HEALTH GUIDELINES
FOR
VEGETATION FIRE EVENTS
Background papers

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CONTENTS

PREFACE

Forest fires, either man-made or natural, as a consequence of extreme drought, occur in many parts of the world. Smoke from forest fires consists mainly of fine particulate matter in the respirable range and to a lesser extent, of carbon monoxide and polycyclic aromatic hydrocarbons. During the episode of smoke in the South East Asian countries, monitoring of particulate matter of mean aerodynamic diameter at or below 10 gm has shown that short-term air quality standards of WHO's 1987 air quality guidelines for respirable particulate matter are largely exceeded.

The recurrence of transboundary smoke originating from uncontrolled forest fires in many countries around the world causing acute and longterm respiratory health problems requires a comprehensive strategy based on broad international consensus. Any comprehensive strategy must include:

a) rapid detection capability of uncontrolled vegetation fire events on a global scale;

b) the gathering of useful and reliable monitoring data and health surveillance;

c. the dissemination of information to all affected parties for appropriate decision making; and
d. the development of national environmental and health response plans to vegetation fire events, based on an international guideline.

The WHO, in a collaboration of the Department of Emergency and Humanitarian Action (EHA) and the Department of Protection of Human Environment (PHE), with the support of the Ministry of Health, Japan, UNEP and WMO convened an Expert Meeting on the Health Guidelines for Vegetation Fire Events in Lima, Peru, 6-9 October 1998. Background papers on the various issues mentioned above were contributed to the meeting. At the meeting, the Health Guidelines for Vegetation Fire Events were formulated and a final draft was delivered by the consultant after review from several experts by 31 January, 1999.

This document, Health Guidelines for Vegetation Fire Events - Background Papers, forms a set of three publications which provide global advice and guidance on the management of vegetation fire events. The others are Health Guidelines for Vegetation Fire Events - Guidelines Document and Teacher's Guide. The background papers serve as valuable materials to understand the scientific basis of the Health Guidelines.

A field application of the Health Guidelines was performed in a training course on the guidelines, held in Kuala Lumpur for the ASEAN countries n December 1998. Another course was subsequently held in Brasilia, Brazil, in May 1999.

I has turned out that the WHO document on Health Guidelines for egetation Fire Events constitutes an important publication needed by many eveloping countries in which recurrent vegetation fires occur. These countries are distributed around the world and eminently in South East Asia, South and Central America, Africa, North East Asia, and Eastern Europe. From the experience with the first two training courses on the Health Guidelines held in Malaysia and Brazil, it became clear that there is a definite need for more training courses.

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Fire Events including the Guideline document, the background papers document and the Teachers' Guide. Moreover, this funding could be used to convene two training courses on the Health Guidelines, the first one in Kuala Lumpur, Malaysia in December 1998, and the second one in Brasilia, Brazil, in May 1999.

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Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

EARLY WARNING SYSTEMS FOR THE PREDICTION OF AN APPROPRIATE RESPONSE TO WILDFIRES AND RELATED ENVIRONMENTAL HAZARDS

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SUMMARY

Wildfires annually affect several hundred million hectares of forest and other vegetation of the world. In some ecosystems, fire plays an ecologically significant role in maintaining biogeochemical cycles and disturbance dynamics. In other ecosystems, fire may lead to the destruction of forests or to long-term site degradation. In most areas of the world, wildfires burning under extreme weather conditions will have detrimental impacts on economies, human health and safety, with consequences that are of significance and severity comparable to other major natural hazards.

Fires in forests and other vegetation produce gaseous and particle emissions that have impacts on the composition and functioning of the global atmosphere. These emissions interact with those from fossil-fuel burning and other technological sources. Smoke emissions from wildland fires also cause visibility problems which may result in accidents and economic losses. Smoke generated by wildland fires also affect human health and, in some cases, leads to loss of human lives. Fire risk modelling in expected climate change scenarios indicate that within a relatively short period, the next three to four decades, the destructiveness of wildfires will increase. Fire

management strategies which include preparedness and early warning cannot be generalized due to the multi-directional and multi-dimensional effects of fire in the different vegetation zones and ecosystems and the manifold cultural, social, and economic factors involved. However, unlike the majority of the geological and hydro-meteorological hazards included in the International Decade of Natural Disaster Reduction (IDNDR) Early Warning Programme, wildland fires represent a natural hazard which can be predicted, controlled and, in many cases, prevented.

Early warning systems are essential components of fire and smoke management. They rely on evaluation of vegetation dryness and weather; detection and monitoring of active fires; integrating and processing of these data in fire information systems with other relevant information, e.g. vegetation cover and values at risk; modelling capabilities of fire occurrence and behaviour; and dissemination of information.

Early warning of fire and atmospheric pollution hazard may involve locally generated indicators, such as local fire-weather forecasts and assessment of vegetation dryness. Advanced technologies, however, which rely on remotely sensed data, evaluation of synoptic weather information and international communication systems (e.g., Internet) are now also available for remote locations.

The paper presents the findings of the IDNDR Early Warning Group on Wildfire and Related Hazards and reviews the current state of knowledge and practice on the subject. It provides a state-of-the-art analysis of existing and projected early warning and fire information systems that can be equally made accessible on a global scale.

