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Chapter 13

Remote Sensing Applications of Wildland Fire and Air Quality in China

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Abstract

As one of the most populous and geographically largest countries, China faces many problems including industrial growth, economic sustainability, food security, climate change, and air pollution. Interwoven with these challenges, wildland fire is one of the natural hazards facing modern China, especially under a changing climate. From a national perspective, wildland fire information is a fundamental and yet challenging prerequisite for understanding forest ecology and hazards in China. In recent years, China has begun to use remote sensing (RS) as a tool for monitoring regional fire hazards, and to a lesser extent, air quality emissions. With the unique features of global coverage, high-resolution, and continuous operation, RS is able to obtain detailed information of fire occurrence, extent, structure, and temporal variation, together with some related fuel properties. Satellite instruments such as the Advanced Very High-Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) have been used in Chinese field experiments and routine monitoring of wildfires and air quality emissions by scientists of the National Satellite Meteorology Center (NSMC) and Chinese Meteorology Agency (CMA). MODIS applications of fire monitoring have also been done by the Chinese Academy of Forestry Sciences. In addition, Landsat measurements have been used for land cover mapping by the Geography Institute, Chinese Academy of Sciences, with land cover being used to determine fuel type and loading and to estimate fire emissions. All of these measurements can be useful for

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both forest management and air quality management in China, especially as air quality concerns and forest fires increase under a warming global climate.

13.1. Air quality in China

Air quality in China is illustrative of a set of environmental issues the country must address as coincident factors. In 2002, China was estimated as emitting 13% of the world's carbon dioxide (CO_2) from industrial sources, only 3% less than Western Europe. A report released in 1998 by the World Health Organization (WHO) noted that of the 10 most polluted cities in the world, seven can be found in China. Sulfur dioxide (SO_2) and particulate emissions caused by coal combustion are China's two major air pollutants. These sulfur and nitrogen emissions result in the formation of acid rain, which now falls on about 30% of China's total land area. Industrial boilers and furnaces consume almost half of China's coal and are the largest single point sources of urban air pollution (World Resources Institute, UNEP and World Bank, 1998). Additionally, rapid growth in the number of privately owned vehicles, especially in the larger cities, has increased emissions of nitrogen oxides (NO_x). A 15-year-old government policy to promote the growth of China's domestic car industry has spurred car ownership to staggering levels. China's roads are expected to be clogged with 130 million vehicles in 2020, by which time the country will have surpassed the United States in total car ownership. Nowhere is this more visible than in the national capital. The number of vehicles on Beijing roads soared by nearly one thousand a day in 2005 for a total of nearly 2.6 million (Bezlova, 2006).

China's national legislature, through its model of "cleaner production" and other attempts to reduce air pollution, has significantly altered the Law on the Prevention and Control of Air Pollution (revised in 2002). Although there have been reports of progress (e.g., reductions in total particulate, NO_x, and SO_2 emissions for the country as a whole during the 1990s according to the State Environmental Protection Administration of China or SEPA), China's major cities have been characterized by some of the highest surface concentration levels of criteria air pollutants in the world, with their annual mean ambient levels in these cities usually exceeding the Chinese urban air quality standards for total suspended particles (TSP), SO_2, and NO_x (Raufer et al., 2000). Sixty percent of the cities countrywide exceeded the second-class ambient standard for TSP in 1999, while 28.4% of the cities exceeded the SO_2 secondary standard.

NO_x has become a major pollutant in a number of metropolitan areas, such as Guangzhou, Beijing, and Shanghai, due to vehicular emissions. In 1997, the average annual NO_x concentration in Guangzhou was $140\,\mu g\,m^{-3}$, the highest value in all large cities of China (Raufer et al., 2000). Beijing's annual NO_x concentration was $133\,\mu g\,m^{-3}$, and Shanghai's was $105\,\mu g\,m^{-3}$. Acid deposition is mainly a problem in the southwest parts of China (such as the Sichuan Basin) and in central portions of the country (i.e., around Changsha, Nanchang, and Ganzhou). The strongest acidity of rainwater and the highest frequency of acid deposition occur in these regions. Acid rain is also found in southern China and in the coastal areas, causing serious environmental damage. Amongst the 106 cities with acid rain monitoring systems, 43 had rainfall pH values lower than 5.6 in 1999. The total area affected by acid precipitation is estimated to be approximately 30% of the country's territory. Changsha had the lowest pH value of 3.54, while Yibin, Ganzhou, and Xiamen had annually averaged pH values of rainfall less than 4.5 (Zhang, 1988).

