Historical Perspective and Future Outlook

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Substantial progress on atmospheric pollution research in recent decades has brought us to our current understanding of the broad aspects of the problems ranging from the street canyon to globalscale atmospheric chemistry and physics, and from fine particles to greenhouse gas radiative forcing and the interactions between them all. Figure 1 summarizes the various issues, the respective dominant precursors and their mutual interactions.

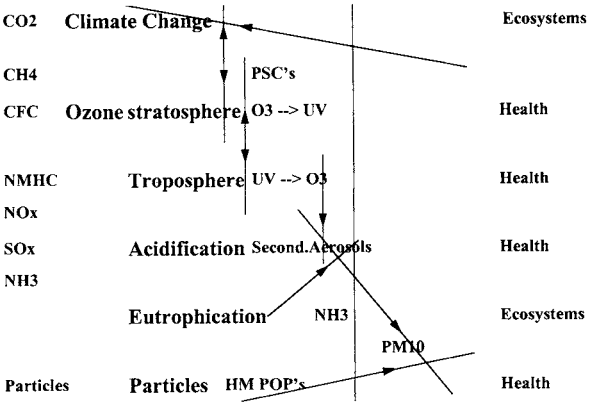

Figure 1. Major air pollution issues, and their interactions.

Current research is to a substantial extent focused on the interactions mentioned, such as:

- the formation of fine particulates / secondary aerosols as a result of tropospheric oxidant formation and oxidation of acidifying compounds,
- the role of these secondary aerosols in both climate change, and effects on health,
- the interactions between stratospheric temperature (climate) changes and ozone depletion by chlorine, bromine and fluorine compounds, including the role of polar stratospheric clouds and,
- the production of ozone in the troposphere in relation to radiative (climate) forcing.

1. CLIMATE CHANGE

Uncertainties in the climate change issue will remain, as illustrated by forthcoming new and plausible theories on the observed global warming. Recently, the theory of Danish researchers on cloud formation, being dependent on cosmic radiation, which in turn is modulated by the radiative activity of the sun, at least explains why the solar sunspot cycle appears so dominant in long-term temperature records. Nevertheless the greenhouse gas radiative forcing theory has gained enough robustness to allow some falsification of the solar activity theory in global warming. According this new theory we can expect stratospheric warming. This, however, contradicts the stratospheric cooling, expected in the greenhouse gas theory, and indeed actually observed / measured in the stratosphere.
All of this illustrates the current position of the state-of-art on climate change. The trends of many observed changes in temperature, precipitation, circulation patterns etc. are in agreement with the theoretical expectations for increased radiative forcing by greenhouse gases.
Simulation studies with climate change models and estimated maximum allowable effects on absolute temperature change, rate of change (to allow migration of ecosystems) and sealevel rise suggest 'safe landing corridors'. Here the global emissions have to stay under 14 GtC for the coming two decades and achieve a 2% per year decrease thereafter. Early action allows more emissions in the long term. Given the expected increase of

CO2-emissions in developing countries / economies, the industrialized countries at least have to stabilize their current emissions in the coming decades.

2. OZONE LAYER

In situ stratosphere measurements of chlorine and ozone, and intermediate compounds, have confirmed the theory of catalytic ozone depletion by halogenic radicals. Recent research further indicates / confirms:

- substantial to large ozone depletion over both the Antarctic and the Arctic,
- observed downward trends in stratospheric ozone over Europe and the USA,
- indicated and estimated effect from increased UV on health and ecosystems.

Successful international policymaking (Montreal-Copenhagen protocols) has resulted in a large decrease in CFC emissions. From model simulations it can be deduced that the CFC concentrations in the stratosphere have passed their maxima; maximum ozone depletion is expected before the year 2000. Nevertheless, complete ozonelayer recovery will not be reached before 2045.

Remaining issues for the stratospheric ozone issue are:

- the increased production of replacing chemicals like HCFC's. As these compounds are more easily scavenged by OH-radicals in the troposphere, their ozone-depleting potential is reduced but has not yet reached zero; moreover, these compounds contribute to radiative forcing (greenhouse gases).
- CFC's are still produced on an illegal basis,
- methyl bromide is still widely used, especially by developing countries; a phase-out would require an additional ten years.

