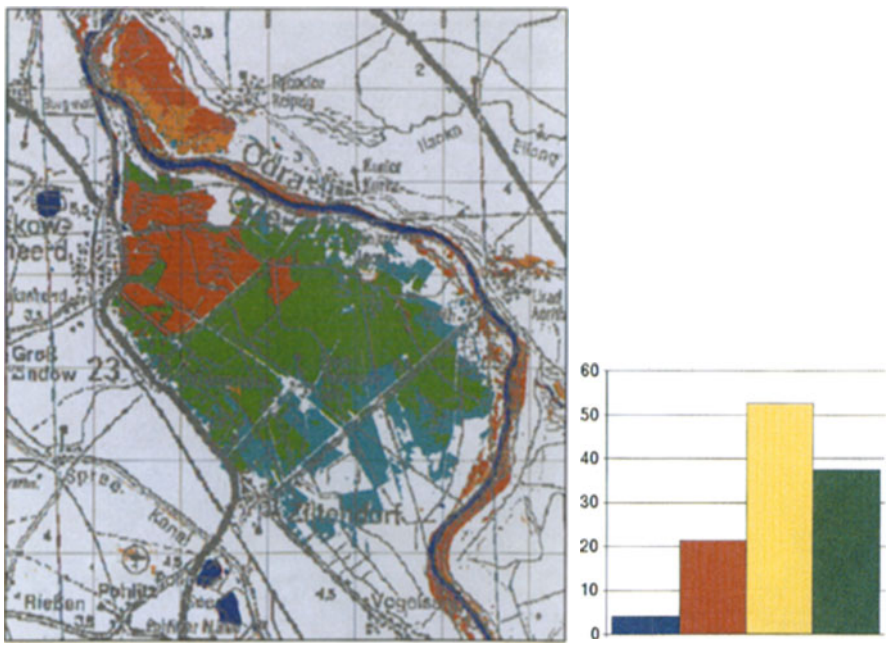


Fig. 5. Water extent at different dates derived from the Radarsat images shown in Figure 4, superimposed over a topographic map (left); from red to blue: decreasing flood durations. On the right, the corresponding area quantities are given in km^2; blue: normal tide, red: tide on 23. 7. 97, yellow: 2. 8. 97 and green: 9. 8. 97. From such information, the duration of water coverage for individual buildings or locations can, for example, be easily determined over large areas

and stability of such structures are sufficient in the current situation. Figure 10 highlights the problem of ecological hazards due to non-removed pollution sources in endangered areas.

Figure 11, in turn, illustrates the potential of current 3D-Digital Elevation Models (DEM), including buildings and tree heights of such quality that flooding simulations can be made with little expenditure ($\Delta z = 20$ cm in absolute and 10 cm in relative precision, grid width in x, y-direction: 0.5 m).

Many other scientific, private and administrative institutions have performed geo-informatics studies on the Oder case, involving

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Fig. 6. Image of the Ziltendorfer Niederung acquired under fair weather conditions with the panchromatic (b/w) sensor of the Indian satellite IRS 1C (Copyright ISRO and GAF-Euromap GmbH). With a ground resolution of approx. 6 m, the broken dike near Aurith is clearly visible, as is an inward stream of sediment-charged water



Fig. 7. The same site as in Figure 6, taken on the 16. 9. 97 by the same satellite to study the after-effects of the event. West of the broken dike, a sand deposit 800 m in extent can be seen

modelling of partial effects of recent architecture; influencing factors of different vegetation covers within the watershed area; geological stability of dikes; risk assessments for insurance; and the impact of increased sediment discharge to the ecosystems in the estuary and Baltic Sea. Some but not all of these used remote sensing and meteorological satellite data. All these parties gathered on invitation by the DLR and the Federal Ministry of the Environment in Berlin on 3 12. 97 for a final presentation (Remote sensing data for an Oder Action Plan – coordination meeting 1997).

The European Space Agency in particular has undertaken and presented extensive studies, in connection with european and national administrative bodies, on the use of satellite information w. r. t. three phases

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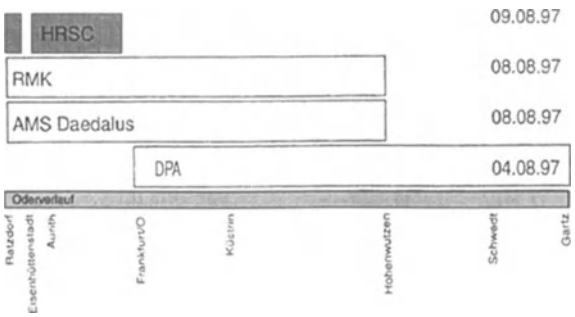


Fig. 8. Schematic diagram of the spatial and temporal coverage of the Oder flooding by airborne campaigns on three days. DPA (Digital Photogrammetric Apparatus) is the airborne version of the space camera MOMS (Modular Optoelectronic Multispectral Stereo-scanner) which is presently in orbit on-board the Mir station, and has 27 cm ground resolution, along with 3200 m swath width at the cruising altitude of 2300 m. Daedalus is a multispectral scanner of 8.8 m resolution and 6500 m swath width at 3,500 m altitude. RMK is an analogue metric camera of 1:23 000 scale at this given altitude. HRSC (High Resolution Stereo Camera) was developed for a topographic mission to planet Mars and can, in its unchanged version, resolve ground features of 13 cm spacing with a swath width of 700 m at 3400 m aerial altitude

- prevention
- crisis
- post crisis

taking different European events, including the Oder, as examples. They also compared the reaction times of different satellite providers (Scot Conseil, Alcatel 1997).

3 Conclusions/Outlook Under Early Warning Aspects

In contrast to Poland, where many natural retention areas got flooded after dike breaches, the most critical part of the German river segment, the 1000 km^2 large Oderbruch (once drained to gain arable land in the 18th century) could be kept under control, and greater damage to the 30 000 inhabitants prevented. This fortunate outcome can in the end not be credited to good forecasts in either form, tradi-

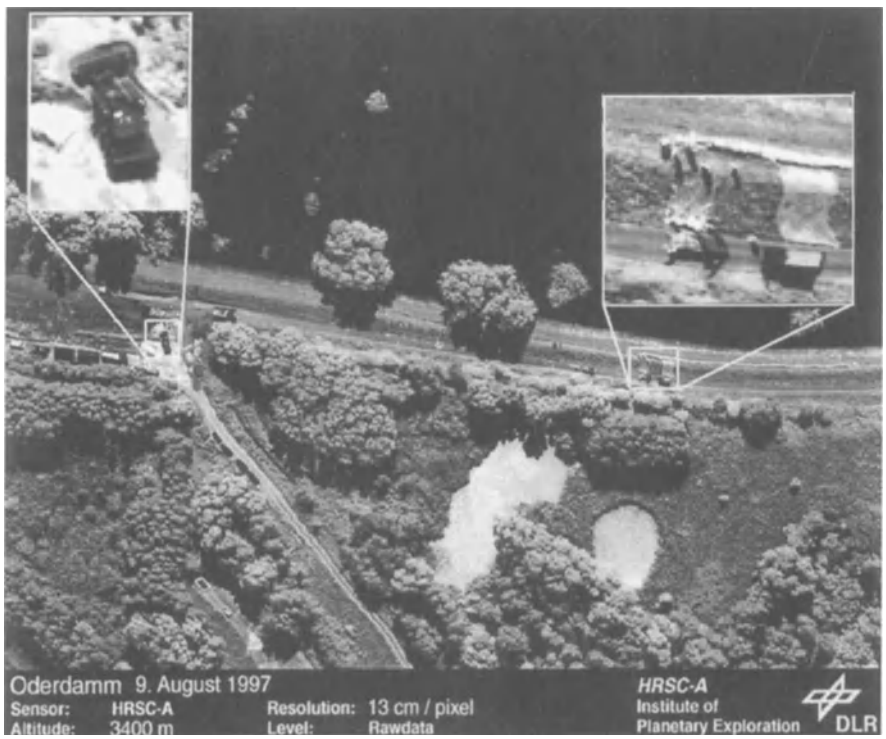


Fig. 9. Dike fortification work (with synthetic sheets, see magnified inserts), captured by the digital camera HRSC

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Fig. 10. Environmental hazard sources form a non-cleared bus-depot "Thälmann-Siedlung" within the endangered area, highlighted with the digital camera HRSC

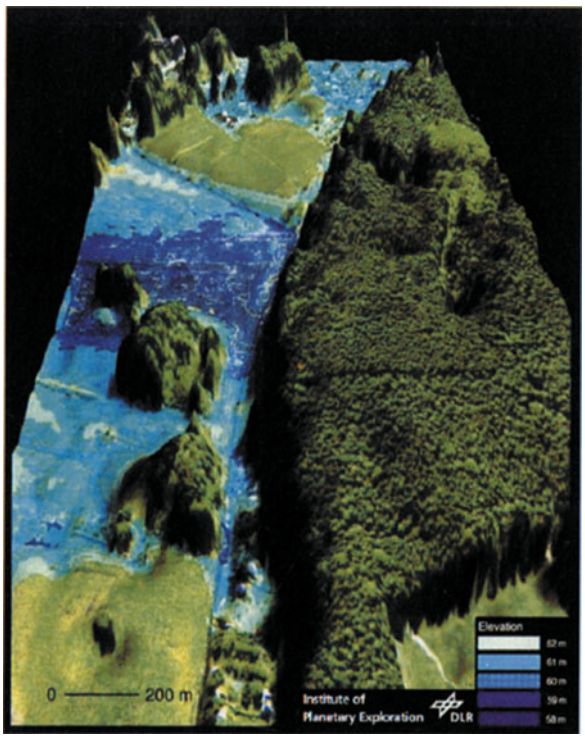


Fig. 11. Flooding simulation (see different elevations corresponding to water depth), calculated on top of a Digital Elevation Model (DEM), derived from stereo images of the digital airborne camera HRSC from a cruising altitude of 3400 m. The accuracy of the DEM is 20 cm absolute and 10 cm relative error in the z-direction, the width of the support point grid in the x/y-direction is 0.5 m

tional or with satellite support, rather only to human efforts, as information technology did not work. There are now several reports analysing the disaster course, its causes and management deficiencies (Grünewald 1998; Federal Agency of the Environment (UBA) 1998; Federal Agency for Hydrology 1998; Moskwa 1997), on the basis of which it can be stated that:

- only a simple hydraulic model was available for the Oder, allowing for no more than very short term predictions,
- damping effects of the extensive dike breaches in Poland could not be modelled,
- gauge values of the upper river course could not be retrieved due to interrupted communication lines or failures of the measurements themselves,
- risk and vulnerability maps were lacking.

If today's state of the art is applied, long-term forecasts have to be built on two complementary types of models

- hydrological models (simulating precipitation run-off in the catchment) coupled with meteorological predictions and data, and
- hydraulic models of high resolution (simulating flow routing in the river bed, accounting for effects of side spills through broken or opened dikes).

In the first case, a DEM (Digital Evaluation Model) and up-to-date land cover data at medium to large scales are needed, to classify different ground porosities related to vegetation, and distinguish sealed from non-sealed surfaces. For this type of information, satellites can be supportive and are being increasingly used. Their major advantages over maps are:

- large area coverage and consistency of datasets across borders (which is of particular

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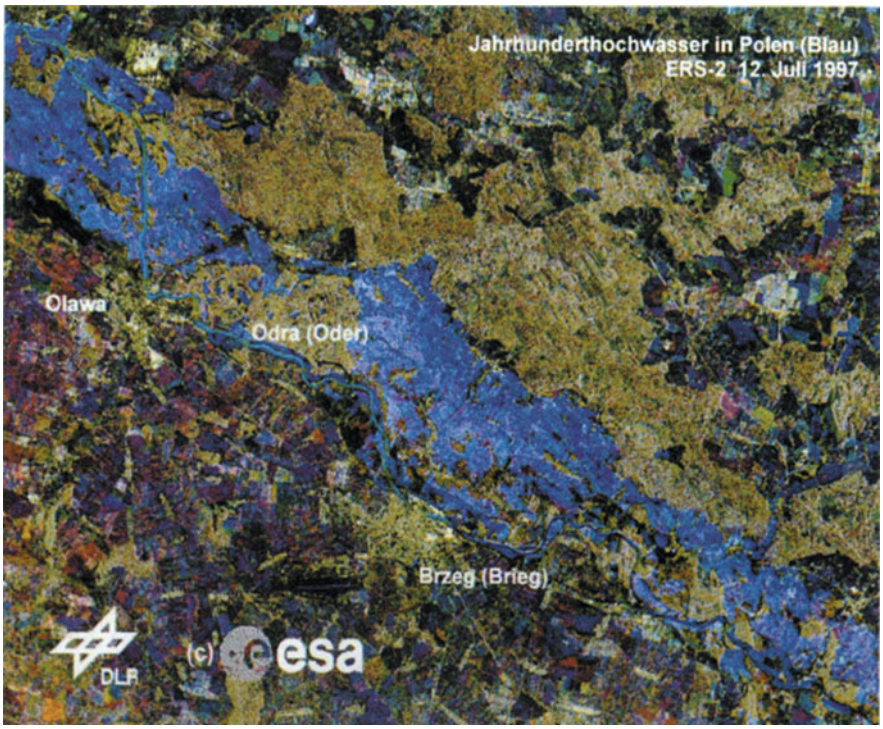


Fig. 12. ERS image taken shortly before the peak water mark in Poland, east of Wrocław/Breslau. The scene diameter is about 45 km. Due to the sensitivity of radar imagery to humidity, not only the extent of water coverage but also different degrees of soil moisture can be derived (different blue colours). Such information, if used in time, is not only able to improve the forecast for downstream areas (relieving effects of side spillings) but can also help regulate compensations to farmers at a later date, by providing evidence for crop soaking

importance for typical European river systems often belonging to different countries with different mapping bases),
- objectivity of information (no generalisation has taken place).