China's air quality management is more difficult when smoke from wildland fire enters areas that experience problems from urban air pollution. In the United States forest fires are a major source of particulate matter, with most fine particulate matter generated each year from a small number of large wildfires (Riebau & Fox, 2006). These fires are mainly due to a very active program of fire suppression in the United States, which extinguishes small- or medium-sized fires. China has also been enacting a program of very active fire suppression. This program, coupled with the location and extent of Chinese forests and other management practices, has ameliorated wildfire smoke air quality issues in China to some extent. As in the United States, Chinese wildland fire suppression activities are unlikely to reduce the number of large fires, which ignite under severe fire weather conditions. There is also potential for China, just as in the United States, to experience significant amounts of fire smoke entering populated areas. Such additions would exacerbate China's air quality problems, if only for relatively short periods. Industrial areas close to large expanses of forest in the northeastern part of the country would be perhaps especially vulnerable to episodic smoke and air pollution episodes. At the present time no studies have been completed to assess either the past impacts or future potential for impacts from wildland fire smoke in China.

13.2. Forests in China

According to an estimate by the United Nations Food and Agriculture Organization (United Nations Food and Agriculture Organization

(UN FAO), 2005) of the United Nations, China has a forest area of 280,170,000 ha (692,315,143 acres). The percentage of Chinese forest cover is about 12% of the nation's area. Altogether, the land assigned to forestry in China includes 115,280,000 ha of rich forest land (rich forests, with a crown shadow rate of above 30%, whereas sparse forests have a crown shadow rate of 10–30%), 17,200,000 ha of sparse forest land, 27,730,000 ha of shrubs, and 119,960,00 ha of desolate mountains and land fit for planting trees. The geographical distribution of China's forests is very uneven, with greatest concentrations in the northeast and southwest. Additionally, there are some subtropical zone and tropical zone forests. The northeast, southwest, and combined subtropical and tropical zones account for 29.9%, 19.6%, and 41%, respectively, of the national forest area. Meanwhile, very few forests exist on the North China plain and the Northwest (altogether 9.6%). In the very arid northwest only 2% of China's forests can be found. The most notably forest-rich area close to mainland China is Taiwan (37%), followed by seven Chinese provinces having coverage above 30%, six provinces above 20%, and thirteen provinces and regions lower than 10%. The provinces with the lowest percentage of forest cover are the Xinjiang province with only 0.7% and in Qinghai province with only 0.3%.

13.3. Climate change and China's natural resources

China faces great threats from a warming and drying climate. It is a paradox for the country that to achieve a higher quality of life for Chinese, the country has been involved in industrial development that is similar to Western nations, which in itself may exacerbate environmental challenges and adversely impact the Chinese population. The Intergovernmental Panel on Climate Change in its recent report has voiced concern over climate change impacts for Asia. They cite potential adverse changes to biodiversity, water resources, deltas and coastal zones, and a potential for increases in forest fires (IPCC, 2001). Regional climate models developed by the UK's Hadley Centre for Climate Prediction and Research have predicted that as global warming events occur, Chinese winters will become warmer and there is a greater likelihood of high summer temperatures and a rise in the number of days of heavy rainfall. Average yearly temperatures could increase as much as 3–4°C. Such changes in climate would almost certainly increase forest fire events in China, especially if evapotranspiration rates increase in forested areas during the wildfire season.