Recommendations are also made for improvements and areas that require additional international attention: the design and implementation of a global fire inventory; establishment of a Global Vegetation Fire Information System (GVFIS); establishment of a system in which real-time information on early warning of wildfire precursors and on ongoing wildfire situations across the globe are gathered and shared, e.g. through the Global Fire Monitoring Center (GFMC); development of spaceborne sensors and platforms with improved early warning capabilities; establishment of an information network which includes the resource status by continuously monitoring the disposition of suppression resources; establishment of a global fire management facility under the auspices of the UN system; promotion of policies and agreements on early warning of wildfires at

international levels; and coordination of research efforts with ongoing and future fire science programmes.

INTRODUCTION

General fire hazard

General remarks

Fire is an important recurrent phenomenon in all forested and non-forested regions of the globe. In some ecosystems, fire plays an ecologically significant role in biogeochemical cycles and disturbance dynamics. In other ecosystems, fire may lead to the destruction of forests or to long-term site degradation. As a consequence of demographic and land use changes and the cumulative effects of anthropogenic disturbances, many forest types adapted to fire are becoming more vulnerable to high-intensity wildfires: often, ironically, due to the absence of periodic low-intensity fire. In other forest types, however, as well as many non-forest ecosystems, e.g. in savannas and grasslands, fire plays an important role in maintaining their dynamic equilibrium productivity and carrying capacity (1-3).

In most areas of the world, wildfires burning under extreme weather conditions will have detrimental impacts on economies, human health and safety, with consequences which are comparable to the severity of other natural hazards. In all ecosystems, fire needs to be managed to balance the benefits derived from burning with the potential losses from uncontrolled fires.

Fires in forests and other vegetation produce gaseous and particle emissions that have impacts on the composition and functioning of the global atmosphere (3-6). These emissions interact with those from fossil-fuel burning and other technological sources. Smoke emissions from wildland fires also cause visibility problems which may result in accidents and economic losses. Smoke generated by wildland fires affects human health and can lead to increased morbidity and mortality.

Fire risk modelling in expected climate change scenarios indicate that within a relatively short period, over the next three to four decades, the destructiveness of human-caused and natural wildfires will increase. Fire management strategies which include preparedness and early warning cannot

be generalized due to the multi-directional and multi-dimensional effects of fire in the different vegetation zones and ecosystems and the manifold cultural, social, and economic factors involved.

However, unlike the majority of the geological and hydro-meteorological hazards included in the IDNDR Early Warning Programme, wildland fires represent a natural hazard, which can be predicted, controlled and, in many cases, prevented.

Recent major fire events and fire losses

Comprehensive reports with final data on losses caused by forest and other vegetation fires (wildland fires) are only occasionally available. The main reason for the lack of reliable data is that the majority of both the benefits and losses from wildland fires involve intangible non-use values or non-market outputs which do not have a common base for comparison, i.e. biodiversity, ecosystem functioning, erosion, etc. (7).

Market values such as loss of timber or tourism activity have been calculated in some cases. The large wildfires in Borneo during the drought of 1982-83, which was caused by the El Niño-Southern Oscillation (ENSO), affected a total of more that 5 million hectares of forest and agricultural lands (8). It resulted in the loss of timber values of about US$ 8.3 billion, and a total of timber and non-timber values and rehabilitation costs of about US$ 9 billion (9).

The damages caused by the fire episode of 1997-98 in Indonesia; Brazil and Central America are not yet fully assessed at the time of writing this report. According to the interim results of a study conducted by the World Wide Fund for Nature (WWF) in the framework of the Economy and Environment Program for South East Asia (EEPSEA), the economic damages caused by fire in Indonesia during 1997 are in the region of US$ 2.8 billion, and additional costs arising due to fire and haze in Indonesia and in the neighbouring countries are in the region of US$ 1.6 billion. Total damage assessed at about US$ 4.5 billion includes short-term health damages, losses of industrial production, tourism, air, ground and maritime transportation, fishing decline, cloud seeding and fire-fighting costs, losses of agricultural products, timber, and direct and indirect forest benefits and capturable biodiversity (10).

The Centre for Remote Imaging, Sensing and Processing (CRISP), National University of Singapore, currently investigates the total area affected by land-use fires and wildfires on the islands of Sumatra and Borneo during the 1997-98 fire season based on the high-resolution SPOT (Système pour la Observation de la Terre) satellite data (11). Preliminary data (which were based on the EEPSEA/WWF study) suggest that a total area affected by fire exceeds 4-5 million hectares.

The economic and environmental damages caused by fires in Latin America (Brazil and Central America) during early 1998 are not yet assessed. Figures released by Mexican authorities in May 1998 indicate that the reduction of industrial production in Mexico City, which was imposed in order to mitigate the additional smog caused by forest fires, involved daily losses of US$ 8 million (12).

Australia's Ash Wednesday Fires of 1983, which were also linked to the ENSO drought of 1982-83, resulted in a human death toll of 75, a loss of 2539 houses and nearly 300,000 sheep and cattle. In South Australia alone, the estimated direct losses of agricultural output (sheep, wool, lambs, cattle, pasture, horticulture) were estimated to be A$ 5.7 million (on the basis of 1976-77 prices), and the estimated net costs of the 1983 bushfires to the government sector were A$ 33 million (13).

Wildfire damage to agricultural lands, particularly in the tropics, may have tremendous impact on local and regional famine. In 1982-83, the West African country, Côte d'Ivoire, was swept by wildfires over a total area of about 12 million hectares (14). The burning of about 40,000 hectares of coffee plantations, 60,000 hectares of cocoa plantations, and some 10,000 hectares of other cultivated plantations had detrimental impacts on the local economy. More than 100 people died during this devastating fire period.