In addition to be put to work in a crisis the hydrological model requires soil moisture data of the upper layers (5 cm) because water-saturated soil behaves like a sealed surface. Remote sensing of such data is less straightforward, though radar satellites are principally sensitive to humidity (see also Fig. 12); and preliminary experimental results have been promising (Rhombach & Mauser 1997). To be operational, however, this information is needed every six hours during the phase of a forming flood, which exceeds by far today's revisit times of satellites (e.g. ERS: 35 days, Radarsat: 3 days).

For the hydraulic model, high precision geometric data (1 dm height resolution) of the dikes and river profiles are needed. These being only accessible from aircraft, there are now three competing airborne remote sensing techniques:
- laser altimetry, with a resolution in the range of a few decimetres and being partly capable of penetrating canopy, thus approaching real digital terrain model (DTM) quality,
- interferometric SAR: decimetres to meters,
- stereo photogrammetry (as in Figs. 9–11), starting from one decimetre and providing simultaneous land cover information.

Satellites, in turn, can be used for the side spillage part of the model, this holds especially for radar satellites with their cloud independence. With images as in Figure 12, along with a DTM, the amount of outstreaming water could be estimated. In the aforementioned case of missing gauge values from the upper Oder course, the imagery could have been used to partially substitute this information, if evaluated in time and acquired more frequently.

Calibration and refinement of all forecasting models is, of course, only possible for the real flood case and, consequently, has little repetition rate. Therefore, any kind of information regarding past events is extremely useful, especially if large areas are covered. In this sense the 30 satellite scenes constitute a wealth of geometric entry data for the set-up of new and better forecast models, which otherwise could not have been obtained (in addition to provid-

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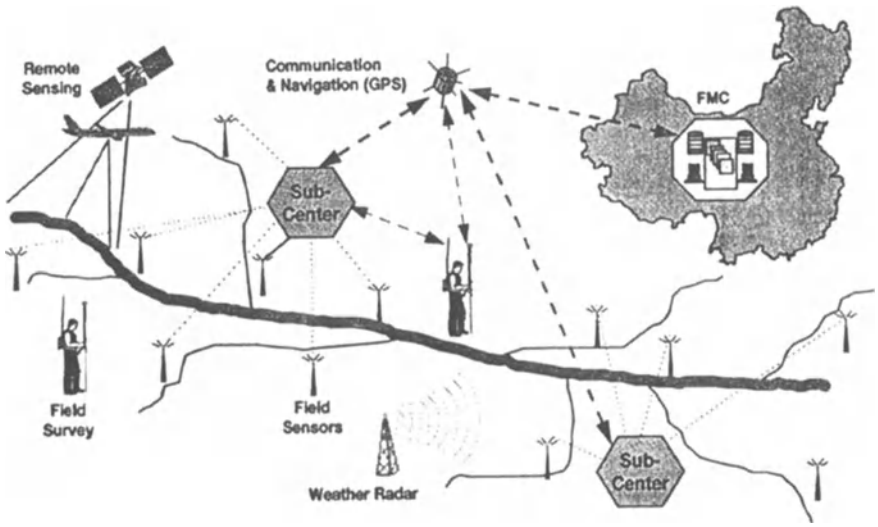


Fig. 13. Concept of a Flood Management System for China built on space-based components including remote sensing for data generation, navigation for field work and communication for central or non-central management

ing benefits to other sectors like land ruling and risk mapping, as mentioned in § 1)

Geo-information technology itself has received impulses from the recent european flood events in several dimensions:

- A "Rhine GIS", incorporating aspects of modelling water levels in cities, as well as the natural retention capacities of a watershed in seasonal variation, was developed by DLR researchers and is now being marketed through a commercial GIS vendor (*http://www.geosystems.de/rheingis*)
- modelling of several European river systems has been advanced, thereby also testing interferometric SAR for topography (European Commission – Joint Research Centre)
- the potential is there to develop animated risk maps (see example in Fig. 11) for Internet broadcasting, permitting individual decision making on the household level
- efforts have been made to use meta-information and catalogue interoperability techniques to make scattered datasets centrally accessible
- satellite providers have accelerated data delivery procedures to better support crisis management itself (e.g. Radarsat from 6 hours (Scot Conseil, Alcatel 1997) down to 2 hours (Remote sensing data for an Oder Action Plan – coordination meeting 1997).

Still to be developed are scenarios for automated inclusion of satellite data in GO and NGO operations, for which money pools need to be established accordingly.

A hypothetical end-to-end flood management system has been studied under a DARA-contract (Kayser-Threde 1996) for China, whose inundations dwarf all european events. It includes three space applications (see Fig. 13):

- Earth observation for early data generation and modelling,
- Navigation for field work of both data gathering and relief actions,
- Communication to connect central and non-central decision makers.

The report concludes with an economic consideration that if only a few percent of property could be saved through increased warning times (the 1996 flood caused losses of USD 26 Billion) the system, including satellite costs, could be afforded.

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The Use of NOAA/AVHRR Data for Flood Disaster Monitoring in the Mekong River Delta

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Abstract

The Mekong River Delta is one of the most important agricultural lands in Vietnam. Every year, it faces flood and water logging, causing a lot of problems and damages. NOAA/AVHRR data sets have been used successfully to monitor flood in this area. The method of Sheng (1996) has been modified, using information from different channels of NOAA/AVHRR data, including visible and infrared split window channels to remove cloud interference, including cloud shadows, when cloud contamination is not very high. The quantitative split window channel threshold value has been given for the identification of a waterbody and land surface under semi-transparent clouds. Hereby, a much wider ground area for any cloud coverage can be analyzed and detected, even under poor weather conditions. Techniques for objectively defining threshold values and the automatic running of the program for flood monitoring have been developed, as well as for the identification of the image's pixels with different rates of mixing between water and land. A case study for flood monitoring in the Mekong River Delta in late 1997 has been carried out. The results of flood monitoring on 15 November 1997 are shown as an example in this article.

1 Introduction

The NOAA/AVHRR data shows a high potential and reliability in flood disaster monitoring of plain areas. The success of flood monitoring using meteorological satellite data mainly depends on the availability of cloud-free images during the flooding process. The main steps in flood monitoring using AVHRR data are:

- the effective identification of the waterbody,
- the elimination of some cloud interference,
- the accurate estimation of the flooded area,
- monitoring of the flood process.

The recognition of ground cover in a remotely sensed image is mainly based on its spectral characteristics. In the near infrared waveband, water has low albedo, whereas vegetation and other objects on land have an absolutely high value. Comparing the visible channel 1 and near infrared channel 2, according to the spectral characteristics, in near infrared 0.9 μm channel 2, the water has a lower albedo, while vegetation and other ground covers on land have a higher value. The visible 0.6 μm channel 1, shows the opposite trend with water having a higher albedo, and land showing lower values. Therefore the ratio band of CH2/CH1 can be used to enhance water and land information. In the ratio image, water has an extremely low value, and land has relatively high values. There are several models for the identification of a waterbody using AVHRR data. In our work we use a ratio of channel 2 to channel 1 (CH2/CH1). If $CH2/CH1 \leq R_o$ (R_o is a threshold value), we know it is water, and it is land if $CH2/CH1 > R_o$.

A big problem is, however, that during flooding, cloud free images are quite rare. The cloud influence is one of the main obstacles in flood monitoring using AVHRR data. When cloud

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contamination is not high (thin cloud), some cloud interference (including cloud's shadow) can be removed using the ratio method (Sheng, 1996). The histogram of the ratio image presents a remarkable bi-peak distribution. The threshold value R_o, which is located between the two peaks in the histogram, can be determined interactively.

2 Defining the Threshold Values for Flood Monitoring

Testing with both normalized and originally visible data, received in September and October 1997, we determined that the value of R_o was not the same for different images received at different time during the day, for different weather systems, for different geographical areas and may also not be the same for different seasons in the year. The interactive determination of R_o on the histogram of the ratio (CH2/CH1)*100 has some disadvantages:

- It is not very precise and the wrong selection of R_o with some units, even with as little as one unit value, can cause big error in an estimation of the flooded areas;
- It is difficult to determine the image pixels, which are mixed between water and land.
- The interactively determining of R_o on the histogram of the ratio is not favourable for fully automatic process of flood monitoring.

It is not difficult to prove that when the area is under cloud's shadow or when the cloud is not so thick the ratio of CH2/CH1 for land has larger values than for water (Sheng, 1996). In the area covered by semi-transparent cloud, the reflective value obtained by the satellite sensors contains information both from the cloud and the under-cloud area. That is:

$$V_{si} = V_{ci} + V_{gi}$$

where, V_{si} is the value obtained by satellite sensor in channel i; V_{ci} is the part from cloud and V_{gi} is the part from ground.

Therefore, the Ratio of CH2/CH1: $R21 = (V_c2+V_g2)/(V_c1+V_g1)$

$$\text{for Water, } R21(w) = (V_c2 + V_g2(w))/(V_c1 + V_g1(w))$$

$$\text{for Land, } R21(l) = (V_c2 + V_g2(l))/(V_c1 + V_g1(l)).$$

According to the spectral characteristics of land and water, $V_g1(l) < V_g1(w)$ and $V_g2(w) < V_g2(l)$, thus, $R21(i) > R21(w)$.

This means that the water and land covered by semi-transparent clouds or in cloud shadow can be distinguished. In the area which is covered by cloud shadow:

$$V_{si} = V_{gi} = A^*E_i + E_{pi}$$

where, A_i is an albedo of channel i; E_i is a received radiance in channel i and E_{pi} is a part of radiance in channel i.

Therefore, the ratio band:

$$R21 = (A2^*E2 + E_p2)/(A1^*E1 + E_p1)$$

$$\text{for water, } R21(w) = (A2(w)^*E2 + E_p2)/(A1(w)^*E1 + E_p1)$$

$$\text{for land, } R21(l) = (A2(l)^*E2 + E_p2)/(A1(l)^*E1 + E_p1)$$

while, $A2(w) < A2(l)$ and $A1(w) > A1(i)$, thus $R21(i) > R21(w)$, implying that water and land in cloud shadow can be distinguished.

It is important to recognize exactly with what kinds of semi-transparent clouds we can still distinguish water and land. If we look for the albedo threshold value to identify water and land we still face many problems. The received images from NOAA satellites are not from the same time in the day. The received images in the early morning or in the late afternoon have much lower albedo than images received at noon. In those cases, it is difficult to identify the albedo threshold value. Furthermore, as the scanning time varies for different pixels in the received images the pixels are received at different sun zenith angle situation. Therefore, for a precise albedo threshold value we have to do a sun zenith angle normalization for every visible image and for all pixels of that image. It is well known that a normalization of visible images is a difficult and complicated process (Binder, 1989).

We have, however, further investigated and this method by giving an infrared split window

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threshold value for the identification of water under semi-transparent cloud. As we know that with differences in infrared split window channels 11 μm and channel 12 μm we can recognize the thickness of cloud (Schejwach, 1982), we measured the differences in temperature between the first 11 μm infrared channel and the second 12 μm infrared channel:

$$D_t = T_{Bb}11 - T_{Bb}12$$

where $T_{Bb}11$ is a black body temperature of 11 μm infrared channel 4 and $T_{Bb}12$ of 12 μm infrared channel 5 respectively.

The results show that with increasing cloud thickness, the value of D_t decreases. From primary testing with AVHRR data in September and October 1997 flood monitoring in the Mekong River Delta of Southern Vietnam, we recognized that the D_t could be used as a good parameter for a threshold limit. We have developed software, called INVEST. We have also created a geographical image file (named AREA.BMP) of an interested area for detecting floods. In our case for AREA.BMP we have selected the area between a latitude of 7.7°N to 13.7°N and a longitude of 109.8°E to 102.5°E, in which the Mekong River Delta of Southern Vietnam is located in the center. The total size of this area is 455792 km^2. The total number of pixels in AREA.BMP image is 211071. The main functions of INVEST are:

- Cutting the images to interested area as the area of AREA.BMP.
- Calibration of images.
- Projection of images with the same projection of the AREA.BMP.
- Geometric correction of images.
- Normalization of visible images.
- Changing of values of D_t with a step = 1 and use of the D_t as a first threshold for detecting thickness of cloud in a water/land identifying process.
- Changing the values of R_o with a step = 1 and use of R_o as a second threshold for checking the ratio CH2/CH1. If Ratio = < R_o it will be coded as a water pixel, if Ratio > R_o it will be coded as a land pixels, where Ratio = integer part of [100*(CH2/CH1)].
- Identifying waterbody pixels, the land surface pixels and the unknown surface pixels under thick clouds by given threshold values for R_o and D_t. Creating of a composite image with an assigning different color to three above-mentioned kinds of pixels.
- After a double looping of calculating with changing values of D_t and R_o, automatically analyzing of all created composite images by statistical methods. Saving of the values of D_t and R_o that gave the best results for water/land detecting.
- Calculating of other images and saving all the best threshold values of D_t and R_o in the archiving file.