13.4. Fire management in China

The occurrence of forest fires varies from year to year depending on interannual climate variability. Furthermore, the variations of fire occurrence, fire size, and fire severity are closely related to the accumulation of combustible material in the forest. The major portion of forest fire occurrence is concentrated in a small number of Chinese regions called "High Fire Occurrence Regions." The highest number and largest sizes of forest fires occur in five provinces: Heilongjiang, Inner Mongolia, Yunnan, Guangxi, and Guizhou. In these provinces, the number of forest fires accounted for 42.5% of the whole country, and the damaged area accounted for 75% of the area affected by fires in the whole country during the period 1950–1998. Within these provinces and in other forest zones the forest fire distribution is not even. The highest concentration is in more than 100 key counties of 16 key regions. This phenomenon results from the fact that these regions, which have a higher share of forest cover, are exposed to more climatic extremes, including extreme wind events, and are remote with limited access and fire management (prevention and control) facilities. In combination with the complexity of fire origins, the high combustibility of forests, and the difficulty in controlling wildfires, the probability of large forest fire occurrence in these regions is very high.

The number of forest fires is large in forests of the south of China while the damaged forest area is largest in the northeast and Inner Mongolia. Because of the gentle regional topography—featuring a broad geographic trench and with accompanying embankments that link (ecotones) between grassland and forest—and the influence of the monsoon in spring and autumn, forest fires in the northeast and Inner Mongolia spread quickly and over large areas. Due to the different characteristics of these varied forest regions, fire prevention methods and control measures are also different in the South and in the North.

Clearly defined responsibilities of governments at different levels and of the different units in the forest regions are an important aspect of forest fire prevention. Through this system, the fundamental and crucial problems in forest fire prevention have been addressed in recent years, resulting in strengthening of forest fire prevention and a visible reduction of forest fire occurrence and damages. In the period 1960–1987, about 16,000 forest fires damaged an area of 950,000 ha in the entire country, representing a forest damage rate of 8.5%. Compared with these figures, the number of forest fires, the damaged forest area, and the forest damage rate from 1988 to 1998 was reduced by 49%, 98%, and 95.4%, respectively (Figs. 13.1 and 13.2; IFFN, 2002). These reported reductions were after the occurrence of the large fires of 1987 (discussed in

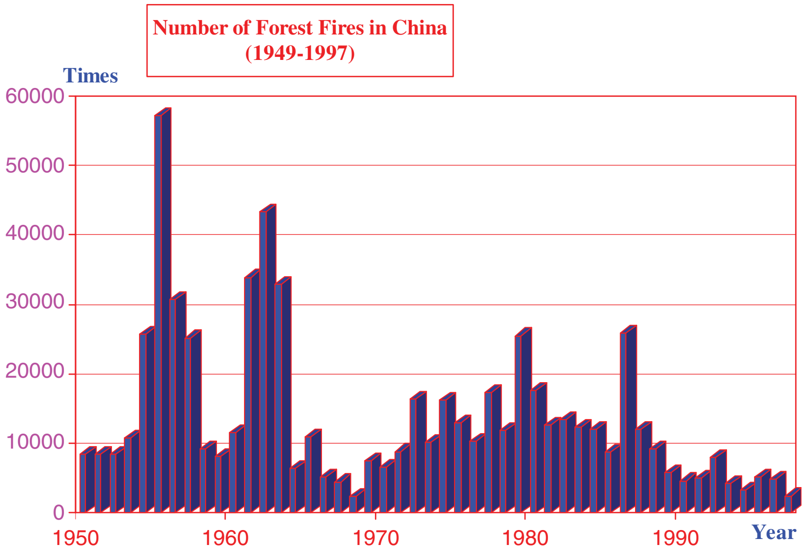

Figure 13.1. Number of forest fires in China have been decreasing over time. (*Source*: IFFN 2002.)