The "Great Black Dragon Fire" of 1987 in the People's Republic of China burned a total of 1.3 million hectares of boreal mountain forest and the houses of 50,000 inhabitants, and resulted in a human death toll of 221, mostly caused by high carbon monoxide concentrations in the forest villages. The long-term statistics in China reveal that between 1950 and 1990, a total of 4,137 people were killed in forest fires (15). In the same period, satellite-derived information reveals that about 14.5 million hectares of forest were affected by fire in the neighbouring Soviet Union, predominantly in the Siberian boreal forests, which have a composition similar to Northeast China (16).

The last major fire episode in central Eurasia occurred in Mongolia between February and June 1996. A total of 386 forest and steppe fires burned over an area of 2.3 million hectares of forest and 7.8 million hectares of pasture land, resulting in the loss of 25 human lives, more than 7000 livestock, 210 houses, 560 communication facilities, and 576 facilities for livestock; the cost of the damage based on the preliminary assessment was about US$ 2 billion (17). Recent evaluation of fire data from Mongolia reveals that 2.47 million hectares of forest were burned in 1993 (18).

The 1988 fires in the Yellowstone area of the United States cost around US$ 160 million to suppress and an additional estimated loss of US$ 60 million in tourist revenues between 1988 and 1990 (19). In the longer term, however, the increased biodiversity created by the fires in Yellowstone National Park may well yield benefits that outweigh these losses.

Reliable statistical data on occurrence of wildland fires, areas burned and losses incurred are available for only a limited number of nations and regions. Within the northern hemisphere, the most complete dataset on forest fires is periodically collected and published for the member states of the Economic Commission for Europe (ECE). It includes all Western and Eastern European countries, countries of the former Soviet Union, the USA and Canada. The last data set covers the period 1995-97 (20). In the European Union, a Community Information System on Forest Fires has been created on the basis of information collected on every fire in national databases. The collection of data on forest fires (the common core) has become systematic with the adoption of a Commission Regulation in 1994. The Community Information System on Forest Fires currently covers 319 provinces (departments, states) of Portugal, Spain, France, Italy, Germany and Greece (21, 22). It contains information on 460,000 fires recorded between 1 January 1985 and 31 December 1995 involving a total of six million hectares. Other countries from outside the ECE/EU region report fire statistics in the pages of International Forest Fire News or are included in the FAO report on global wildland fires (23).

In many countries (e.g. Australia) where fire is used as a management tool by the indigenous population, graziers and managers of forests and natural areas, it is impossible to discriminate between management fires and wildfires. Statistics for wildfires are usually available only for production forest and national park lands.

A global dataset has been developed on the basis of active fires detected by the National Oceanic and Atmospheric Agency (NOAA)'s Advanced Very High Resolution Radiometer (AVHRR) sensor. The "Global Fire Product" is an activity of the International Geosphere-Biosphere Programmme Data and Information System (IGBP-DIS; for details see section on "Global fire monitoring, p. 43).

Impacts of fire on the environment

From the perspective of the IDNDR, wildland fires may affect two basic environmental problem areas: (i) atmospheric pollution (direct impact of smoke on human health and economies; influence of gaseous and particle emissions on the composition of the atmosphere); and (ii) biodiversity, ecosystem performance, and landscape stability. Both these areas can have deleterious consequences for the severity of other hazards.

Atmospheric pollution

Human fatalities and health

Smoke pollution generated by wildland fires occasionally creates situations during which human lives and local economies are affected. Fatalities in the general public caused by excessive carbon monoxide concentrations have been reported from various fire events, e.g. the large forest fires in China in 1987. Firefighters who are regularly subjected to smoke are generally at higher health risk.

The use of fire in forest conversion and other forms of land clearing, and wildfires spreading beyond these activities are very common in tropical countries. In the 1980s and 1990s, most serious pollution problems were noted in the Amazon Basin and in the South East Asian region. The most recent large smoke episodes in the South East Asian region were in 1991, 1994 and 1997 when land-use fires and uncontrolled wildfires in Indonesia and neighbouring countries created a regional smoke layer which lasted for several weeks. In 1994, the smoke plumes of fires burning in Sumatra (Indonesia) reduced the average daily minimum horizontal visibility over Singapore to less than 2 km; by the end of September 1994, the visibility in Singapore dropped to as low as 500 metres. In the same time, the visibility in Malaysia dropped to 1 km in some parts of the country. A study on asthma attacks among children revealed a high concentration of fire-generated carbon monoxide (CO), nitrogen dioxide (NO_2) and inhalable suspended

particulate matter (PM_{10}) was responsible for the health problems (24). The worst smoke pollution in the region occurred in September 1997, as reflected by a value of 839 of the Pollutant Standard Index (PSI; see section on "Atmospheric pollution warning", p. 35) in the city of Kuching (Sarawak state, Malaysia); the Malaysian government was on the verge of evacuating the 400,000 inhabitants of the city.

In the same regions, the smoke from fires caused disruption of local and international air traffic. In 1982-83, 1991, 1994 and 1997-98, the smoke episodes in South East Asia resulted in closing of airports and marine traffic, e.g. in the Straits of Malacca and along the coast and on rivers of Borneo. Several smoke-related marine and aircraft accidents occurred during late 1997. The loss of an airplane and 234 human lives in September 1997 in Sumatra was partially attributed to air traffic control problems during the smoke episode.