We have applied INVEST for calculating of all NOAA images, which were received in September and October 1997. Analyzing the results from the calculation of all above-mentioned images, we recognize that:

- D_t has the best meaning for a water/land identifying with the values from −1 to 3.
- For a $D_t > 3$ the total number of identified pixels is very small and has no meaning for flood monitoring.
- For $D_t < -1$ the water/land detecting is not better than for the case $D_t = -1$.
- For $D_t = -1$, 0, 1, 2 and 3, R_o has respectively different values R1, R2, R3, R4 and R5 and R1 < R2 < R3 < R4 < R5. It means that with a decreasing D_t the value of R_o also decreases. We know that the channel 2 is near infrared and is more sensitive to temperature. In comparison with the land surface, when the cloud is thicker, the contribution part of radiance from water under cloud cover in channel 2 decreases faster than in channel 1, so that when D_t decreases the ratio CH2/CH1 decreases and the threshold value of R_o also decreases (as shown in above results).

3 Process of Flood Monitoring

In late 1997, we carried out tests to define a flooded area in the Mekong River Delta. We created a second masked image file, called MEKONG.BMP, with the same projection as the AREA.BMP image file, to mark all interested pixels belonging to the Mekong River Delta of Southern Vietnam. In AREA.BMP file we have coded all the pixels, which belong to the Mekong River Delta, with a value = 1 and all other left pixels in MEKONG.BMP with a value = 0. The total area of pixels, which belong to our studied area of the Mekong River Delta of

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Southern Vietnam, is 30484 km^2 (14247 pixels). We use MEKONG.BMP file to calculate the number of flooded pixels and to estimate the total flooded area only for the Mekong River Delta of Southern Vietnam.

Base on the procedure No. 1 (Fig. 1) and procedure No. 2 we have developed a program FLOOD.EXE, running automatically on a microcomputer, for flood monitoring process. A waterbody has been identified in each image. Waterbody maps of time series derived from images can show us how the flood changes in area. During flooding, what we care most about is the area of the flooded region. Base on the accuracy of area estimation in each image, we can demonstrate graphically the dynamic area changing.

1. After a Normalization of visible images, Create 5 image files as follow:

Image C1 for $D_t = -1$ and $Ro = R1$
Image C2 for $D_t = 0$ and $Ro = R2$
Image C3 for $D_t = 1$ and $Ro = R3$
Image C4 for $D_t = 2$ and $Ro = R4$
Image C5 for $D_t = 3$ and $Ro = R5$

where R1, R2, R3, R4, R5 are values, received from applying INVEST.

In these images pixels coded as waterbody, pixels coded as land surface and pixels coded as unidentified due to cloud contamination have different values.

2. Creating of a new composite image called COMPOSITE.BMP from the 5 images, created in step 1, according to the following principle:

If pixels from the same position in all 5 images are identified as water then we will code this pixels in COMPOSITE.BMP image as a waterbody; if all of them are identified as land we will code them as land surface; if all of them are unidentified we will code them as cloud with a brightness value as near infrared channel 2; Calculate the total number Nw of waterbody coded pixels, the total number Nl of land surface coded pixels and calculate the total number Nc of cloud coded pixels: if $Nw > 0$ and $Nl = 0$ then code pixel with value of waterbody; if $Nl > 0$ and $Nw = 0$ then code pixel with value of land surface. In all another cases, where we obtained a combination of waterbody and land surface, we will code them with different values (for mixed pixels) following the principles in procedure No. 2. The result of this step is a COMPOSITE.BMP image file with pixels coded as waterbody, land surface, clouds and mixed surface with different rate of mixing between water and land.

3. Using the COMPOSITE.BMP and MEKONG.BMP files for calculating pixels of the Mekong River Delta by the formula of Sheng (1996) as follow:

$$S = 2R2*Dl*p*[A*\sin(Dm/2)*\cos(M) - B*\sin(3Dm/2)*\cos(3M) + C*\sin(5Dm/2)*\cos(5M) - D*\sin(7Dm/2)*\cos(7M)]$$

where Dm is latitude different of pixel; M is latitude of pixel center; Dl is longitude different of pixel; R is short sem-axis of the Earth ($R = 6356.863$); $p = 57.295$; $A = 1.0033636075$; $B = 0.0011240273$; $C = 0.0000016989$; $D = 0.00000027$.

Fig. 1. Procedure No. 1: Flood Monitoring

3.1 Identifying the Mixed Pixels

How can we calculate the area of water/land in the studied area as there are many pixels mixed between water and land. In the Mekong River Delta of Southern Vietnam there are many regions, which are mangrove, aquacultural, intertidal, mudflat or wetland. After investigation from composite image files, which we created and checking with a topography map of Mekong River Delta, we recognized that all of the mixed pixels are located at the boundary of flooded area/non-flooded area or sea/land or lake/land or river/land. After many logistical checking of mixed pixel with a topographical map and inter-tidal pixels we have classified the mixed pixels in 6 different classes. The procedure mentioned below is used to classify the mixed pixels with different rates of mixing between water and land (Fig. 2).

We do not yet have the possibility to check all of the estimated mixed pixels with measurements in the field. But for now we can accept this classification from logistical deducing and logistical checking with the topographical map and inter-tidal pixels. We have assigned different colours to the mixed pixels from different classes. Displaying those images we reveal that the distribution of the pixels with smaller rate of water are always directed toward land, and the pixels with a higher rate of water are directed toward a sea or lake respectively. The results, received from using INVEST show that the threshold value D_t can receive only 5 different values -1, 0, 1, 2 and 3, smaller or bigger values than this interval of D_t have no meaning for flood monitoring. If we calculate with INVEST using a smaller step for D_t, for example step = 0.5, we can increase a number of threshold values for D_t and we can classify mixed pixels in more classes. With the measurements in the field, we can check those mixed pixels to obtain a better understanding and better classification.

Climatic conditions and damaging influences can cause some changes in leaf morphology

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Read coded values of the pixel from 5 image files C1, C2, C3, C4 and C5

Calculate the total number Nw of waterbody coded pixels
Calculate the total number Nl of land surface coded pixels
Calculate the total number Nc of cloud coded pixels

If Nw=1 and Nl=4 then code pixel with value of class A
If Nw=2 and Nl=3 then code pixel with value of class B
If Nc>0 and Nw=Nl then code pixel with value of class C
If Nw=3 and Nl=2 then code pixel with value of class D
If Nw=4 and Nl=1 then code pixel with value of class E
If Nc>0 and Nw<>Nl then code pixel with value of class F

Write the value to the same position in COMPOSITE.BMP image file with the new classified code

The different classes are defined as follows:

Class A is for pixels with approximately 20% of the area being water
Class B is for pixels with approximately 40% of the area being water
Class C is for pixels with approximately 50% of the area being water
Class D is for pixels with approximately 60% of the area being water
Class E is for pixels with approximately 80% of the area being water
Class F is for pixels with an unknown rate of mixing of water/land

Fig. 2. Procedure No. 2: Classifying mixed pixels

and physiology, so the vegetation reflectance pattern may change when climate conditions change or a disaster occurs, such as insects, disease, fire, flooding, water deficits, etc. Differences among vegetation types can be revealed not only by spectral characteristics but also by growing regularity with time. Based on the sun's motion, one year is defined as the growing cycle for vegetation. Within this cycle, different types of vegetation has its own phonological metrics from greening, luxuriance to death. It has its own growing regularity. Due to the above-mentioned reasons we have to consider that for different climatic conditions, for different times in the year and for different geographical areas, there are changes in the characteristic of Earth's surface. These changes of surface may impact the threshold values of R_o and after that they may impact the threshold values of D_t. Now we are in process of preparing topographical maps for Northern and Middle parts of Vietnam and surrounding areas, and masked files for calculations using INVEST (similar to AREA.BMP and MEKONG.BMP image files). We plan to calculate the same parameters using INVEST for Northern and Middle parts of Vietnam and for different seasons (including the Southern part of Vietnam). We do not have good possibilities for checking the results of flood monitoring process as in the case of the Southern part of Vietnam, because in the Northern and Middle parts of Vietnam flooding is more rarely and the areas of flooding are much smaller than in Mekong River Delta. With the results of R_o and D_t, which are received from calculations for different areas and for different season and for different weather systems, we will have a chance to investigate whether in fact these have some impacts to threshold values of R_o and D_t.

4 Case Study: Flood Monitoring in Mekong River Delta of Southern Vietnam on 15 November 1997

The Mekong River Delta (in Southern part of Vietnam) is a very important agricultural region of Vietnam. The total area of the Mekong River Delta in Southern Vietnam is about 39000 km^2. In general the Mekong River Delta in southern Vietnam is a lowland area with many depressed regions. The slope of the Mekong River Delta are very small, so that changing of flooded areas in this Delta is very sensitive and dynamic and flooding causes a lot of problems to people as well as high economical damages. Every year flooding in Mekong River

Table 1. Results of calculation by the procedure No. 1 and No. 2

Number of waterbody pixels	3255
Total flooded area	6951 km^2
Total flooded area in %	22.8
Number of land surface pixels	10461
Total land surface area	22391 km^2
Total land surface area in %	73.45
Number of mixed pixels	531
Total mixed area	1142 km^2
Total mixed area in %	3.75
Number of unidentified pixels	0
Total of unidentified area	0 km^2
Total of unidentified in %	0

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Table 2. Results of calculation by the procedure No. 2 for mixed area

Class	Rate of Water/Land	Number of Pixels	Total area (km^2)	Total area (%)
A	20%	190	409	1.340
B	40%	153	328	1.079
C	50%	71	153	0.501
D	60%	59	127	0.416
E	80%	47	101	0.332
F	Unknown	11	24	0.078
All classes		531	1142	3.75%

Delta lasts from 3 to 5 months (from August to November or December) and sometimes serious floods have continued for longer than 2 months.

To demonstrate, we show the results of calculations using two of the above-mentioned procedures for the NOAA/AVHRR data received at 08h GMT (local time was 15h), on 15 November 1997, for the Mekong River Delta of Southern Vietnam (Table 1, Table 2).

In this case, at 8h GMT 15 November 1997, the cloud cover on the Mekong River Delta of Southern Vietnam was not so thick, so that as we can see from results of calculations we removed all cloud contamination and we identified the whole area of the Mekong River Delta. However, results of calculations show that around the Mekong River Delta, in the area of AREA.BMP, there are 788 unidentified pixels. Those pixels take only 0.37% of whole area in AREA.BMP.

When the cloud contamination over a studied area is high we can use different additional techniques for flood monitoring. For example, based on an already identified waterbody area under cloud-free and under thin cloud cover, we can use the high-resolution topographical map for an extrapolation of the whole flooded area. From our investigation we noticed that there is a good correlation between the flooded area in Kampuchea and the flooded area in Southern Vietnam Mekong River Delta. Thus the results of calculations for the flooded area in Kampuchea can sometimes be used to make an interpolation for the flooded area in Southern Vietnam Delta.

5 Conclusions and Some Remarks

We can use the above-mentioned method, techniques and programs for flood monitoring for different NOAA/AVHRR images, which are received at different time during the day and at different time in the year, for different weather systems, and for different geographical areas. Using this method we can detect a much wider area under cloud cover and we can carry out fully automatic flood monitoring.

If we increase the level of quantization of ratio, for example Ratio = INT [200*(CH2/CH1)], we may obtain more precise threshold values of R_o. With a decrease in step for D_t we may also obtain a better classifying for mixed pixels. In this way we can increase the accuracy of the flood monitoring process. However, the calculation and analyzing with INVEST will take much more computer time.

The good geometric correction of images is very important for a high accuracy of the flood monitoring process. With a good quality and high-resolution topographical map of an interested area we can increase the accuracy of the flood monitoring process and estimation of a flooded area.

Using field measurements we can check and compare with our estimations from NOAA/AVHRR data mixed pixels and we will have a better definition and classification of those pixels.

With the good normalization of NOAA visible images we will have a better albedo information for flood monitoring process and the chance to try to use albedo as an additional threshold in the flood monitoring process.

Up to now in the board of geostationary satellites, including the Japanese GMS-5 and the Cairese FY-2, there is only one visible channel. If there is an additional near infrared 0.9 μm

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sensor on board geostationary satellites, we will have much better opportunity for flood monitoring. In that case, from two different geostationary satellites and from the morning to the afternoon, we can have much more visible images every day and we believe that we can detect flood more effectively with geostationary meteorological satellite data than with NOAA/AVHRR. The GMS-5 and FY-2 visible images have quite a good space resolution and with geostationary satellites we can use data from the water vapour channel and from other channels to identify thick cloud and to estimate rainfall capacity more frequently. Information on the rainfall situation over flooded area is very important for flood monitoring and flood warning. When we have images from two different geostationary satellites, with double look techniques we can improve normalization of visible images and thus improve methods and techniques for flood monitoring. We do believe that if there is an additional near infrared channel data from geostationary satellites we can improve a lot of methods and discover new methods and techniques for monitoring of different natural disasters such as typhoon, heavy rainfall, drought, environmental pollution, forest and grassland fire, dust storm, climate change impacts, ENSO impacts, etc.