3. TROPOSPHERIC OZONE

Ozone formation in the troposphere from NOx and Non Methane Volatile Organic Compounds (NMVOC) is well-understood. The Nox concentration is critical for much of

the ozone in rural areas, whereas the ozone level in densely populated regions is mainly determined by the NMVOC levels. In many European countries the ozone threshold values are frequently exceeded. European (ECE) policies have resulted in a 3 % NMVOC decrease, and a 10 % Nox decrease between 1990 and 1994.

However, the targets for the 5th European Action Programme and UN-ECE will probably not be met. No consistent downward ozone trend has been detected to date. Further emission cuts, especially for traffic emissions (both NMVOC an Nox), are needed to reduce ozone to acceptable levels. Additional European regulations (Euro3 and 4) are under way. Further Nox reductions will be adopted in the new EU ozone directive and the second (ECE) Nox protocol. This protocol will be based on an integrated approach benefiting from:

- effect-based concepts (e.g. health and critical levels)
- cost estimates of emission reductions and,
- consideration of several pollutants simultaneously.

4. ACIDIFICATION AND EUTROPHICATION

The full process of acidification is now understood to a reasonable extent, both with respect to the atmospheric chemical transformation of primary pollutants like Sox, Nox and NHx into secondary aerosols, the deposition processes under various (micro-meteorological) conditions, and the subsequent soil-chemistry processes (leading to decreased ecosystem vitality). Current research on soil chemistry has indicated that (at least for The Netherlands) the critical levels for the total(potential) acidifying deposition could be relaxed from 1400 moles to about 2000 moles per hectare (average levels for various soil types).

In contrast with this total potential acid deposition, the eutrophying nitrogen flux / deposition into the soil is seen as critical; current (critical) loads cannot be relaxed.

European policies (ECE) have resulted in substantial decreases in SO2 emissions. Nox emissions are decreasing at a much slower rate (see above) and NH3 emissions remain

high in certain areas of intense cattle breeding.

Current research is directed both to the role of (acidic) secondary aerosols in the radiative balance in relation to the climate change issue and to the renewed interest in the effects on health of the fine particulate fraction of aerosols.

5. FINE PARTICULATES

Relatively little progress has been made on the issue of fine particulates. After decades of research the problem still is seen as complex and only partly understood. Monitoring of fine particles is under way, but not yet fully operational. The fine particles (< 10 microns or < 2.5 microns, PM10 and PM2.5) appear as divers conglomerates of sulphates, nitrates, polycyclic hydrocarbons, glycerides, dioxins and oxidized hydrocarbons. Epidemiological research has shown for these complexes associations with potential, serious health effects. Cost benefit calculations show that benefits of concentration reductions exceed costs up to a factor of 200. Legislation of PM10 at the European level is under way.

Remaining (scientific) issues:

- the quantification of non-anthropogenic sources; current emission inventories and model simulations underestimate the measured ambient concentrations. Apparently, unidentified sources are missing from the inventory.
- the emission inventory of primary emitted (anthropogenic) particles needs to be improved.
- knowledge of the photo-chemical carbonaceous material in the conglomerates, is unsatisfactory at the moment.
- associations with effects on health remain empirical; the causality and / or plausibility of such associations are still undecided. Given the high variability in the composition of the conglomerates, this is considered to be a serious weakness in the fine particle issue. Given the additional variability in other, highly correlated atmospheric pollutants (in time and space), the statistical relationship, and subsequently deduced evidence of effects on health are weak ('multi-collinearity').

6. THE SCIENTIFIC PERSPECTIVE

Summing up, scientific research, as discussed during the various US-Dutch workshops and symposia over the last decades, has brought insight into the whole spectrum of air pollution-related issues ranging from fine particles to global change (see figure 2). For the issues on the intermediate level such as eutrophication, acidification and ozone in both troposphere and stratosphere, the scientific knowledge achieved is adequate for supporting and legitimating sound policies. However, at the outer ends of the spectrum the extremes meet; complexity and uncertainty remain high for the fine particulate and climate change issues. Both issues have in common that the number of correlated variables within the real ambient world experiment are very high, compared to the variability, which can be observed anyhow. For the fine particulates, the large spatial scale of the concentration (and composition) pattern limits the potential of empirical / statistical analyses, in addition to which the mechanism of human-health impacts (inhalation toxicology) also lack insight in causal mechanisms. This perspective is seen in the convergence of epidemiological (statistical) and toxicological approaches, for instance, by means of exposure via particle concentrators. In this, the test objects (animal or human) are exposed to the real (complex) conglomerates, and not just to simplified single laboratory exposures.