Wildfires burning in radioactive-contaminated vegetation has led to uncontrollable redistribution of radionuclides, e.g. the long-living radionuclides caesium (^{137}Cs), strontium (^{90}Sr) and plutonium (^{239}Pu).[1] In the most contaminated regions of the Ukraine, Belarus and the Russian Federation (the Kiev, Zhitomir, Rovmo, Gomel, Mogilev and Bryansk regions), the prevailing forests are young and middle-aged pine and pine-hardwood stands of the high-fire-danger classes. In 1992, severe wildfires burned in the Gomel region (Belorussia) and spread into the 30-km radius zone of the Chernobyl power plant. Research reveals that in 1990, most of the ^{137}Cs radionuclides were concentrated in the forest litter and upper mineral layer of the soil. In the fires of 1992, the radionuclides were lifted into the atmosphere. Within the 30-km zone, the level of radioactive caesium in aerosols increased 10 times; for more details on resuspension of radioactive matter from forest fires, see reports by Dusha-Gudym (25).

Fire emissions, atmosphere and climate

In recent years, increasing attention has been given to the role of vegetation fires in biogeochemical cycles and in the chemistry of the

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[1] Radionuclides of plutonium are found mainly within the 30-km zone around the Chernobyl power plant. Radionuclides of strontium have contaminated a number of districts in the Kiev region (Belarus) and in the Bryansk region (Russian Federation). Radionuclides of caesium are the largest contributors in the contaminated areas in these states. In the Russian Federation, the soil surface, in which caesium radionuclide contamination exceeds 37 GBq/km^2 [(1 GBq (gigabequerel) = 10^9 Bq], totals 4.9 million hectares within 15 regions. The areas in which the radiocaesium contamination density is between 0.55 and 1.5 TBq/km^2 [1 TBq(terabequerel) = 10^{12} Bq) and higher, are mainly in the Bryansk region (about 250,000 hectares).

atmosphere (4). According to recent estimates, some 1.8-4.7 billion tons of carbon stored in vegetation may be released annually by wildland fires and other biomass burning (26). It must be noted that not all of the biomass burned represents a net source of carbon in the atmosphere. The net flux of carbon into the atmosphere is due to deforestation (forest conversion with and without involving the use of fire) and has been estimated by Houghton (27) to be in the range of 1.1-3.6 billion tons per year. Important contributions to the total worldwide biomass burning, which are included in the numbers mentioned above, are fires in savannas, shifting agriculture, agricultural waste burning and firewood consumption (28).

Although the emissions from tropical vegetation fires are dominated by carbon dioxide (CO_2), many products of incomplete combustion that play important roles in atmospheric chemistry and climate are emitted as well, e.g., a number of gases that influence the concentrations of ozone and hydroxyl radicals and thus the oxidation efficiency of the atmosphere, in particular, NO, CO, CH_4 and reactive hydrocarbons. The influence of these emissions affects especially the southern hemisphere during the dry (winter) season, i.e. during August - November, and manifests itself in strongly enhanced tropospheric ozone concentrations, extending from the regions regularly affected by biomass burning in Brazil and southern Africa across the Atlantic and the Indian Ocean all the way down to Tasmania (3,29,30). Other gases whose atmospheric concentrations are strongly dominated by biomass burning are CH_3Cl and CH_3Br, which together with CH_4 play a significant role in stratospheric ozone chemistry (31).

Biodiversity, ecosystem performance, and landscape stability

The impacts of wildfires on the performance and stability of ecosystems has been described widely in numerous publications, covering the full range of geographical, ecological, socio-cultural and economic conditions of the globe. The magnitude of the phenomena resulting from wildfires prohibits any detailed review in the context of this paper.

On the one hand, fire is an integrated element which contributes to the stability, sustainability, high productivity and carrying capacity of many ecosystems. On the other hand, wildfire, in conjunction or interaction with land use systems and exploitation of natural resources, leads to the loss of forest and agricultural products and can have negative impacts on biodiversity, ecosystem function and land stability. For example, in the dry forests of Australia, low-intensity fire is regularly applied to maintain understorey plant

species and habitat for native fauna, as well as to reduce surface fuels to mitigate against the impacts of high-intensity wildfires. During the dangerous summer period, all fires are suppressed as quickly as possible both to reduce damage to forest values and to reduce the chance of wildfire burning out of the forest and causing severe losses to houses and structures in the built environment.

Many plant and animal species, e.g. in the tropical lowland rain forest ecosystems and elsewhere, are susceptible to fire influence and are easily destroyed by fire and replaced by less species-rich communities. Human-induced fire regimes in tropical rain forests result in degraded vegetation types (grasslands, brushlands) which are less stable and productive, both from an ecological and economic point of view. Fires may also lead to the depletion of soil cover, resulting in increased runoff and erosion, with severe downstream consequences, e.g. mudflows, landslides, flooding or siltation of reservoirs.

Fires often interact with other disturbances, e.g. extreme storm events (hurricanes) or insect outbreaks. The extended rain forest fires of 1989 in Yucatan (Mexico) represent a typical example because they were the result of a chain of disturbance events. Hurricane "Gilbert" in 1987 opened the closed forests and increased the availability of unusual amounts of fuels. The downed woody fuels were then desiccated by the subsequent drought of 1988-89, and the whole of the forest area was finally ignited by escaping land clearing fires. None of these single three factors, the cyclonic storm, the drought, or the ignition sources, if occurring alone, would have caused a disturbance of such severity and magnitude on an area of 90,000 hectares (32).