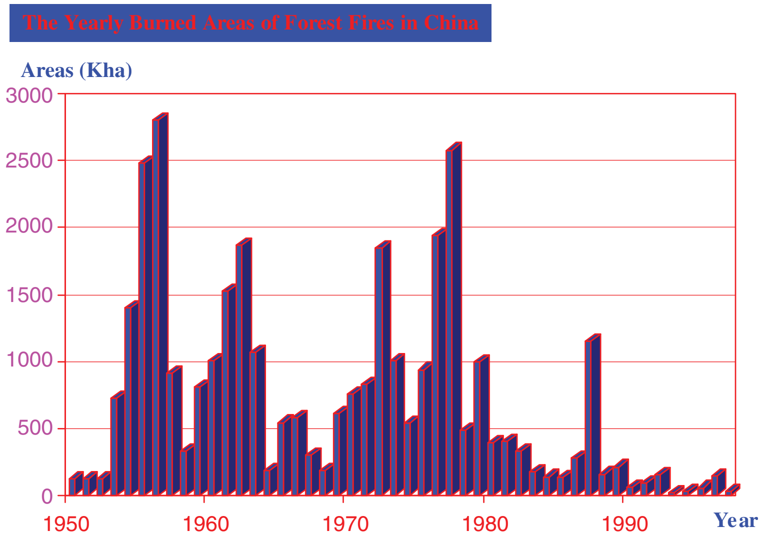

Figure 13.2. The yearly surface burned by wildland fires in China has been decreasing (*Source*: IFFN 2002.)

Section 13.6), and perhaps make fire suppression appear unrealistically successful in China. However, important steps were taken to revise and improve regulations on the use of fire in the agricultural and forestry sectors. Several important laws, decrees, regulations, and stipulations became effective after being passed by the local people's congress and promulgated by the governments. Many villages have developed community regulations and agreements and have strengthened forest fire management at the local level very successfully. Such measures may continue to be effective against smaller, low-intensity fires, but may be much less effective as protective measures during periods of prolonged drought and extreme fire weather conditions.

13.5. Remote sensing and wildland fire in China

Satellite remote sensing (RS) is a new technique for wildfire monitoring and fire danger assessment. Satellite instruments like the Advanced Very High-Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) can be used to create global high-resolution products like the Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST) (Qu et al., 2002), which have been shown to be closely related to fuel moisture status. Thus, RS can overcome some problems facing the traditional fuels-based fire danger estimation techniques, including low spatial resolution and unavailability of meteorological data over parts of forest regions.

RS mapping and characterization of vegetation and fire fuels parameters and datasets were clearly defined as technology goals in strategic documents such as the U.S. National Fire Plan. They have also been required by international fire management and science communities. Applications of satellite RS have been made during many large wildland fires, including monitoring fire lines and total fire smoke. The Wildland Fire Assessment System (WFAS) developed by the USDA Forest Service, became operational in the mid-1990s, and has been providing useful information such as a "greenness" map using AVHRR-NDVI (Burgan et al., 1997).

Satellite RS also has great potential to provide information for calculating seasonal fire danger. The fuel moisture detected by satellite RS is mostly the moisture of live fuel, which predominately represents long-lag moisture (e.g., 1000 h fuel moisture), a determining factor of seasonal fire danger. Thus, it is possible to develop a capacity to assess the seasonal fire danger using RS of fuel moisture and other products. These products are limited by spatial resolution of 1 km or more and thus are generally only representative at meso or synoptic scales (Qu et al., 2003).

The estimation of forest fire danger from satellite RS data is an important research area, with potential for great practical application. Fuel moisture is an important index of fire potential. Over the past decade, research on fire danger estimation from RS data has concentrated on determining fuel moisture. The accurate estimation of fuel moisture using RS data is very difficult, as most of the approaches use proxy variables as indices of fuel moisture. Currently available techniques can be placed into two categories: methods based on the relationship of Land Surface Temperature (LSTs) and the NDVI, and methods based on regression analysis of vegetation indices directly.

As a key research instrument of the NASA Earth Observing System (EOS) missions, the MODIS instrument was launched onboard the NASA Terra and Aqua satellites. It has proven itself as a useful tool for wildland fire and smoke mapping worldwide (Fig. 13.3). Because the MODIS instrument senses the earth's entire surface in 36 spectral bands, it spans from the visible (0.415 μm) to infrared (14.235 μm) spectrum with spatial resolutions of 1 km, and 500 and 250 m at nadir, respectively. One strength of MODIS, especially important to fuel property estimation, is that strong absorbance of water in the middle infrared region (1.3–2.13 μm) makes this band 7 (2.13 μm) most suitable for the estimation of forest fuel moisture content. This band 7 is not included in most satellite systems, suggesting that MODIS should be useful for improving the capacity of applying satellite RS data to more accurately