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IX Special Problems of Early Warning Systems for Developing Countries and Small Island States

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CHAPTER 9.1

An Early Warning System for Use in Developing Countries and Small Island States

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Abstract

An early warning system for disaster management can be judged to be functional if its elements are reliable, affordable and can, to a large extent, be maintained by the people that it is supposed to serve. Similarly, it can be classified as effective if those who are to benefit from its deployment pay particular attention to both what the system is supposed to do for them as well as to how it works. The latter would require adequate investment in disaster management measures and appropriate education and training, all of which will need to be put to good use in the eventuality of a disaster. On the basis of what is commercially available today, this paper proposes a satellite-based communications network that can provide sudden disaster warning capability for rural, remote and outer communities of developing countries and Small Island States (SIDS). Of paramount importance are the cost, simplicity of warning message, speed and reliability of warning delivery of such a system.

1 Introduction

Most of the Small Island States (SIDS) are geographically located within the tropical zones, where they are exposed to a variety of natural disasters such as cyclones, hurricanes, typhoons and tropical storms. The latter are environmentally induced. Many SIDS, such as Montserrat in the Caribbean region, are also not spared for the devastating effects of ash fallout and mud and lava flows that often represent the aftermath of volcanic eruptions. Earth observation satellites (meteorological and remote sensing satellites) are now able to (1) obtain regular information of thermal signatures of volcanic mountain caps, and (2) track the development and movement of weather formations in order to provide advance warnings of pending disasters. The information obtained in the process can be broadcast through a variety of media channels to the inhabitants of a pending disaster area. Disasters such as earthquakes, both on land and within the seabed as well as tornadoes are, however, very sudden in character, and the resulting shock-waves often create havoc of great magnitude. The requirements for an early warning system for such disasters are very different from those needed for slowly approaching disasters such as drought, desertification and insect (locust) infestation.

Early warning is a deceptively simple notion. Too often it is narrowly understood as the means by which a potential danger is detected or forecasted, and an alert issued. Unaccounted for in this narrow definition are the more difficult and less precise human responsibilities of disseminating these warnings and organising the activities needed to respond to the alert in question in order to avoid potential danger, including the loss of human lives. While technological advances have increased the capacity of early warning systems in the developing and disaster-prone countries, these developments have also widened the gap between the time when the message alert is issued and when the

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end user receives it. This discrepancy lies in the often highly technical content of the warning message itself, and the capacity of communities in disaster-prone areas to understand and act upon the message. This is a critical issue, particularly in countries with different languages and local dialects. A functional preparedness organisation at the national and local levels is very essential for the successful translation of early warning signals into an understandable message at the community level.

2 Steps Taken to Date

Natural disasters are of special concern to SIDS because of (1) their small size, (2) their economic dependence on agriculture and tourism, both of which are very vulnerable to natural and environmentally-induced disasters, (3) their narrow resource base, and (4) the pervasive impact of the natural disasters on the local population, environment and economy. The United Nations Global Conference on the Sustainable Development of Small Island States held in Barbados in May 1994 focused on these issues. In its communiqué, the conference proposed the following[1]:

- to strengthen the capacity of local broadcasting to assist remote rural and outer-island communities within countries and among neighbouring countries during disaster events;
- to increase access to telecommunication links and satellite facilities for disaster monitoring, assessment and information exchange;
- to establish and/or strengthen existing regional mechanisms and communication systems for rapid response to disasters; and
- to provide and facilitate technical support and training through the United Nations and other relevant international organisations for disaster preparedness (including early warning) and relief programmes.

The United Nations Development Programme (UNDP) subsequently developed a proposal for a SIDS network. The proposal focussed on using computer technologies to form *SIDSnet* for the island communities[2]. The five-year project to launch *SIDSnet* would include donor funding of USD 20 million, with the SIDS contributing about USD 10 million. The study assumed an average annual cost of USD 60 000 for a leased line to implement full Internet access. The proposal also focused on using mainly terrestrial technology; however, satellite communications could be used where fibre cables could not be justified by traffic volume. If other satellite options are used, such as sharing a transponder, the overall costs could be reduced. In this regard the study further noted that low Earth orbiting satellites (LEOS) were potentially of tremendous value to SIDS. The equipment needed to link a personal computer (PC) for e-mail services via LEOS could cost as little as USD 500. Such an affordable cost would ensure the availability of an early warning facility on most inhabited islands.

The most challenging requirement for a disaster warning system is its ability to respond to very rapid emergency developments. For example, in the case of tsunamis, a wave or a series of waves at speeds up to 1 000 km per hour can reach an island in several minutes. This means that telecommunications/broadcasting delivery systems must be extremely reliable, should avoid as many switchings as possible and should be able to provide the needed alert in a matter of seconds. Such demands put severe limitations on stored- and forward-LEO messaging systems, especially when the satellite segment is comprised of one or two satellites, and site revisit time is only two to four times per day. On the other hand, geosynchronous systems will require unobstructed views of a geostationary arc, whereas the LEO-based system will use semi-omnidirectional antennas.

The use of satellites to extend communications services to remote rural areas in recent years has been based on three types of technologies: Standard Very Small Aperture Terminals (VSAT), Single Channel Per Carrier (SCPC) Mode, and hubless terminals, such as VSAT Plus. Experience has shown that VSAT networks with star configurations are susceptible to disasters; once the hub is destroyed by the calamity, the entire network becomes paralysed. Both SCPC and SCPC/DAMA are relatively ex-

[1] Report of the United Nations Global Conference on the Sustainable Development of Small Island Developing States, Barbados, May 1994.

[2] SIDSnet: Small Island developing States Network – Feasibility Study Report, UNDP, New York, 1994.

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pensive solutions that also require technically qualified personnel to operate the equipment. Such solutions also address different and more challenging communication requirements than simple alerting systems, that the developing countries, including SIDS, are able to afford. Unlike data-delivery systems, voice-delivery systems require several Kbps. This difference results in a greater than 10 dB advantage to data transmission, in terms of size and cost, for both satellites and terminals.

3 Background to the Current Proposal

Because approximately 95% of all resources spent on disaster-related activities are for relief and recovery operations, relief continues to be the main form of disaster management today. Nevertheless, some disasters can be prevented, or their effects reduced, if adequate research and proven prevention, preparedness and emergency measures are taken. This can be accomplished only through the deployment of a very functional system which should be an integrated part of a well-prepared overall national and regional contingency plan.

In addressing the need to focus on early warning methods for disasters, the General Assembly of the United Nations, in its Resolution of January 1995 requested,

> the Secretary-General to report to the General Assembly, at its fiftieth session, on early-warning capacities within the United Nations system and make proposals on how they may be improved and better coordinated in order to provide for an adequate response to natural disasters and similar disasters with an adverse impact on the environment and, in this context, also to make concrete proposals on the transfer of technologies related to early warning, in particular to developing countries.

The aforementioned 50th session of the General Assembly emphasised,

> that early warnings of impending natural and similar disasters are key factors to successful disaster prevention and preparedness.

The United Nations Office for Outer Space Affairs (OOSA) subsequently proposed to develop, in cooperation with interested UN agencies, a project document to implement a satellite-based communications network for rural, remote and other communities of Small Island Developing States (SIDS) to provide sudden natural disaster warning capability. The three principal driving factors for defining the scope of the project proposal are (1) cost, (2) simplicity of the warning message, and (3) speed and reliability of the warning delivery. The project proposal was presented to the UN Inter-Agency Meeting on Outer Space in February 1996. Official positive responses have since been received from DHA, IDNDR, ITU, UNESCO and WMO as well as from Inmarsat and VITA.

Traditional terrestrial telecommunications – particularly in remote areas of disaster-prone countries – have been costly to install, difficult to repair, and vulnerable to damage. Consequently, such systems have been virtually useless in areas where geography or climate inhibited their installation and maintenance, and thus have been of limited value to disaster managers. Although fixed satellite services may be useful in disaster planning and warning, they have, however been of relatively limited effectiveness in disaster response, principally because of the need for large receiving and transmitting antennas, associated high power requirements and their vulnerability to disasters. Of special concern to SIDS are the power requirements for terrestrial networks. Rural and remote telecommunication sites always present difficulties with regard to the provision of economical and reliable power supplies. Battery operation or solar power is often the only energy choice in the rugged terrains of high mountainous areas and coastal zones with very low density population.

Today, mobile service by satellite provides one of the most dynamic communications technologies available to disaster managers. Even in the relatively short time of its commercial availability, this low-cost communication capability has provided unprecedented services in relief efforts. As a complement to remote sensing, GPS space technology and GIS information management applications, mobile communication service has the capability to dramatically improve risk assessment, disaster preparedness, early warning, the onset of disasters and post-disaster relief operations. This service is now available to areas previously considered inaccessible because of their location, terrain, weather or demography.

In the very near future, all types of global mobile satellite (geosynchronous, medium, low

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earth orbit) and stratospheric communications systems will greatly enhance the disaster mitigation efforts of relief organisations. Providing truly global personal communications, these systems will facilitate a wide array of opportunities for information exchange through voice, digital data transfer and paging. In the process, they would enhance the capability for ground-based emergency alerting, or for local services (to immediately report and request assistance for a natural disaster, accident or other emergency). Because of these features, wireless technologies are the most promising alternatives for SIDS to deploy in their efforts to combat sudden natural disasters in remote rural and outer communities.

Proven wireless technologies of today include the following: land mobile radio; high frequency radio; terrestrial broadcasting; multichannel multipoint distribution service; wireless telephone systems; and radio paging. Others include packet radio; wireless local area networks, wireless digital modems and satellite systems. And because of their resilience to disasters, amateur radios and portable satellite terminals are invaluable in an emergency situation.

Presently, humanitarian organisations, including national, international, governmental and non-governmental relief organisations and rescue teams world-wide, are among the major users of state-of-the-art mobile telecommunications technology; these include an array of mobile satellite terminals, thousands of walkie-talkies, and short-wave transmitters and receivers. Various types of Inmarsat terminals have proven to be an integral part of the widespread utilisation of these mobile communication services. Of critical need for developing countries and SIDS is an early warning system that is simple, affordable, functional and reliable. The Inmarsat-D and D+ systems meet such requirements.

4 Service Types

The Inmarsat-D pager provides low bit rate one-way (fixed-to-mobile) data transmission. Its other features include the following[3]:

- tone only messages with four alert signals;
- numeric messages of up to 32 characters;
- alphanumeric messages of up to 128 characters;
- a *transparent* data service with messages of up to 2000 bits (or 400 characters), allowing service providers to provide services tailored to their own needs such as character sets (e.g. Chinese) in addition to Roman characters and short *macro* (or compressed) messages to enhance efficiency;
- numbered messages to enable the mobile subscriber to identify any *lost* messages which can be automatically repeated; and
- group calls with all of the above features.

Inmarsat-D+ is very similar to Inmarsat-D in many ways. The biggest differences are that Inmarsat-D+ offers two-way communications and GPS location data.

The Inmarsat-D and D+ pocket portable receiver is compact, lightweight and smaller than a personal organiser. It is designed to be simple to use; it has sufficient capacity to store a large number of messages (up to 1 K of memory or about 25–40 character messages), and its battery has a minimum life of one week, and can be either disposable or rechargeable. Some of its basic features are:

- signal strength indicator
- reception of partially corrupted messages
- power saving features, with 'battery low' indicator
- time-stamped and numbered messages
- sufficient storage capacity.

The receiver, which is slightly larger than many of today's alphanumeric pagers, offers the same functionality but with increased coverage. Signal strength indicators on the receiver will enable the user to position the receiver for optimum reception.

The services offered by both Inmarsat-D and D+ are compatible with both current operational Inmarsat-2 and Inmarsat-3 generations of satellites. Tests of both the forward link (the broadcast paging) and the return link (the acknowledgement function on Inmarsat-D+) have already been conducted using current, second-generation Inmarsat satellites. It is expected that this service will be cheaper within the individual spot beam, the latter being a new feature of Inmarsat-3.

Comparable paging receiver systems which can be employed for the same purpose are

[3] LING, Ruth (1998). Inmarsat-D and D+ Global Satellite Paging, http://www.inmarsat.org/index3.html.

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being developed by Kyocera of Japan and Motorola of USA[4] to operate on the Iridium constellation of mobile communication satellites that are scheduled to begin operating from September 23, 1998. The characteristics of these two pagers are as follows:

- Alpha and numeric messaging;
- Four line, 80 characters display;
- International character sets;
- Phone book memory;
- 128 KB RAM;
- Battery gauge; Battery life of 30 days; 1.5 volts (AA); and
- Dual time zone clock (home and local time) with travel alarm.

New Little LEOS that will operate non-voice services below 1 GHz and which may offer similar services are on the horizon. Three of these, *E-Sat Inc, VITA* and *Final Analysis* have just been licensed by the FCC in the United States.

5 Costs

The introductory price of a personal portable receiver is currently in the range of USD 600 to USD 1000. A bulk purchase of 1000 receivers of this type, for the humanitarian goal of this project, would result in an outlay of USD 600 000 to USD 1 000 000. The cost of a leased channel to the United Nations (or an organisation responsible for this project) would depend on the power required/selected, any special access requirements and other arrangements. Given the large number of sites (user terminals), anticipated to be about 1000 in developing countries and SIDS in the first UN-supported phase of the project, the cost per site per annum would be less than USD 300[5]. Inmarsat's favourable policy toward disaster events could be used as a basis to request the organisation to provide, gratis, the space segment of broadcasting messages that are related to disaster warnings, particularly those related to tsunamis or cyclones.

Because of the simplicity of the receiver, no costs are expected to be incurred in providing special training to operate it. However, a receiver's manufacturer should develop detailed and very simple instructions, taking into account the local conditions.