In the Krasnoyarsk region, Russian Federation, an on-going mass outbreak of the Siberian gipsy moth (*Dendrolimus superans sibiricus*) since 1989 has meanwhile affected a total of 1 million hectares of boreal forest (33). It is expected that large wildfires will occur in the partially or completely killed stands within the next few years.

Early warning systems in fire and smoke management

Early warning (fire intelligence) systems are essential components of fire and smoke management [2]. They rely on

[2] For clarification of terminology used in this report, the terms “fire management”, “prescribed burning” and “smoke management” are briefly explained (34):

- evaluation of vegetation dryness and weather;

- detection and monitoring of active fires;

- integrating and processing of these data in fire information systems with other relevant information, e.g. vegetation cover and values at risk;

- modelling capabilities of fire occurrence and behaviour; and

- dissemination of information.

Early warning of fire and atmospheric pollution hazard may involve locally generated indicators, such as local fire-weather forecasts and assessment of vegetation dryness. Advanced technologies, however, which rely on remotely sensed data, evaluation of synoptic weather information and international communication systems (e.g., Internet) are now also available for remote locations.

In this report the large variety of standards, methods and technologies of fire and smoke management which are used in national programmes cannot be described in detail. Generally speaking, however, it is obvious that, due to the lack of resources, fire management systems are disproportionately less available in developing countries.

In some industrialized countries, e.g. in Central and Northern Europe, wildfires have been largely eliminated due to high-intensity land use, improved accessibility of potentially threatened land and the availability of infrastructures and advanced fire management technologies. Regions with less developed infrastructures are found in densely populated lands (e.g., in the tropics and subtropics) and in sparsely inhabited regions (e.g., in the

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Fire management embraces all activities required for the protection of burnable forest values from fire and the use of fire to meet land management goals and objectives. This includes fire prevention, early warning of fire risk, detection and suppression of fires, and the application of prescribed burning.

Prescribed burning is the controlled application of fire to wildland fuels in either their natural or modified state, under specified environmental conditions which allow the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to attain planned resource management objectives.

Smoke management is the application of knowledge of fire behaviour and meteorological processes to minimize air quality degradation during prescribed fires.

northern boreal forests). They are equally subjected to high wildfire risk because of the abundance of human fire sources or the lack of human resources to control fires, respectively.

This paper provides a state-of-the-art analysis of existing and projected early warning and fire information systems which can be equally made accessible on a global scale.

Relations to other activities of the IDNDR early warning programme

Some of the issues described in this report are closely related to other activities of the IDNDR early warning programme, e.g. the reports on hydrometeorological hazards, technological opportunities, and local perspectives. The cross-cutting issues show that there are areas of potential common activities and programmes.

The conclusions of a recent global wildland fire forum, the "Second International Wildland Fire Conference" (Vancouver, Canada, May 1997), clearly underscored the fact that unlike other natural disasters, fire is one of the few natural disturbances that can be forecast and mitigated (35). This fact may explain why forecasting fire events and the potential of mitigating fire impacts are comparably better developed as compared to other natural disasters. The description of the early warning systems for wildfires, which are available, in the development stage or proposed, may therefore serve as examples for other local, regional and international mechanisms of cooperation in early warning and management of disasters.

HAZARD ASSESSMENT AS THE BASIS OF RISK ANALYSIS

Early warning systems for fire and smoke management for local, regional, and global application require early warning information at various levels. Information on current weather and vegetation dryness conditions provides the starting point of any predictive assessment. From this information, the probability of risk of wildfire starts and prediction of the possibility of current fire behaviour and fire impacts can be derived. Short- to long-range fire weather forecasts allow the assessment of fire risk and severity within the forecasting period. Advanced space-borne remote sensing technologies allow fire weather forecasts and vegetation dryness assessment covering large areas (local to global) at economic levels and with accuracy, which otherwise cannot be met by ground-based collection and dissemination of information. Remote sensing also provides capabilities for detecting new wildfires, monitoring ongoing active wildfires, and, in conjunction with fire-weather forecasts, an early warning tool for estimating extreme wildfire events.

Fire danger rating (fire risk assessment)

Introduction

Fire danger rating systems have been devised by fire authorities to provide early warning of conditions conducive to the onset and development of extreme wildfire events. The factors that predispose a particular location to extreme wildfire threat change over time scales that are measured in decades, years, months, days and hours. The concept of fire danger involves both tangible and intangible factors, physical processes and hazard events. By definition: "Fire danger" is a general term used to express an assessment of both constant and variable fire danger factors affecting the inception, spread, intensity and difficulty of control of fires and the impact they cause (36).

The constant factors in this definition are those which do not change rapidly with time but vary with location, e.g. slope, fuel, resource values, etc. The variable factors are those which change rapidly with time and can influence extensive areas at one time, and these are primarily the weather variables which affect fire behaviour. All the potentials referred to in the definition must be present. If there is absolutely no chance of ignition, there is no fire danger. If fuels are absent or cannot burn, there is no fire danger. If fires can start and spread, but there are no values at risk, as may be perceived for remote areas managed for ecological diversity, there is no fire danger for values at risk.

Fire danger rating systems produce qualitative and/or numerical indices of fire potential that can be used as guides in a variety of fire management activities, including early warning of fire threat. Different systems of widely varying complexity, which have been developed throughout the world reflect both the severity of the fire climate and the needs of fire management. The simplest systems use only temperature and relative humidity to provide an index of the potential for starting a fire [e.g. the Angstrom index (36)]. Fire danger rating systems of intermediate complexity combine measures of drought and weather as applied to a standard fuel type to predict the speed of a fire or its difficulty of suppression (37-39). The most complex systems have been developed in Canada (40) and the United States (41) which combine measures of fuel, topography, weather and risk of ignition (both caused by lightning and human activity), to provide indices of fire occurrence or fire behaviour, which can be used either separately or combined, to produce a single index of fire load.