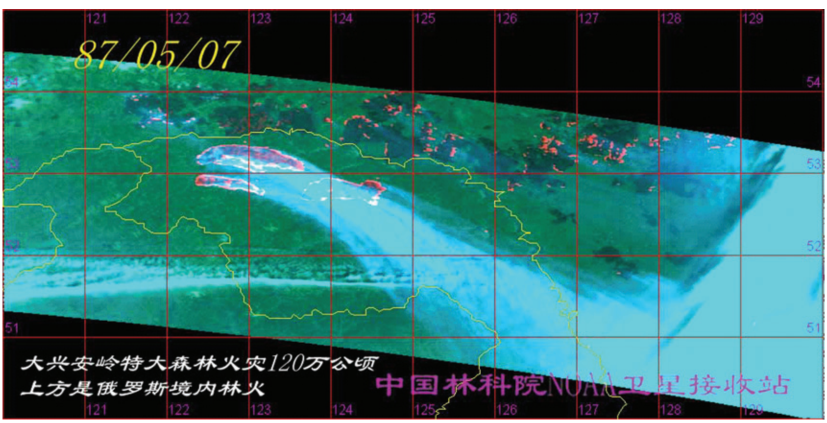

Figure 13.3. NOAA advanced very high-resolution radiometer (AVHRR) image of the black dragon fire taken on May 7, 1987.

estimate fuel moisture content and fire danger indices (Qu et al., 2003; Xinwen et al., 1998). Figure 13.4 shows the Aqua MODIS true color (RGB) image of forest fires around the China-Russia border at 04:20 UTC time. The smoke plumes and clouds can be seen clearly. The false color image shows the burnt areas clearly (Fig. 13.5).

In China, RS of wildland fire has been successfully implemented on a routine basis. This is especially true for fire detection using MODIS. Satellite data has been regarded as a primary information source by many

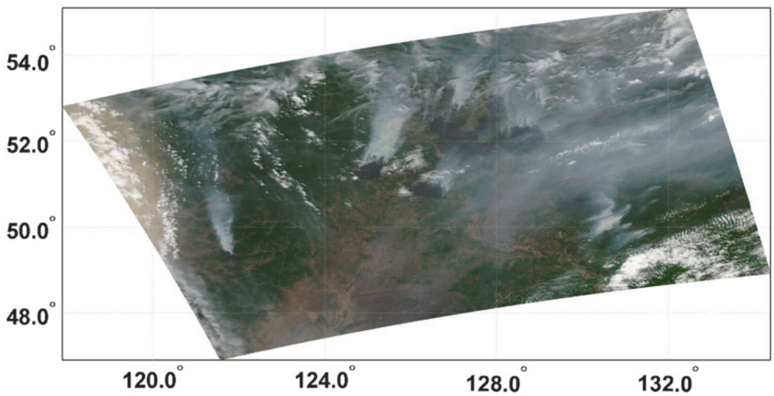

Figure 13.4. Aqua MODIS true color (RGB) image of forest fires around the China–Russia border (05/30/2006 04:20 UTC time). The smoke plumes and clouds can be seen clearly.

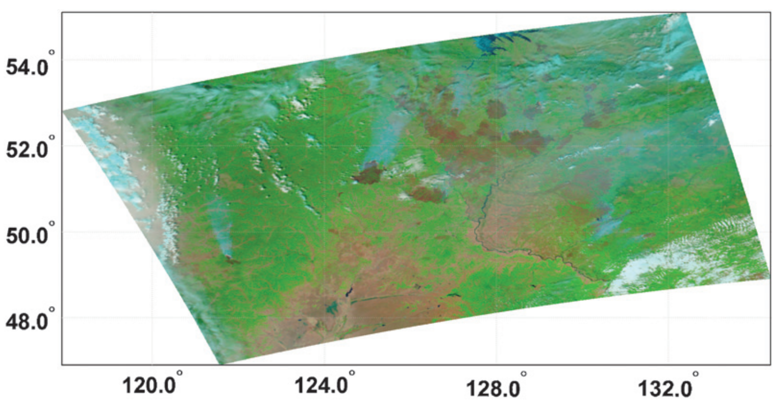

Figure 13.5. Aqua MODIS false color (Band 7, 2, and 1) image of forest fires around the China–Russia border (05/30/2006 04:20 UTC time). The burnt areas can be monitored.

key projects in forestry for the past 20 years; examples of such uses include comprehensive forest RS inventory, monitoring and assessment of forest fire, mapping evaluation of the Yunnan provincial tropical forest in southwestern China, assessing forest ecological impacts, preventing desertification, monitoring insects, and developing innovations over the current national forest resources survey system.