The uncertainty on the global-scale issue given the uniqueness of the global experiment in time, rather than in space, remains high. Here, the strict rules of science apply where new measurement results never prove or confirm the greenhouse gas-theory but, at best, make it more likely. On the other hand, new results (if contradictory to the phenomena as expected) may falsify the theory, paving the way for a new one. Still, the current position, also formally confirmed by the IPCC scientific consensus, is to improve likelihood from current research results.

Both for the global change and the fine particulate issue, policy makers have to learn to live with the principal and inherent uncertainties. Our further scientific research only can make the associations between causes and effects more likely, not proven.

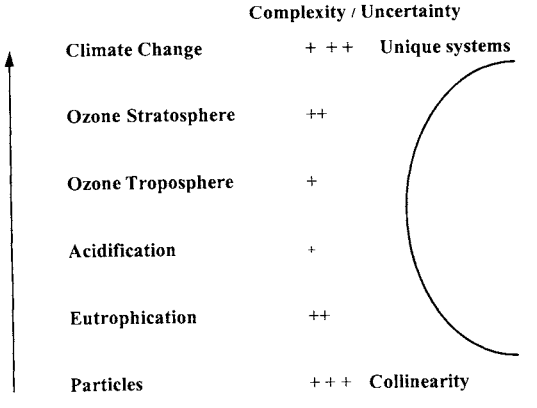

Figure 2. Complexity / Uncertainty for the air pollutant issues

7. THE POLICY / SCIENCE PERSPECTIVE

The focus of research for direct policy support centers, on the following aspects:

- Integrated Assessments and linkage of the various issues as described above, linking these environmental, pollutant-oriented issues to the social / economic actors. Policy measures on CO2, for example, will also bring down the levels of all the other 'fossil fuel' pollutants. Economic sectors will also interact: examples are industrial processes and required transport intensity.
- Burden sharing, partly based on these integrated assessments. As convincingly demonstrated by the UN-ECE process, cost-effective and substantial measures can be taken so that costs can be allocated to the various economies, proportionally and/or justifiably.
- Regionalization, by adopting simultaneous top-down (global scale) and bottom-up (regional) analyses, of both environmental / physical issues, as well as actors in economic sphere.
- Decreasing resource intensity: in the end the remaining - hard to solve - air pollutant problems which are left all depend on the current use of fossil fuels.

More than marginal improvements have to come from alternative options like solar energy, biofuels, and changing lifestyles.

8. CONCLUSIONS

What is the increment of the results presented during the few days of this symposium compared to the preceding decades of scientific research and policy development? The results of the various sessions are summarized, referring partly to the 'Historical Perspective and Future Outlook' presented earlier this week.

Climate change

- Observations made in the stratosphere, troposphere and oceans are in agreement with theoretical (model) expectations.
- The US and Europe differ in their position with respect to the climate change approach. The US aims at long-term budget approaches (tradable emission permits), whereas Europe tends to targets for the short term, i.e. 15 % reduction of greenhouse gas-emissions in 2010. With respect to Joint Implementation, Europe takes the position that this would only refer to industrialized countries.
- The monetary impact of Climate Change is estimated at 1 - 2 % GDP; the former Soviet Union and China are expected to end with net positive global change effects; developing countries will probably be the net losers.
- The 'safe landing emission corridor' for industrialized countries is very narrow, given the minimum restrictions on absolute and relative temperature change and sealevel rise. Stabilization in the coming decades is the upper limit of a development to meet these restrictions.

- Many options for reduction of HFC's (US) and methane (Europe) are in discussion. The reduction of non-CO2 greenhouse gases is complicated by interactions between gases and techniques.

Ozone concentrations

- From both toxicological and epidemiological evidence, the causal relationship between ozone exposure and health effects explicitly has been confirmed. There is a growing concern for chronic health effects.