While a single fire danger index may be useful to provide early warning of wildfire activity over broad areas, it is impossible to communicate a complete picture of the daily fire danger with a single index. Therefore, it is necessary to break fire danger rating into its major components to appreciate where early warning systems for single factors fall into the overall picture of fire danger rating. These fall into three broad categories: changes in fuel load; changes in fuel availability or combustion; and changes in weather variables that influence fire spread and intensity.

Early warning of fire precursors

Changes in fuel load

In all fire danger rating systems, fuel load is assumed to be constant although specific fuel characteristics may be formulated for specific forest or other vegetation types, as in the Canadian fire danger rating system or for specific fuel models; i.e. combinations of vegetation and fuel with similar characteristics as in the US National Fire Danger Rating System. These fuel models may overlook major shifts in total fuel loads which may be changing over periods of decades or even centuries. Fuel changes start immediately after the cessation of cultural or agricultural burning. This change usually runs in parallel with increased suppression efficiency whereby small fires under moderate fire danger conditions are suppressed early in their life. In this scenario, fire authorities and the general public may be lulled into a false sense of security because the potential for high-intensity forest fires is not manifest except under rare events of extreme weather. In some places, this may be complicated by the introduction of exotic forest species (e.g. the establishment of eucalypti forests on formerly oak woodland savannas in central California), and a shift of the population from living in relatively low-fuel areas, which were maintained either by frequent burning through cultural or agricultural practices, or through frequent low-intensity wildfires.

Thus, the first element of early warning for a potential fire risk is a major shift in the total forest fuel complex towards denser forests with a large build-up of surface debris and a change in vulnerability of the population by living more intimately with these fuels. Over the last 20 years, this change has occurred in the urban/forest intermix associated with most of the population centres located in forest regions of many of the more developed countries.

Fuel availability

The seasonal change in fuel availability as fuels dry out during the onset of the fire danger period sets the stage for severe wildfires. Under drought conditions, more of the total fuel complex is available for combustion. Deep litter beds and even organic soils may dry out and become combustible. Large fuels such as downed logs and branches may burn completely. Drought stress on living vegetation reduces the moisture content of the green foliage. Dried plant matter such as leaves and bark can be shed, adding to the total load of the surface fuel. Under extreme drought conditions, normally moist areas such as swamps and creek lines dry out and are no longer a barrier to the spread of fires as might be expected in a normal fire season. Long-term moisture deficiency in itself cannot be used to forecast critical fire situations, because, if the smaller fine fuels are wet or green, serious fires will not occur at any time of the year. However, most devastating fires occur when extreme drought is combined with severe fire weather variables.

There are a number of book-keeping methods of monitoring the seasonal development of drought. The Keetch-Byram Drought Index is a number representing the net effect of evapo-transpiration and precipitation in producing a cumulative measure of moisture deficiency in the deep duff and soil layers (42). It is a continuous index which can be related to the changes in fuel availability mentioned above and the occurrence of severe fires. The Index has proved to be a useful early warning tool and is now incorporated into the US National Fire Danger Rating System (43) and the Australian Forest Fire Danger Rating System (38). Most recently, the index has been used to establish a user-friendly early warning system in Indonesia (44).

There are a number of similar drought indices used elsewhere in the world. For example, the drought code component of the Canadian Fire Weather Index System (40), the Mount Soil Dryness Index of Australia (45) and the Drought Index used in France [quoted in (33)].

Although drought indices can be built into a broader fire danger rating system, they are most effective as an early warning system when they are maintained separately and charted to illustrate the progressive moisture deficit for a specific location. This allows the fire manager to compare the current season with historical records of past seasons. The fire manager can also make associations between level of drought index and levels of fire activity which are specific to the region. This overcomes the problems

caused by variation of both forest and soil type which can mask the recognition of severe drought when a drought index is applied across broad areas.

Regular charting of bookkeeping-type systems such as the Keetch-Byram Drought Index (42) or the Mount Soil Dryness Index (45) are particularly useful in monitoring the effects of below-average rainfall during the normal wet or winter season. Moisture deficits from the previous dry season may be carried over winter. As the next fire season develops, high levels of drought may occur early in the season when, under the normal seasonal pattern, large and intense fires rarely occur. In some parts of the world, there are indices which indicate the changes in the global circulation patterns which may provide warning as much as six to nine months in advance of extremely dry conditions. One of these is the Southern Oscillation Index which records the difference in atmospheric pressure between Darwin in the north and Melbourne in the south of Australia. This index can be related to the El Niño events in the southern Pacific Ocean. When the Southern Oscillation Index is strongly positive, wetter than normal conditions are expected in south-eastern Australia; when the index is strongly negative, drought conditions are forecast for the south-east of Australia.

Early warning of fire behaviour

The fire spread component of fire danger rating systems is designed to combine the weather elements affecting fire behaviour, and provide a prediction of how fires will change hourly during the day. Most indices use 24-hour precipitation, and daily extremes or hourly measurements of temperature, relative humidity, and wind speed to predict the rate of spread of forest fires. In some systems, notably the US National Fire Danger Rating System (43) and the Canadian Fire Weather Index System (40), indices of fire spread are combined with a long-term measure of drought to provide an index of the total severity of the fire. This is termed a Burning Index in the United States system or a Fire Weather Index in the Canadian system.