6 Service Implementation

Securing the type of service described above requires the use of land Earth stations (LES) by land Earth station operators (LESO), such as Station 12 in The Netherlands: the only current operator for both Inmarsat-D and D+ systems. These facilities are able to offer typical basic services, with a daily average of two minutes, given the basic design of the message frame of 4 minutes. As many receivers as necessary could be deployed.

Receivers can be grouped geographically, so that a single message can reach them collectively or selectively, depending on the designed configuration. The LESO is also able to offer a dedicated channel within the basic Inmarsat-D and D+ design. Such a channel can be assigned solely for disaster warning for an entire ocean region, or within a specific spot beam. A configuration of this nature would offer a much faster response; for example, a 30-second delay between LESO input and the sounding of the alarm.

7 Conclusions

The adoption and implementation by the United Nations, of a proposal of this nature would put at the disposal of the organisation a full, dedicated and versatile mobile communication channel that can offer a variety of services to the organisation and its member states in a number of key areas. The advantages of such a system include: (1) warnings delivered, on average, in one minute, a time frame that is extremely important to the main goal of an effective early warning system; (2) the United Nations could use the system for any other broadcasts during non-emergency times, e.g. in peace-keeping operations or election-monitoring activities: the system could be used to inform/instruct UN troops and/or observers in the field; and (3) the capacity of the channel could also be leased for commercial purposes on the condition that emergency messages will be given the highest priority.

[4] Iridium: Products – Kyocera and Motorola Pagers, July, 1998, *http:www.iridium.com.*

[5] At the current rate of USD 18/month for connection to the LESO and between USD 0.07 and USD 0.25 per message, depending on the pager being used.

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CHAPTER 9.2

Small Island States and Early Warning Systems

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Islands in the Eastern Caribbean stretch in a line from North to South in close proximity to each other. On a good day, from some of them one can see neighboring states in both directions.

There is an annual Atlantic Hurricane season during the period June to November, which threatens the area, and represents the major and most prevalent natural disaster phenomenon that affects the region. Hurricanes have been known to occur outside of this period, but are rare.

Because of the annual hurricane threat, there now exists a Severe Weather Watch and Warning System in the region, in close collaboration with the WMO RA IV Hurricane Committee, including the Miami Hurricane Center, which offers timely and reliable services in the region.

As desirable and necessary as early and accurate warnings of severe weather are for the protection of lives and properties in the vicinity of severe weather systems and experienced though the services may be, the small sizes and close proximity of Caribbean states create problems of effective warnings that the peculiar to the region.

A satellite photo of a well-developed hurricane over the Eastern Caribbean will show extensive cloud coverage over the whole chain of islands. This does not necessarily mean that all areas covered by the cloud mass will be severely affected. Hurricanes have well-defined areas of high winds near the center and heavy precipitation, but also have spiral bands and other less defined areas, including tornadoes, within the system that have the potential to inflict severe damage in areas removed from the center. Hurricanes may or may not also be very wet and their rate of movement over a target inversely influences the severity of damage and flooding. The major damage from these disturbances arise from storm surges and flooding. High winds, while dangerous and spectacular and not to be ignored, are confined to relatively smaller areas. It is not unknown for a system to devastate one area with heavy precipitation or high winds or both, while locations in close proximity escape with minimal effects. Topography plays a role.

While there are well-understood principles and models of areas in which maximum intensities are to be found, the phenomena are known to exhibit some deviation in characteristics. Techniques for ascertaining, in advance, those areas or islands in the vicinity of a system that will experience major effects are limited by incomplete knowledge of deviations from known models. The existing radar network is now 26 years old. Because of its age and the level of technology at that time, the units do not identify areas of major intensities and potential development as well as the more modern Doppler radar systems. Time and technological advances have rendered our existing units inadequate to deal with public expectations.

Due to these limitations, a precautionary measure is adopted in which many islands in the vicinity are placed on alert, with varying degrees of an approved warning system.

Inevitably, there are islands not too seriously affected and they are less than enthusiastic at having to resort to closing down their businesses unnecessarily, and at having their populations unduly alarmed. It is not good for business, it lessens confidence in future warning events and does little to inspire confidence in the meteorological community.

Early warning systems are equally of little use if proper implementation procedures are not put in place. In some small islands there are limited avenues for mass evacuation except movement to higher ground away from coastal and low lying areas, or into shelters. The popu-

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lation is confined to the island, and movement to higher ground could lead to movement into areas prone to mudslides and possible isolation, depending on the level of damage to roads and bridges.

Warnings are issued to designated national institutions from severe weather warning centers not necessarily located on all the islands receiving the warnings. It is uneconomical to duplicate forecast and warning facilities. It is believed that cultural mores will enhance opportunities for effective warnings to be issued in formats more readily understood by the local population, for, despite their proximities, the islands do have subtle cultural differences, different accents, and in some cases, a local patois.

Increasing development of media sources, radio and TV stations, Internet services etc., have widened the availability of data, including those on severe weather systems likely to affect states. These have complicated the picture somewhat, since they create increasing avenues for uncoordinated reporting on the event. Regional agreement at the official level has been established regarding which sources national disaster coordinators would use to initiate local actions. There are also those who live in remote areas and out of direct contact, with no access to the media and who can be unaware of the warnings. There are always those who will prefer to be guided otherwise.

For the second consecutive year a Weather Convention sponsored by the Bahamian Tourist Agency, to which USA and other Weather TV presenters are invited, was held in April. The author was invited to present a paper on the effect of US and other international TV weather presentations on the Caribbean. The increasing availability of global TV in the region includes increasing availability of these presentations. Reference from international sources to a severe weather event in the region results in cancellation of hotel bookings and holiday plans to list the region. Would-be visitors, unaware of the geography of the area, simply panic. The severe weather phenomenon may affect only a small area or divert and miss the islands, or simply not be a genuine threat to the area, but the business is lost. The author sought to alert foreign presenters to obtain more specific information before making these broadcasts so casually.

He also suggested that they do not make forecasts of island weather based on early-morning satellite pictures showing clear blue skies, since they do not take into account later local convective cloud developments which do lead to quite contrary results. Tropical island local forecasting requires local experience and skills. It is not the same as forecasting for continental temperate zone areas.

A point of view which has not made the author too popular in some circles is his questioning of the high cost of existing telecommunication services used for purposes of disaster preparedness and warnings in the region. A telephone call from the Caribbean to the USA, for example, costs considerably more than a call from the same US source to the Caribbean. In fora, where the issue of emergencies are being discussed, he has insisted that considering the limited financial resources of the region, these costs inhibit the adoption of modern, more efficient and reliable communications technologies for emergency purposes. Efficient and reliable means of making early warnings available create better opportunities for appropriate life-saving and disaster-mitigation activities. The fact that some of the major beneficiaries of such warnings are the telecommunications agencies themselves, insofar as they would be better able to put their emergency procedures in place to protect their exposed antennae and other equipment, appears to be enough cause for special concessionary rates for telecommunications to be made available for all disaster related agencies. Telecommunications agencies are not in agreement thus far. My presence here would not have been in vain if this matter of more economical rates for use of Telecommunications systems associated with disaster preparedness is taken up at the appropriate international level, as we seek to explore and provide opportunities to mitigate the effects of natural disasters. I have not given up the cause in my region, unpopular as it may be at present.

Small size limits opportunities for broad-based economic activities. Many islands have single crop economies dominating. Agriculture, Tourism, Fishing and maybe some small scale industries reflect the economies of many states. There are exceptions, but in the main the industries listed dominate. Most are easily devastated by an active severe weather system. Bananas, a major crop, can be destroyed by sustained winds of 60 kph. Hurricanes and even some thunderstorms guarantee much higher

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winds. Storm surges destroy beaches and hotels located just beyond high water marks, despite advice from the meteorological community to encourage construction further back. Beaches and hotels take time to regain their original status. Tourism slows. Fishing fleets are destroyed.

Tropical trees and forests, because of the year-round growing season, tend to have abundant growth and do not develop sufficiently deep compensatory root systems which would enable them to resist high winds as do their counterparts in temperate zones, so that loss of tree cover and ensuing damage to telephone and electricity supply wires and poles from falling trees are major hazards with the passage of a severe weather system, even if the stations remain operational.

From an economic standpoint, a direct hit from a severe weather event such as a hurricane could mean total devastation of small islands which historically require a period of about 10 years to return to minimal levels of normalcy. Many small states are ill-equipped to restore services in a hurry. External help is absolutely necessary. There are no guarantees that the annual occurrence of the hurricane season will permit such breathing space. Two hits on the same island in one or successive seasons is not unknown. Economies of scale also render duplication of redundant systems non viable.

Limited economies, with increasing demands on the public purse, restrict the luxury of application of expensive redundancy procedures with proven capability to alleviate perceived limitations. The matter of telecommunications charges for disaster operations, construction of hurricane proof shelters, the institution of enforceable building codes for housing, resisting pressures for occupation of flood prone areas by the dispossessed and by hotel owners for construction of facilities close to the seashore, are realities which need to be undertaken, but are not fully pursued and serve to amplify the scope for disaster.

In wealthier countries, these omissions may seem to reflect carelessness on the part of the country. In reality, minuscule government budgets, telecommunication agency influence, limited space, the need to cooperate with hotel chains for investment and bare shelter affordability are practical reasons for the situation.

From an operational perspective for those of us charged with issuing the warnings in this scenario, efforts have been undertaken to develop a nucleus of well trained and experienced tropical meteorologists, facilities for training, and for repair and calibration of equipment in order to maintain services which deal with other meteorological demands including severe weather. A continuous exercise in public education, stepped up before each hurricane season, is intended to familiarize the public with the significance of the warnings as well as the actions that should be taken. Interaction between the meteorological community and the national disaster coordinators and participation by them in our annual Hurricane Committee meetings are encouraged.

The limitations of identifying specific locations of intense weather to embellish our data base and decrease the number of islands under warning, demand acquisition of modern Doppler radar units to replace the existing aging radar units which have served the region for over 26 years, spare parts for which are no longer readily obtainable. The existing units do not have the same sensitivity to identify intensities as Doppler units, and are becoming uneconomical to maintain. A project is now before the European Union (EU) seeking to modernize the existing system. Caribbean Governments cannot afford to replace the old units.

English-speaking Caribbean countries have established the Caribbean Meteorological Organization (CMO), an organization in which I have the honor to serve as its Coordinating Director, to combine our limited resources by closer cooperation, standardizing training etc. The CMO has made significant strides in the field of meteorology, with a good level of technically and professionally trained personnel, many of whom have extended experience in tropical weather systems. The economic limitations of the region are reflected in the need for the CMO to seek external assistance in the acquisition of high cost items, such as radars. The Organization takes a very active part in the World Meteorological Organization (WMO).

Should we be successful in obtaining EU's support for implementation of the CMO Radar Project, it is believed the will significantly enhance our capability to offer a warning service with more specific delineation of areas under threat. It would reduce the level of annoyance experienced by those who, because of our existing limitations, have to take precautionary mea-

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sures that are in vain sometimes with resulting economic losses.

Concessional rate charges by Telecommunication agencies to institutions engaged in warnings and emergency activities would minimize limitations arising from the inability to afford efficient communication procedures.

There is an ongoing need for public education on disaster preparedness.

The WMO RA IV Hurricane Committee meets annually to review past experiences, to find out how well or otherwise our warning systems have worked with a view to improving perceived deficiencies, to be kept abreast of advances and improvements, new research etc. at the Miami Center and internationally and to update our Operational and Technical plans in light of new developments.

The Hurricane Committee is an action-oriented one and an absolutely necessary part of our regional attempts to deal with this annual menace.

The annual Hurricane season is and will be with us for all time, it will always be a threat and a source of major concern for the preservation of life, limb and property. It has the capacity to annihilate small island economies. The best we can do is to develop a capability to exercise damage control by early and accurate warnings, by developing techniques and systems to offer resistance to less intense severe weather systems and to educate our populations to develop drills and practices to mitigate severe weather effects. The regional meteorological community pursues avenues within its mandate – and even outside of it – to ensure that within our limited resources every opportunity to do a better job is seized.

Nature, however, always laughs last.

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CHAPTER 9.3

Tropical Cyclone Warnings and the Factors that Influence Response: The Trinidad and Tobago Experience

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1 Background

Trinidad and Tobago is a twin-island state located at the southernmost end of the Lesser Antilles, an archipelago of the Eastern Caribbean islands. Its location between 10 N and 11 N (Trinidad) and 11 N and 12 N (Tobago) is mainly responsible for the low frequency of tropical cyclone activity (weak Coriolis factor). This is particularly true for the island of Trinidad which lies furthermost to the south.

The National Meteorological Service is comprised mainly of two offices: (a) the forecasting centre at Piarco airport in Trinidad, responsible for Tropical Cyclone Watch and Warning Services, and (b) the observing station at Crown Point airport in Tobago, where the country's weather Radar System is located.

The radar system in use is a Mitsubishi RC-32B 10 cm weather radar, installed and commissioned in 1970. The radar has a peak power of 540 kW with a maximum range of 500 km (operational range – 300 km). The radar was one of a series of 6 radars installed in the region (Guyana, Tobago, Barbados, Antigua, Jamaica and Belize) and which complemented other existing systems, e.g. in the French islands, to form a virtual 'radar fence' to any approaching Tropical systems.