  The critical ozone levels for health and ecosystems have the same magnitude.
- Background levels of ozone are still increasing on a global scale; this will be a persistent problem in the next century.
- The ozone issue will be linked to pollutants like PM10, according to the idea of an integrated 'one-atmosphere approach'. This will enable a source oriented, cost-effective optimization.

Persistent Organic Pollutants

- Modelling POPs (long range) is complicated and still unsatisfactory; pesticides have been modelled on the European scale; deposition and resuspension (volatizing) processes complicate the modelling efforts.
- For pesticides, interest is shifting from bio-accumulation, via soil contamination to (long-range) atmospheric transport.
- (Very) Long-range transport is a US-Dutch (or CLRTAP) problem; for example Toxaphene is transported from the US Cotton Belt to Europe.

- In European Risk Assessment there is a need for simplified procedures:
  from allowable concentrations - to allowable emissions, avoiding the complex process of atmospheric transport and transformations.
- The (political) discussion on Tolerable Daily Intake for Dioxins proceeds to lower levels.
  The observed daily intake (mother's milk) decreases as the apparent result of policy measures.

Endocrine Disrupters

- The study on endocrine disrupters is triggered by scientific information on decreasing male fertility / sperma counts.
- There is an evident increase of breast and testicle cancer in the US and Europe; the geographical variation is significant; however the relationship with persistent pollutant exposure remains unclear upto now.
- The relationship of endocrine disrupters with effects on ecosystems is found to be plausible.
- The issue of possible effects of endocrine disrupters should be prioritized with respect to other health issues; the relevance of this issue has not yet been confirmed.

Particulate Matter

- Particulate Matter is definitely (statistically) linked to significant health effects, notwithstanding principal complications with respect to the statistical process (collinearity). The causal relationship has not been confirmed!
- However, it would be prudent to assume that the relationship is causal; this plausibility is supported by toxicological results.

- Research should be directed to source-effect (in addition to dose-effect) relationships; through this way of source apportionment, the variability in the composition of the PM conglomerates can be handled more effectively. This may also be a 'way-out' to the problem of 'mass concentration' versus 'number concentration'.

- Dispersion models (indeed) only partly explain PM10 (and PM 2.5) observations.

Industry

In Europe the policy for control of industrial emissions is focused on the formulation of Best Available Technologies (BAT). This approach is fairly 'demand-driven' and has the consequent advantage of adopting emerging non-BAT technologies into the system.

The US-approach is more supply-driven and based on Verification and Certification of existing, proven technology (Environmental Technical Verification EVT).

Mobile sources

- Technological improvements are not adequate to offset growth trends. This is mainly due to the growth in freight traffic (lorries), which offsets the improvements which have been made with respect to passenger cars.
- The CO2 emissions from traffic form a persistent element of the global change issue.
- The lifecycle analysis for electrical cars questions the environmental effectivity; the energy efficiency indeed increases, but so do the emissions e.g. Lead (Pb) may increase.

Agriculture

- Novel foods are expected to increase the environmental efficiency of food production by a factor of 5 to 20 in terms of energy conversion, waste etc.
- The effects of ozone on agricultural crops is again under study; the production losses are estimated between 10% and 40%.
- Priority should be given to the rural development of the poorest Third World countries. This should be achieved by introducing fertilizers, genetic manipulation (leading to, for example, drought-resistant species) and intensified educational programs. These measures should essentially counteract the ongoing, dramatic urbanization trend.

Energy

- Air pollution problems are almost all related to fossil fuel use. Fossil fuels will become cheap in the future. There will be a shift from oil to gas and from gas to coal.
- Given the remaining uncertainties, CO2 reduction policies should be flexible. More research is needed on solar energy and biomass.

Environment and Economy

- There is general need to base further policies increasingly on full cost pricing, i.e. internalization of environmental costs. This should stimulate a market-driven shift to more environment-effective technologies and production-consumption patterns.
- More general economic / fiscal instruments are seen as being indispensable for further policy development.
- Tradable Emission Permits are seen as a potentially valuable instrument.
- From current cost-benefit analyses, it can be concluded that the benefits are often higher than the costs (long-term / short-term problem).