In some systems, the risk of ignition from either lightning activity or human activities is calculated to form an index of fire occurrence which can be combined with a Burning Index to give an overall Fire Load Index (41). These are rarely used in the USA today (46). The risk of ignition by lightning is calculated separately and areas with historical records of high human-caused ignitions are mapped as a constant fire danger variable and are

used in concert with a burning index to calculate fire threat in a wildfire threat analysis system.

Fire spread indices are essentially weather processors (47), and the data required to provide early warning of severe fire conditions depends primarily on the ability to provide adequate space and time forecasts of the weather. The synoptic systems which are likely to produce severe fire weather are generally well known but the ability to predict their onset depends largely on the regularity of movement and formation of atmospheric pressure systems. In Australia, the genesis of severe fire weather synoptic systems has, at times, been recognised up to three days in advance; more often less than 24 hours warning is available before the severity of fire weather variables can be determined. Extended and long range forecasts contain greater uncertainty, and there is less confidence in fire severity forecasts at these time scales. Even so, these forecasts are useful in fire management in that the forecasts can be used to develop options, but not implementing them until the forecasts are more certain.

As improved fire behaviour models for specific fuel types are developed, there is an increasing need to separate the functions of fire danger and fire spread (48). A regional fire weather index based on either fire spread or suppression difficulty in a standard fuel type and uniform topography is required to provide public warnings, setting fire restrictions, and establishing levels of readiness for fire suppression. At a local level, fire spread models which predict the development and spread of a fire across the landscape through different topography and through a number of fuel types are required for suppression planning and tactical operations. However, these systems can be confusing on a broader scale by providing too much detail. They may be influenced by atypical variations of critical factors at the measuring site and may lose the broad-scale appreciation of regional fire danger that is required for early warning purposes.

Use of satellite data to help assess fire potential

Introduction

The amount of living vegetation, and its moisture content, has a strong effect on the propagation and severity of wildland fires. The direct observation of vegetation greenness is therefore essential for any early warning system. Current assessment of living vegetation moisture relies on various methods of manual sampling. While these measurements are quite

accurate, they are difficult to obtain over broad areas, so they fail to portray changes in the pattern of vegetation greenness and moisture across the landscape.

The current polar orbiting meteorological satellites provide the potential for delivering greenness information and other parameters needed for fire management and fire impact assessment at daily global coverage at coarse spatial resolution [see section on “Active fire detection by satellite sensors”, (p. 32) and (49)]. This is achieved using wide angle scanning radiometers with large instantaneous fields of view, e.g. the NOAA Advanced Very High Resolution Radiometer (AVHRR) instrument which measures reflected and emitted radiation in multiple channels including visible, near-infrared, middle-infrared, and thermal ones (50). Because of its availability, spatial resolution, spectral characteristics, and low cost, NOAA AVHRR has become the most widely used satellite dataset for regional fire detection and monitoring. Currently, AVHRR data are used for vegetation analyses and in the detection and characterization of active flaming fires, smoke plumes, and burn scars.

Since 1989, the utility of using the Normalized Difference Vegetation Index (NDVI) to monitor seasonal changes in the quantity and moisture of living vegetation has been investigated (51-56). Daily AVHRR data are composited into weekly images to remove most of the cloud and other deleterious effects, and an NDVI image of continental US is computed by the US Geological Survey's Earth Resources Observation Systems Data Center (EDC). These weekly images are obtained via the Internet and further processed into images that relate to fire potential (57, 58) so that they are more easily interpreted by fire managers.

Vegetation greenness information: An early warning indicator

Four separate images are derived from the NDVI data - Visual Greenness, Relative Greenness, Departure from Average Greenness, and Live Shrub Moisture.

Visual Greenness is simply NDVI rescaled to values ranging from 0 to 100, with low numbers indicating little green vegetation. Relative Greenness maps portray how green each 1 km square pixel is in relation to the historical range of NDVI observations for that pixel. The Departure from Average Greenness maps portray how green the vegetation is compared to the average NDVI value determined from historical data for the same week of the year.

Use of this map, along with the Visual and Relative Greenness maps, can give fire managers a good indication of relative differences in vegetation condition across the nation and how that might affect fire potential.

As for Live Shrub Moisture, the National Fire Danger Rating System (NFDR) used by the United States requires live shrub and herbaceous vegetation moistures as inputs to the mathematical fire model (59). For this reason, and to help fire managers estimate live shrub moistures across the landscape, Relative Greenness is used in an algorithm to produce live shrub moistures ranging from 50 to 250 percent.

The above maps may be viewed at this Internet site:
http://www.fs.fed.us/land/wfas/welcome.html

Development of fire hazard maps

Improvement in the spatial definition of fire potential requires use of a fire danger fuel model map to portray the spatial distribution of fuel types. In the USA, the Geological Surveys Earth Resources Observation Systems Data Center (EDC) used a series of 8 monthly composites of NDVI data for 1990 to produce a 159 class vegetation map of continental US at 1 km resolution (60). Data from 2560 fuel observation plots randomly scattered across the US permitted the development of a 1 km resolution fuel model map from the original vegetation map. This fuel model map is now being used in two systems to provide broadscale fire danger maps.