While many of its companion radars have either died or now function at a fraction of their initial capacities, the Tobago radar, through continued maintenance and the competence of its technicians, continues to work well and at almost 100% of its initial capability. It is instructive to note however, that in April 1997, an earthquake measuring 5.4 on the Richter scale damaged the platform supporting the antenna pedestel preventing the rotation of the said antenna for safety reasons. The damaged platform is now in the process of being repaired and it is anticipated that the radar system will be operational in the near future. It was designed by its manufacturers for a ten-year existence, and original spare parts are no longer available. We get along with the utilization of substitute parts.

The Trinidad and Tobago Meteorological Service in addition to its national responsibilities, is also responsible for hurricane watch and warning for the island of Grenada and its dependencies, viz – the islands of Carriacou and Petit Martinique in the southern Grenadines. In the event of a direct and crippling strike to Barbados, another warning centre, the Trinidad and Tobago Service takes over the added warning responsibility for the island of Barbados itself, St. Vincent and the Grenadines (WMO/TD – no. 494).

The Trinidad and Tobago Service is headed by a Director who assumes final decision-making responsibility during periods of storm/hurricane threat to the area described.

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2 Strategies for More Effective Warnings to the Public

Over the years, improvements in the quality and frequency of observation of the physical structure of tropical cyclones have significantly advanced the knowledge of the location, motion, intensity and asymmetry of various parameters in the cyclone circulation. However, a dilemma arises between the increased awareness among meteorologists, with respect to the uncertainties in cyclone behaviour, especially in track prediction, and the heightened expectations of a public that has been conditioned by the performance of more precise scientific disciplines. The public, therefore, finds difficulty in accepting the fact that meteorologists are incapable of a precise answer every time; that there are remaining uncertainties in our science and so uses that disappointment to vent its impatience at prediction errors that cause inconvenience and economic losses.

Track predictions in particular, have for sometime appeared to have plateaued-out in terms of the determination of the mean vector error of predicted location for fixed time periods. Because of this, undesirably large stretches of coastline, or as in the Caribbean situation, large groups of islands (sovereign states in many cases), still have to be placed on alert (full warning phase). A simple comparison of the many numerical prediction models displays the often large variances in predicted locations for the same storm. Nevertheless, there is increasing light at the end of the tunnel, as models slowly display improved performance from year to year.

The challenge, however, remains with how to bridge the gap between public expectancy of high performance and the limitations of scientific predictability. The answer, it appears, lies in the management of meteorological information to the public, from the first stages of cyclone discovery, to the now-casting period surrounding landfall. The public, taken along on this journey, better appreciates the complexities of the ride as partners and is more likely to make allowances for any shortcomings. Information sharing therefore appears to be the key.

3 The Bret Experience

During the episode of tropical storm 'Bret' on August 6–7, 1993 the Trinidad and Tobago Meteorological Service experimented for the first time with the live use of the electronic media (TV) to inform its public. Through a series of live television hookups from the meteorological office itself, the Trinidad and Tobago and Grenadian publics participated with rather spectacular results.

It is known, that the population of Trinidad and Tobago (moreso Trinidad) does not have any meaningful history of tropical cyclone experiences, and as such, is subject to a varied range of perceptions and misconceptions, the majority of them fanciful, as they relate to hurricanes. It was also noted that persons without hurricane experience, if informed via the television medium, are best motivated if such warnings are issued by a respected authority figure. In this case, the telecasts done by the Director of the Meteorological Service were quite effective, so much so that the flood of telephone calls to the office, which disrupts work programmes and is normally associated with such events, and which earlier in the day was very much in evidence, virtually ceased. People were beginning to listen. The warning message was getting through. Nevertheless, in the midst of this success, we discovered that the information being dissiminated to politicians, the public, the media, disaster management officials etc, was unfortunately also responsible for a whole new set of problems.

4 Problems Associated With Tropical Cyclone Alerts

Timely and accurate warning messages about impending storm conditions, disseminated quickly and effectively to the population at risk, are in themselves ineffective or may generate an inappropriate response if that target population fails to react in a meaningful way. It is at this point that perceptions come into play. The goal of a successful warning system is to mitigate or avoid the destructive effects of tropical cyclones. The individual who takes inappropriate action such as celebrating at hurricane parties, or leaving his fate to the power of

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prayer, refusing in the meantime to take the necessary preparedness measures, negates the effectiveness of the warning system and jeopardises his or her chances of survival.

A worrying discovery during the Bret episode was the level of ignorance displayed by media presenters. This became evident by the questions asked. Some displayed an unfamiliarity with the local geography, others a discomfort when working with the metric system. A complaint that surfaced after the event was the confusion listeners felt when faced with two systems of measurement – the metric and sometimes in the same text, the imperial system. Many times questions were raised about anticipated severe weather yet to be experienced from the hurricane's tail – a media derived term. One could not help the feeling that the storm was being viewed as a live writhing animal entity, whose flailing tail dealt telling blows to all in its path.

At no time was this meteorologist convinced that the television news personalities were aware of facts such as the significance of water in tropical cyclones as the major contributor to death and property damage. Storm surge, when explained, assumed unreal proportions in the minds of media personnel with the spectre of giant tsumani-sized waves approaching. There was little feel for the structure of the cyclone. Point locations were taken as storm points to be considered with little understanding of the spatial extent of the system, the distribution of strong winds and heavy rainfall. Eye diameter varied wildly in perceptions with little appreciation of the average length of shoreline as found on small Caribbean islands.

The nightmare arose with the realisation that these people held the ears and eyes of the population, many of whom were simple rural folk, unschooled the ways of science, and trusting in the message received.

To this end, the Meteorological Director used the television medium to explain any area of information that he felt might mislead, any concept that might confuse, and corrected any bit of erroneous thinking that was forthcoming from an uninformed news presenter. The effort was greatly appreciated by the listening public who for the first time showered compliments on the Meteorological Office for the service provided.

5 Some Commonly Held Perceptions

1. *God is a Trinidadian* – There is a commonly held belief that the island of Trinidad (as separate from Tobago) is blessed and is therefore protected by the Almighty. Recent developments with Tropical Storm Bret narrowly missing the island has only served to further cement this view. This supports a bad case of public apathy which tends to render the warning system impotent.
2. *Topographic Controls* – The northern range in Trinidad runs from east to west across the top of the island. These hills are seen by many members of the population as a barrier to would-be storms affecting the island. In fact, quite the opposite is true as this peculiar orientation of the island's mountains may very well serve to channel a storm across densely-populated areas in northern Trinidad.
3. *Trinidad is too far south to be affected by Tropical Cyclones* – Past history belies this belief. The island of Trinidad was struck in 1933 by a full hurricane. The storm which was not named passed over the southwestern part of the island. There have been several weak systems over the years since then: Alma (1974); Joan (1988); Arthur and Fran (1990). Tobago was struck by hurricane Flora in 1963.
4. *The Weatherman's lying* – These are words of an old but popular calypso that has caught the fancy of would-be detractors. Although flippant in nature as many calypsoes tend to be, the song is remembered every time the public is disappointed over the outcome of a forecast, warning or piece of advice. Psychologically, it continues to encourage a negative personal response and further contributes to public apathy.

6 Public Misconceptions of Tropical Cyclones

The following are examples of inadequate understanding of tropical cyclones as noticed in the Trinidad and Tobago population.

- There is a lack of understanding as to why a cyclone does not move at a similar speed to the wind it generates. In other words, a storm

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with winds of 100 km/h moving at 25 km/h appears as a contradiction in terms;
- There is a lack of appreciation for the difference between a "Watch" and a "Warning";
- Wind is seen as the most significant destructive factor in tropical cyclones, a view fostered by the visual media, movies, etc.;
- There tends to be an over-reliance on the predicted or monitored position of the centre of a cyclone as the sole hub of highly dangerous gusts, or sea surge, when making decisions, such as evacuation or closure of industrial plants or ports;
- There tends to be a literal acceptance of the quoted intensity or speed and direction of approach of a system in decision-making, without allowance for moderate changes;
- There is little appreciation of the limitations of the synoptic processes. This leads to an unawareness of the errors inherent in a satellite fix or a radar fix, and the effect this has on the forecast position;
- There is no appreciation of the spatial relationship between the eye or centre of a cyclone and its core of maximum winds, peripheral gales, and the probable extent of damage in the area covered by a warning;
- There is little understanding of the rapid increase in wind speed between the peripheral gales and the core of maximum winds. People are at times taken unawares, especially those that postpone evacuation decisions and adopt a "wait and see" attitude.

7 Recommendations for Addressing Noted Weaknesses in Warnings

- It may be advantageous to utilize a more personal persuasive message than the more coordinated precise one, due to the differences in perception among varied classes of individuals e.g. sex, age, educational level, income, occupation.
- It may be better to speak in simple terms to the public about a storm situation than try to educate the listening audience in the precise technical language of the forecaster. Local interpretation runs the risk of introducing bias and misinterpretation.
- Latitude and longitude means little to most people. Use positions in terms of distance from some familiar (known) geographical landmark.
- Warnings must be frequent and consistent to counteract rumours.
- Warnings must be short and concise with minimal technical information. Use an intensity scale and inform people of the differences in the scale. Some people consider all hurricanes above Category 1 as "bad".
- Use the medium of television as much as possible. Use maps to give an idea of geography. While the use of radio broadcasts is helpful, especially to those without TV service, it still suffers from overplaying and eventually ceases to attract attention.
- Use respected authority figures to disseminate warning information to the public and to motivate listeners. This approach has the added benefit of providing the opportunity to counsel listeners against the tendency of the media to focus on higher gust figures as the predominant wind speed. In this way, the effect of overprediction is controlled.
- Do not use point/dot indicators to convey information on a storm's position. Use some icon that bears some relationship to the spatial extent of the approaching storm.

8 Summary Reflections and Recommendations

In the aftermath of Bret and with the knowledge gained by its passing, the management of the Meteorological Service seized the opportunity for a proactive approach towards hurricane preparedness regarding future seasons. The lessons were too significant to ignore and some sort of corrective measures were necessary if we were to avert any large scale disaster with the potential for heavy loss of lives. To this end, hurricane familiarisation seminars immediately preceeding each season (June to November for the Atlantic/Caribbean Basin), were mounted with the focus on media personnel, disaster preparedness officials, environmentalists, the protective services, government officials (health, education, etc.), and amateur radio operators. Lecture sessions sought to enlighten through discussion, visual aids and feedback. In addition to the information dissemination strategies, good media relations were encouraged and maintained throughout

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the year as a means towards the development of goodwill. So far, this has worked well.

These recommendations are therefore offered, with the greatest respect, to services in those developing countries vulnerable to tropical cyclones and which may have experienced similar problems in information dissemination during critical situations.

In review, a few additional points are presented along with a summarized few.

1. Wherever possible, use the electronic media, in particular the visual medium of TV, for communication of tropical cyclone warnings and watches;
2. Designate a familiar authority figure (a popular TV weathercaster for example) to interact with the public. By so doing, the level of credibility is enhanced;
3. Do not assume an audience totally enlightened in the science of meteorology or other related sciences. Make allowances for information gaps due to gender, age, religion, income level, social and educational status;
4. Try not to "talk down" to your audience. A simple conversational style will do;
5. Avoid jargon and the use of technical terms as far as possible. Keep it simple;
6. Use local cultural concepts, familiar terms to transport the message across to the listener. By doing so, you are more likely to buy support even when a forecast does not turn out quite as expected;
7. Be totally honest and transparent with respect to the shortcomings of the discipline. Audience perceptions as to the reliability of the forecast or warning must be corrected if partnership is to be achieved;
8. Don't forget to praise the team.

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CHAPTER 9.4

Special Problems Faced by Sri Lanka as a Small Island State with Regard to Early Warning Systems for Cyclonic Storms

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1 Introduction

The island of Sri Lanka is situated in the Indian Ocean between 5′ 55° and 9′ 51° N and 79′ 41° and 81′ 54° E (Fig. 1). It has a coastline of 1585 km and a land area of 65000 km. More than half of its eighteen million people live in villages, towns and cities in the coastal districts.

Depression in the Bay of Bengal may develop into cyclonic storms which affect Sri Lanka and the Maldives. November–December is regarded as the cyclonic season in Sri Lanka since over 80% of the cyclones have been recorded during this period (Table 1). The average life time of cyclonic storms in our region is about 4 to 5 days.

Meteorological observations commenced in Sri Lanka in 1891. Since then a number of cyclones have crossed into Sri Lanka (Table 2). Of these, only three could be classified as severe cyclones with hurricane winds exceeding 73 m.p.h. They occurred in March 1907, December 1964 and November 1978 and all three struck the eastern coastal belt from Jaffna Peninsula to Pottuvil.

It is estimated that when a cyclone develops in the Bay of Bengal, there is only a 10% chance of it coming to Sri Lanka. On average, we could expect a moderate cyclone once in eight years and a severe cyclone once in 20 years. As a small island, when a cyclone makes landfall, the most destructive winds are experienced near the coast. For example, at Batticaloa in 1978, the height of the sea waves from the storm surge was estimated to be two metres. At Kalkudah on the East Coast, the sea encroached the land up to a distance of 1.5 km.

A storm surge accompanies every cyclone and the east coast is affected by a storm surge during a passage of a cyclone; the west coast may also be affected by back surge (Fig. 2). The average height of the surge on the coast line appeared to be between 6 ft (1.8 m) and 7 ft (2.12 m), but locally in estuaries the surge may have risen to 9 ft (2.78 m).

A storm surge will move into the island until it reaches a point where the ground is as high above sea level as the top of the storm surge. In other words, if the storm surge is 8 ft (2.4 m) high, it will continue moving inland until it reaches a point where the land is above sea level.