13.6. The black dragon fire

China is often not considered as a country in which large forest fires occur, which has been correct in most years in the recent past. However, this assumption does not hold true for years with extreme climate conditions. In terms of sheer destruction and ecological damage, the fires that swept the Hinggan forests of Manchuria and Siberia in May 1987 (Fig. 13.1) rank as one of the worst environmental disasters of the 20th or any other century (Salisbury, 1989). The fires were more than 10 times the size of the 1986 fires in Yellowstone National Park. Yet, little is known about them outside China and official circles in the Soviet Union. Even among experts, there is only sketchy information on possibly the world's largest forest fire in the past 300 years, a conflagration that blackened an area almost the size of New England (3,000,000 acres of land and killed 220 people).

The Greater Hinggan Forest was the world's largest stand of evergreens, stretching like a green velvet sea approximately 500 miles long and 300 miles wide. It is bisected by the Heilongjiang, or Black Dragon River (known in the West by its Russian name, the Amur), which forms the border between Chinese Manchuria and Soviet Siberia. Before the fires, the Manchurian part of the forest accounted for one-third of China's timber reserves. In 1987, there had been a prolonged period of dry weather, and the danger of fire was high on both sides of the river in the spring. At that time, Chinese fire prevention and detection methods and firefighting resources were primitive by American and Canadian standards. Despite the hazardous conditions, people smoked in the forest, built campfires, and used unsafe logging practices. From natural and accidental causes, a number of fires broke out about the same time in Manchuria and Siberia, quickly consolidating into several large ones.

The Black Dragon Fire had much significance for China's future under a changing climate. The specific weather conditions that allowed the fire to become such a large and intense complex event fit well with climate change scenarios depicted by the United Kingdom's Hadley Climate Center. Recently, even in areas of southern China where firefighting resources are considered good, climate variability has overwhelmed firefighters when fires start. For example, mobilized firefighters were unable to put out a forest fire that was spreading rapidly through the parched timberlands of the Chongqing Municipality on August 31, 2006. More than 4000 people were mobilized to fight the fire that began at 1 pm on a Wednesday in Yakou Village, 40 km northeast of downtown Chongqing. It soon spread to neighboring areas, ravaging 66 ha of forest. The cause of the fire was unclear, but the prolonged drought contributed to its spread. Officials cited a change in weather (rainfall) as the reason the fire was contained at 66 ha. Even with more than 4000 people to fight this fire, they were unable to extinguish it until fire weather conditions allowed. Thus, the Black Dragon Fire is perhaps an example that climate considerations need to be fully integrated into fire management not only in China but also worldwide.

13.7. Conclusions

China values its forest resources and wishes to increase forest cover. Although air pollution is a significant issue for China, at the present time Chinese fire suppression policies and available resources meet most normal fire challenges. By using satellite instruments, effective systems can detect large fires and assist in fire danger predictions. Climate change predictions for China suggest that wildland fires will increase in frequency, size, and intensity. Should this occur, the wildland fire smoke, especially in the north of China, may become a significant issue.

Thus, due to this predicted climate change in China, fire suppression as a management tool may itself need reassessment. In the United States, past policies of fire suppression have been postulated to have caused massive fuels build-up in forests, particularly in the western states. Recent evidence has shown, however, that due to a period of relative calm from drought, such suppression strategies were more successful than they perhaps might have been without the coincidence of this calm period (Westerling et al., 2006). Currently, China has entered into a fire suppression policy that parallels the policies employed in the 1950s and 1960s in the U.S. Climate variability and change, interacting with exclusion of fire from ecosystems, may prove to be as interesting a challenge for fire and air quality management in China as they are for the United States.

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