2 Early Warning Systems

The development and movement of cyclonic disturbances in our region is closely observed using the following data.

1. Regional surface and upper air data
2. Cloud imageries from the polar orbiting NOAA satellites and Japanese Geostationary Meteorological satellite
3. Cyclone warning radar at Trincomalee, East Coast
4. Indian Geostationary satellite.

3 Problems

There are three types of special problems faced by Sri Lanka.

1. Technical Problems
2. Problems in Warning Systems
3. Lack of Expertise/Resources.

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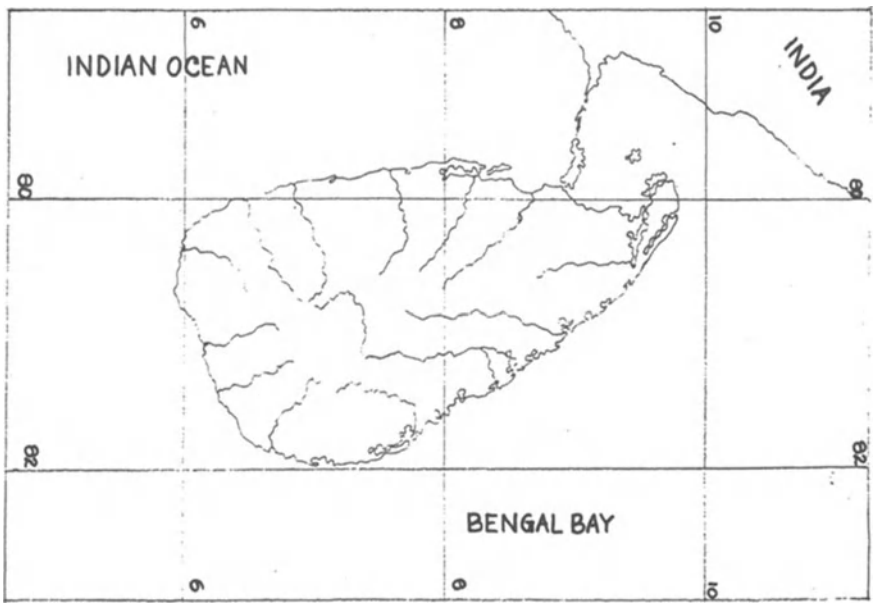


Fig. 1. Map of the small island state Sri Lanka

Table 1. Number of cyclonic storms that reached the coast of Sri Lanka in different months since 1881; Source: Department of Meteorology

Month	Number	Year
January	1	1906
February	0	
March	1	1907
April	0	
May	0	
June	0	
July	0	
August	0	
September	0	
October	1	1967
November	5	1912, 1922, 1966, 1978, 1992
December	7	1908, 1912, 1913, 1919, 1931, 1964, 1967

Table 2. Number of cyclonic storms that reached the coast of Sri Lanka during different decades since 1881; Source: Department of Meteorology

Decade	Number	Year
1881/1890	0	
1891/1900	0	
1901/1910	3	1906, 1907, 1908
1911/1920	3	1912, 1912, 1913, 1919
1921/1930	1	1922
1931/1940	1	1931
1941/1950	0	
1951/1960	0	
1961/1970	4	1964, 1966, 1967, 1967
1971/1980	1	1978
1981/1990	0	
1991	1	1992
Total	15	

3.1 Technical Problems

We get only two satellite printouts per day: one at night and one during the day. The day time imagery is more useful for establishing a fix on the cyclone. This means that only one exact fix is available over a 24-hour period.

The electricity supply in the offices of EWS failed several times during the warning periods. The standby generator supplies electricity to the equipment only which made work very difficult, and at other observation points, there are no means to generate standby power.

The prediction of the speed and direction of movement or any intensification needs to be further studied and improved.

> For example: Although the present position of a cyclone could be located accurately, it is not possible to always anticipate a change in its movement. In a 24-hour forecast, the mean error in position can be about 70 miles or more in Sri Lanka.

Satellite reception equipment needs to be upgraded to increase the frequency of satellite data reports.

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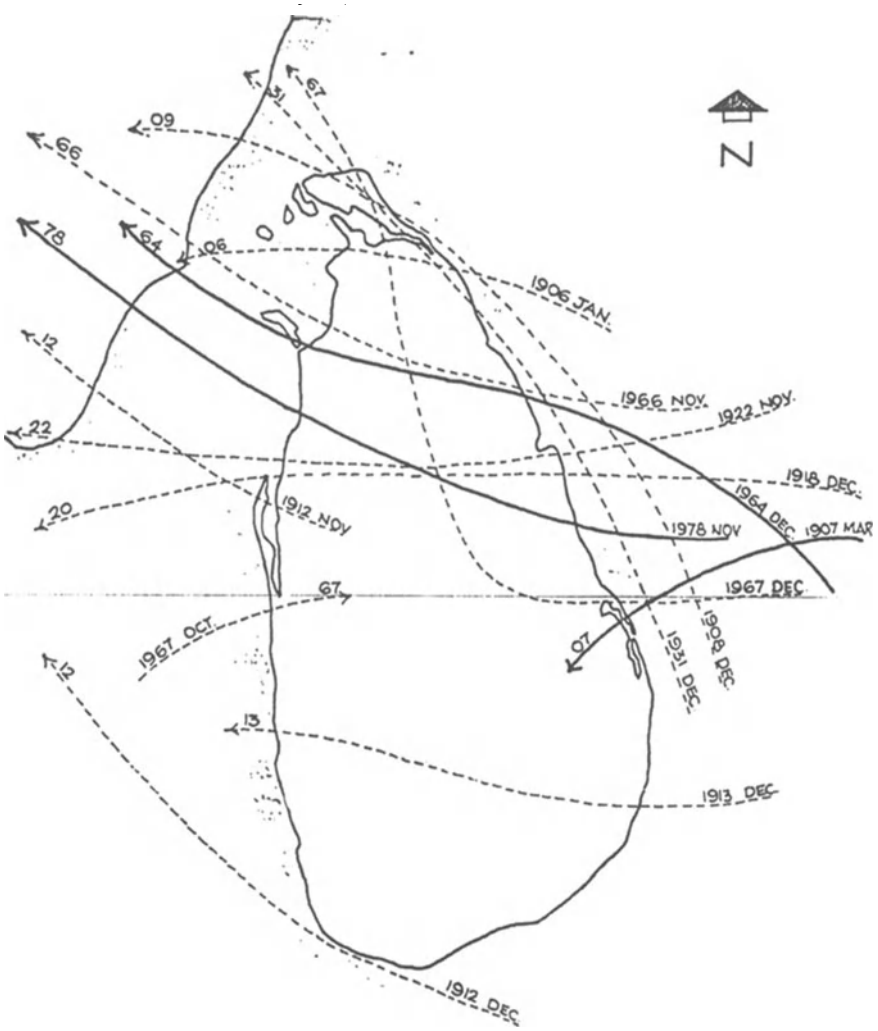


Fig. 2. Tracks of cyclones and storms (1901–1978); Source: Department of Meterology, Sri Lanka

3.2 Problems in Warning Systems

As you know, there is an important distinction between weather forecasting and issuing of warnings. In Sri Lanka, the Meteorology Department issues weather bulletins under the headings of "Bad weather warning/Cyclone warning". These bulletins provide technical information such as wind speed, position of a cyclone, its movement and characteristics.

No information is provided in forecasts about what action should be taken in response to the weather information.

> Example: A forecast may predict winds of hurricane strengths but will not recommend what protective measures should be taken.

There is no responsive warning system based on preparedness, which would include public education programmes, preparedness plans etc.

3.3 Lack of Expertise and Resources

It is observed that the weather forecasting unit gives no priority to wind monitoring because it does not recognize that cyclones are a major threat.

This unit gets information from various satellites and there are computer systems to monitor the wind progress. Furthermore, they do not use resort to computer forecasting due to lack of expertise.

Our problems as a small island, are unique and early warning systems and disaster preparedness should be improved before the next cyclone.

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4 Conclusions

We, at Team DPSD (Team for Disaster Prevention and Sustainable Development) have urged the relevant authorities in Sri Lanka to look into these matters and take appropriate action so that innocent lives and property worth millions of Rupees could be saved. One of the best ways of achieving this aim is conducting community awareness programmes on facing impending disasters. In this respect, education of school children on cyclones and their impact is very important. We have already established a local network of community based organizations (CBOs) in areas prone to cyclones. Since Sri Lanka lacks equipment and expertise needed to prevent major disasters, the developed world has a pivotal role to play in assisting countries like ours to mitigate the affects of disasters. This will make the world a better place to live in for all of us.

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Transferring Flood Warning Technology to Vulnerable Communities in Jamaica

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1 Background

Jamaica, 18N, 77W, lies within the north Atlantic hurricane belt. It therefore faces threats from hurricanes, tropical storms and a variety of severe weather Systems. Flooding is caused by:

- riverine overflow
- inadequate drainage Systems
- blocking of natural drainage features such as sinkholes

Annual distribution of flood events shows that most floods occur in May–June and during November, and that these are associated not with hurricanes, but with weak tropical storms or depressions which slow or stall over the island.

2 Historical Flood Warning Approaches

Forecasting of severe weather for the island is based on the radar system operated by the National Meteorological Services (NMS) which also receives real-time data through satellite links. Close links with the National Hurricane Centre in Miami allow forecasting of Systems beyond the range of radar. The NMS operational orders detail the alerting process for severe weather. These include issuing flood watches and warnings for areas under threat. Official bulletins are sent to the disaster management agency, aviation interests and media houses. The NMS bulletin is for warning and alerting and does not include awareness precautions. That is the responsibility of the Office of Disaster Preparedness and Emergency Management (ODPEM) which issues precautions to be taken by the public following the NMS warning. Both these agencies depend on the electronic data for widespread and rapid dissemination of alerts and warnings to the public. The emergency Services radio network is used to alert emergency response agencies. This system, while quite effective at national level, does not adequately cover flood-prone areas which are at threat from more localised floods events. The Flood Loss Reduction Programme seeks to address this gap.

3 The Flood Loss Reduction Programme

The loss of lives, socio-economic disruption and environmental damage caused by floods prompted the Government of Jamaica to implement a multi-agency flood loss reduction programme in the 1980s with funding support from the UNDP and WMO.

The programme included development of flood risk maps, installation of an automated flood warning System in a major river basin, and development of community-based flood warning systems.

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3.1 The Rio Cobre Automated Flood Warning System

This is the only automated flood warning System on the island. It consists of four automatic self reporting rain gauges, two radio repeaters and two pressure type transducers located in the river channel. Data from these ram and streamflow gauges are transmitted via the repeaters to three base stations located at the offices of the NMS, ODPEM and Water Resources Authority (WRA) where the incoming signal is decoded and passed to a Computer. Evaluation of incoming signals by Computer as well as a trained team determines whether a flood event is imminent. In such a case, warning messages are communicated to relevant agencies. The WAR, through the River Flood Forecast Centre, is responsible for monitoring and evaluation of data and for alerting agencies, but back-up personnel have been trained at the other two base stations. The NMS is primarily responsible for severe weather alerts and flood warnings and provision of quantitative precipitation forecasts, and the ODPEM for dissemination of warnings, safety advice and evaluation orders to the public.

4 Community Flood Warning Systems

Community flood warning systems are based on computerised hydrologic and hydraulic analyses for the prediction of flood conditions, but are modified in a way such that they can be applied by the community. This represents a successful effort in applying technology at the Community level. These systems consist of a radio or a telephone network for communications, staff gauges, Community volunteers, a means of predicting flood conditions, and a set of instructions or contingency plans for community action once flooding is likely.

4.1 An Example of a Community Flood Warning System – Aenon Town

Aenon Town was chosen as the first area for the implementation of a community-based flood warning system.

4.2 Vulnerability of Aenon Town

The Cave River runs through the village of Aenon town, discharging into a number of sinkholes which take the water underground. The largest of these sinkholes is located dose to the village. The Cave River caused flooding of Aenon Town resulting in loss of life and property on six occasions between 1950 and 1986. Following flooding due to the passage of Hurricane Kate in 1985, it was decided that a programme was needed to reduce the negative consequence of floods, and that this programme would be best implemented by the community itself, including Operation of a flood warning system.

4.3 Cause of Flooding

The major cause of flooding is collection in the river of bamboo stakes used by small farmers in the area for planting yams. These stakes block the sinkholes which serve as intake for the runoff from the river. In addition, denudation of slopes leads to considerable soil erosion, and this silt helps in blocking the sinkholes.

The consequent reduction in capacity of the sinkhole near Aenon Town results in flooding. The solution proposed included:

- cleaning of the sinkholes
- development of a community flood warning System
- a public education programme covering operation of the system
- maintenance of the sinkhole and suggestion for reducing debris generated by farming activities.

4.4 Development of the Flood Warning System

The flood forecasting model here uses rainfall data as an input to simulate discharge and time to peak values using estimated watershed conditions. Hydrologic analyses are carried out using the HEC 1 model, to determine relationships between rainfall intensity, duration and peak flows at control cross sections. Peak flows associated with different rainfall conditions are estimated. Calibration of the model is carried out using actual storm events and comparing data generated by the model with measured discharge values. Refinements are made to ar-

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rive at the closest approximation between measured and calculated values. After calibration, the combination of different amounts of rainfall over varying time periods is used to produce peak discharges and times to peak flow, which make up the forecasting table used by the community. The table shows expected time to flooding based on total rainfall quantities and duration of rainfall from the beginning of the storm. It assumes that the rainfall in the upper watershed at Spaldings (where the readings are taken) is representative of the total rainfall in the river basin, and that rainfall intensity is constant for the duration of the storm.

4.5 Operation of the System

Following a general alert by the NMS or observation of heavy rainfall, ram gauges are read in the upper watershed to determine rainfall amount and duration. Information is communicated to Aenon Town by these gauge readers via Citizen Band Radio. The radio operator at Aenon Town interprets the rainfall data using a prediction table, and when the estimated time to flooding approaches three hours the emergency Operations centre in Aenon Town is activated, and the emergency response committee starts to monitor water levels in the river by reading staff gauges and relaying the readings to the Operations centre. Once the 11 ft (3.5 m) level is reached on the gauge located at the point in the town where flooding would prevent safe egress, evacuation to higher ground must begin. The radio Operator in the upper watershed remains in contact with Aenon Town throughout the event and is available to pass requests to appropriate emergency response agencies should outside help become necessary. This has to be done from Spaldings, as the topography around Aenon Town prevents direct radio links out of the valley to the parish capital.

5 Discussion

Community-based flood warning Systems are necessary in situations where regional or national warnings cannot predict the level of danger faced by a particular community. Their success depends on the full acceptance of the system by the community, and their willingness to operate it. The experience in Jamaica has shown that the community will become involved if there are a few individuals willing to take charge and to work at keeping the system functional. It is also important that the community perceive that the authorities are handing over their responsibility to the community. In Aenon Town, the entire village turned out one occasion to clean the sinkhole. They were unwilling to do this on a permanent basis, however, because it is perceived as being the responsibility of the Government to allocate budgetary funds for this purpose. Since the first year, the community has volunteered some time and the ODPBM has provided funding for the cleaning.

The integration of the community system into the wider emergency response network is important as it gives the community a feeling of being supported by the wider network. The radio link out of Spaldings into the Police Station and horn there to ODPEM is not only important from a practical point of view but also from a psychological point of view.

Public education is an important part of the community flood warning system. Volunteers must be trained in operation of the system, and a simulation exercise has to be done to detect potential problems. Regular simulation exercises must also be run by the emergency management agencies or their local representatives. This provides refresher training and orients new volunteers, as well as keeping interest in the system alive in between flood events. At Aenon Town where farming practice was a contributing factor to the flooding, it was necessary to sensitise farmers to the problems created by their traditional approach to hill-side farming. In cooperation with the Ministry of Agriculture, a tree-planting exercise was undertaken in the watershed to reduce erosion. In the long term, funding has been provided for continued cleaning of the sinkhole from the ODPEM budget, and the community continues to donate time to the cleaning. The community is being encouraged to start an environmental non-governmental organisation which would start some kind of business venture, the profits from which would guarantee sustainability of the cleaning of the sinkhole. An NGO would also qualify for project funding from donor sources.

Establishment of the flood warning system, although a good emergency response measure, is best developed as part of an overall mitigation strategy.

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X Future Technology Needs, Accessibility and Affordability of Early Warning Systems

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CHAPTER 10.1

Technical Requirements for Early Warning Systems

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This introduction is based on the R&D that has taken place in two working groups: the WG-3 of Whelen and Daimler Aerospace Cooperation, and the System for Electronic Control and Monitoring in environmental protection, called the SELCOM-project, carried out in cooperation with the Danish rescue service Falck, one of the most important insurance companies (Baltica), Jydsk Telefon (telephone company), universities and public authorities.

In the working groups we have defined the purpose of an Early Warning System as follows:

An Early Warning System must provide the right persons with relevant information at the right time.

1 The Growing Threats to the Population

Nearly every day, television shows the world environmental emergencies, resulting either from

- natural phenomena:
  - Earthquake
  - Hurricane
  - Volcanic eruption
  - Flood
- or manmade circumstances:
  - Aircraft crash
  - Nuclear power station accident
  - Oil refinery of chemical plant fire
  - Road traffic accident resulting in spillage of chemicals or poisons
  - Terrorist attacks and riots
- or, a combination of the two:
  - Damaged or sinking oil tanker near the coast
  - Breaching of a dam
  - Collapse of a suspension bridge.

These are just a few of the threats, in this increasingly advanced technological age, that the population and the environment which surround it have to face. The damage caused to life and property and the costs involved, even when compared to war damage, are astronomical. As population densities increase, these environmental emergency conditions become more complex and costly to control and coordinate.

2 The Situation Now

In most countries nation-wide civil defence systems have been designed to detect incoming military attack, and to provide sufficient warning for the population to take the necessary protective action. These systems have now reached the limits of their capabilities. With the end of East-West confrontation, and in times of general détente, the threat of war has been considerably reduced and therefore the need for civil defence systems especially designed for war times is under question.

In most cases, the initial responsibility for disaster control and environmental protection resides with many, divided and decentralised departments: Police, Fire, Ambulance, District, Regional and National Authorities are all involved. Demarcation lines are not clearly defined, and rapid automated interdepartmental communication facilities are not available. The resources available locally for recovery, rescue and for contending with the emergency are lim-

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ited, and very often expensive. Cooperation across demarcation lines generally takes a long time, and is frequently too late.

If a disaster cannot be prevented, then timely and instructive information must be given to the population to ensure that their responses are appropriate to the situation. This, together with, a coordinated, effective and quick damage control will save lives, property and the environment.

Integrated emergency management system are needed which must provide the decision makers with the appropriate technology. The systems must be able to:

- Detect hazardous conditions;
- Predict the extent to which they cause a hazard to life, who is going to be affected by these conditions, and how long they are going to last;
- Control the measures which should be taken to counter the hazard, and provide information on how these measures should be best implemented;
- Warn the authorities and the affected portion of the population about the conditions and the measures they should take;
- React to the hazard as it changes.

Such systems must include sensors, modern communication facilities and computer-controlled operation centres to provide the decision makers with all the necessary tools for the most appropriate response and effective warning.

The aim of an Early Warning System must be to warn and inform those who are going to be affected by, or involved in, a disaster or emergency. This should always involve:

- giving timely and effective warning,
- spreading credible and accurate information about what *is* happening and what *is going to* happen.

In developing the design for an Early Warning System (EWS) it is necessary to first establish the requirement in conjunction with any criteria listed by the Emergency Services and authorities. There are five main questions that must be answered:

- What happened, where, when and to what extent?
- How serious is the hazard to life, where is it likely to go, who is going to be affected and how long is the hazard likely to last?
- What measures should be taken to counter, remove or minimise the hazard, the danger to life and/or property and how should there measures be implemented?
- Who must be informed when and by what means?
- How is the affected population likely to react, and how is that reaction going to be controlled or managed by the decision makers?

3 System Elements

These five questions should lead to the concept of a system which has five main elements (Fig. 1) and a sixth 'hidden' element. These are:

- Detection
- Prediction
- Planning and Decision Making (Command and Control)
- Response (Countermeasures and Warning)
- Reaction (Population Reaction and Hazard Behaviour)
- and the hidden element would be communications regarding all the above.

Each system element has a number of problems of its own which have to be identified and overcome. These are:

3.1 Detection

It is necessary to monitor the environment and establish the normal baseline criteria. The detection systems must monitor air (atmosphere), water and soil and look for fluctuations that could signify a potential threat (for example, an escape of a toxic material). These systems, which should include defence early warning must be designed to register the standard values, and only send quantitative warning information when one of a set of predetermined thresholds has been reached or exceeded with either increasing or decreasing values. Sufficient time must be allowed for the prediction, decision making, reaction and warning processes to take place effectively.

Table 1 is an example of what would be relevant to measure. Some sensors are used for measuring long term impact – CO_2, or other long term impacts. These measurements should form the basis for governmental regulations.

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Fig. 1. Integrated Early Warning Systems

Other sensors must measure peak influences, such as earthquakes, tsunamis, floods, volcanic eruptions etc. All types of sensors, however, must be situated at the right place and must work in critical situations.

Apart from mechanical stability, it is equally essential that sensors be provided with batteries that are able to supply power for long periods of time, and that the sensors be connected to an effective communications system. Public radio or telephone systems tend to be down in critical situations. Therefore, only dedicated telephone lines should be used, and preferably radio systems based on dedicated frequencies. Furthermore, sensors should be provided with test systems in order to be able to check the validity of the collected data.

A missing sensor in a system may lead to erroneous conclusions if it is impossible to decide whether a given indication is due to a possible error in communications, or to critical input on the sensor.

Communications between sensor and centre, as well as between centres, may also be inadequate. So far, we have seen several early warning systems that are based on the public GSM radio system. GSM systems have proven to be very busy during emergency situations and therefore, police and civil defence groups have been without means of communication. This shows the importance of a dedicated communications system, preferably of web-structure so that the disconnection of one line or radio will not cause the entire system to fail. The new European, digital TETRA standard system is recommended as a dependable system for communications.

3.2 Prediction

The system must be able to gather all the monitoring information from each different source, and coordinate it so that it can be presented in such a way that those in control may be given a comprehensive overview of the developing situation. This information will then be processed into the prediction system, which, utilising additional input from meterological services and relevant information databases, will, in turn, calculate the likely hazards, and threats to population and property.

It is important to understand that it will not be sufficient to look at each value separately, and to register whether they are above or below the set threshold. It will be necessary to ensure that all the outputs are combined so that the general trend can be monitored, and the combined effect of all the different influences can be calculated and presented.

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Table 1. Environmental Impact expressed as risk potential

Medium	Potential Accidents	Pollutants
Earth	Process technical accident Store of hazardous waste Transportation/handling Natural sources Weather conditions	Radioactive fall-out Oil/petrol Heavy metals Tar/phenols Chemical compounds Gases (CH_2, CO_2)
Water (Ground water and recipient)	Process technical Leakage from: dump waste depot chemical depot farms Transportation/handling of hazardous material Airborne particles (natural, anthropogenic)	Radioactive fall-out Heavy metals Tar/phenols Chemical compounds Particles Nitrates Pesticides
Air	Process technical Transportation/handling of hazardous material Store of hazardous waste Natural sources	Radioactive substances CO_2, NO_X, HCl Particles Toxic Gases Toxic Aerosols Poisonous dust
Parameters may be defined as: Radio-activity, Heavy metals, Light organic compounds, Heavy organic compounds and Inorganic compounds		

3.3 Planning and Decision Making

The output from the prediction process becomes the input for the command and control system (CCS), which will assist the decision makers in the construction of an appropriate response. Additional tools within the CCS system could be:

- Input from a relational database, either designed to a common standard, or modified according to requirements.
- Regulations and instructions from government and/or regulatory bodies.
- Contingency plans.

A detailed response plan related to the immediate situation can be formulated based on this input data, and put into action.

Having been presented with all the information provided by the detection system, the prediction system and the CCS, the decision makers must prepare their response and activate the relevant contingency plans for the type of emergency or disaster that is developing, has been predicted or has happened.

3.4 Response

The response to a threat consists of two different types of activity which could run concurrently. Firstly, the response of the relevant authority that has to deal with the threat or hazard, and secondly, the warning process designed to minimise the effects on the population. Where possible, this can be achieved through the use of preplanned procedures.

Countermeasures

The authorities responsible must take all possible measures to counter the threat. The Early Warning System will play a major role at this stage, in assisting the coordination of the emergency services and supporting agencies.

Warning

Depending on the situation, the most likely essential response will be to warn those who are

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going to be affected. It will probably be necessary to graduate the level and distribution of the warning messages according to the nature and severity of the situation. This will be achieved through:

- Issuing signals to the public warning systems, using sirens/public address systems.
- Issuing preplanned warning to radio and television stations.
- Advising the local media, newspapers and wire services.
- Warning neighbouring agencies or countires that could be affected.

3.5 Reaction

Regarding the two types of response, there is also likely to be two different forms of reaction, the reaction of the population and the subsequent behaviour of the threat or hazard.

Population Reaction

Consideration has to be given as to how the affected population is going to react in the event of disaster. Depending on the circumstances, there may have to be mass evacuation in the event of a serious hazard. There could be widesperad panic, refugee and traffic chaos, and disorganisation amongst the emergency services if these possibilities are not carefully considered during the 'decision-making phase'.

Threat Behaviour

The nature of the threat will have to be monitored as it developes, and the success of the response will have to be continuously assessed. This will entail the further use of detection and monitoring systems, thus closing the overall EWS system control loop.

4 Conclusions

It has been shown that the technology is available for an Emergency Warning System. The necessary sensors are available on the market. Software for collection of data is available. Software for prediction is on the market, but international exchange of data is limited to only a few areas, such as the meteorological and seismological areas. Adequate communications equipment is still lacking, both in terms of communication between sensors and centres and between rescue services. In addition warning sirens with public address facilities are needed to convey public announcements with a view to directing the population in emergency situations.

In order to prevent or minimise disasters and emergencies that may present a threat to people and property it will be necessary to employ early detection, accurate prediction, sound decision making and effective warning. To achieve these objectives, the following technical means have been identified:

- Guidelines should be elaborated for the correct placement of monitors.
- Communications should be transferred from public to dedicated domain.
- Relational databases must be established.
- International exchange of data should be formalised.
- Further development of prediction software.
- Education of control centre staff.
- Efficient communication with the population in crisis situations should be prepared, e.g. through sirens and Public Address Systems.
- An international organisation should be established, by the UN for example, to coordinate, collect and exchange information.

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