Integration of satellite data into fire danger estimates

The state of Oklahoma provides a good example for early warning of wildfires. The state operates an automated weather station network that consists of 111 remote stations at an average spacing of 30 km. Observations are relayed to a central computer every 15 minutes. Cooperative work between the Intermountain Fire Sciences Laboratory (US Forest Service) and the Oklahoma State University resulted in the development of a fire danger rating system that produces map outputs (61). The satellite-derived NFDR fuel model map is used to define the fuel model for each 1 km pixel, and the weekly Relative Greenness maps are used to calculate live fuel moisture input for the fire danger calculations. This results in a fire danger map showing a smooth transition of fire danger across the state. These maps may be viewed at this Internet site: http://radar.metr.ou.edu/agwx/fire/data.html.

A goal of fire researchers in the US is to expand the techniques provided for Oklahoma to other states and nations. An alternative method of estimating fire potential has been developed (62) using just the 1 km resolution fire danger fuel model map, relative greenness, and interpolated moisture for dead fuels about 1.25 cm in diameter. This map was found to be highly correlated with fire occurrences for California and Nevada for the years 1990 to 1995 (63). It is now being, or will be, further tested by Spain, Chile, Argentina, and Mexico as part of an effort between the Intermountain Fire Sciences Laboratory and the EDC, sponsored by the Pan American Institute for Geography and History. The Fire Potential Map is updated daily and can be seen at this Internet address: under "experimental products".

http://www.fs.fed.us/land/wfas/welcome.html

While these examples, and many other published papers (64), indicate the usefulness of current satellite data for fire management purposes, it is obvious that satellite data will become ever more useful and accurate. Instruments that were presented at the IDNDR Early Warning Conference 1998 in Potsdam, e.g. the satellites and sensors BIRD and FOCUS of the DLR, hold great promise for several fire management requirements, such as fire detection, fuel mapping, monitoring seasonal greening and curing (65).

Fire weather forecasts

Introduction

Improved fire weather forecasts are needed at a variety of time and space scales. At large space and time scales, accurate fire weather forecasts have potential for long range planning of allocation of scarce resources. At smaller time and space scales, accurate fire weather forecasts have potential use in alerting, staging and planning the deployment of fire suppression crews and equipment. At the smallest time and space scales, accurate fire weather forecasts can be helpful in fighting fires as well as determining optimal periods for setting prescribed silvicultural fires (66-68).

Current US fire weather forecasts are prepared from short-range weather forecasts (1-2 days) by the Eta model of the US National Center for Environmental Prediction (NCEP), other model output statistics, and human

judgement. These fire weather forecasts include information about precipitation, wind, humidity, and temperature. To test whether even longer range forecasts focused on fire weather products would be useful, an experimental modelling system, developed at the NCEP for making short-range global to regional weather forecasts, is currently being developed at the Scripps Experimental Climate Prediction Center (ECPC) (69). Although this system is currently focused for Southern California on making and disseminating experimental global to regional fire weather forecasts, it could be easily transferred to and applied anywhere else in the world.

Global to regional fire-weather forecasts

At the largest space and time scales, a modelling system utilizes NCEP's Global Spectral Model (GSM) (70). A high resolution regional spectral model (RSM) (71) 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 (70).

Global to regional forecasts of the fire weather index and precipitation are currently displayed on the world-wide web site of the ECPC as follows:

> http://meteora.ucsd.edu/ecpc/ (hit the predictions button, then the ecpc/ncep button)

Due to bandwidth limitations of the Internet, only the complete initial and 72-hour forecasts 4 times daily (00, 06, 12, 18 UCT) for the global model are transferred. From these global initial and boundary conditions, regional forecasts at 25 km resolution are then made and also displayed.

Future work

New forecast methods are being developed. Besides preliminary development of longer-range monthly global to regional forecasts, the current fire weather forecasting methodology will be validated. Experimental global to regional forecasts for other regions are also being prepared. Provision of additional output of corresponding land surface variables such as snow, soil and vegetation moisture are now being extracted and may soon be provided as part of the forecasts; these additional variables are needed to transform fire weather indices into fire danger indices, which include vegetation stresses.

Active fire detection by satellite sensors

Introduction

The middle-infrared and thermal AVHRR bands of the NOAA polar-orbiting satellites have been used for identifying fires. Several techniques are currently used to detect active fires at regional scales using multispectral satellite data. A comprehensive validation of AVHRR active fire detection techniques through a range of atmospheric and surface conditions has not yet been performed. A number of studies, however, have provided some level of validation.

Limitations in AVHRR fire detection

Data are sensed by all channels simultaneously at 1.1 km spatial resolution. Data acquired by the instrument are resampled on board the satellite to 4 km spatial resolution and recorded for later transmission to one of two NOAA Command Data Acquisition (CDA) stations, at Gilmore Creek, Alaska, and Wallops Island, Virginia. This is known as the Global Area Coverage (GAC) mode of transmission. In addition, the full spatial resolution 1.1 km data can be recorded for previously scheduled areas of the world, in the Local Area Coverage (LAC) mode, or can be received directly from the satellites by suitably equipped receiving stations, in the High Resolution Picture Transmission (HRPT) mode.

Even in full configuration, with two NOAA satellites in operation, the AVHRR data provide only a limited sampling of the diurnal cycle. The orbital characteristics of the satellites result in two daytime and two nighttime orbits per location. The afternoon overpass provides the best coverage in terms of fire detection and monitoring in tropical and subtropical regions (72). In addition, the afternoon overpass enables detection of the full range of parameters described (i.e. vegetation state, active fires, burn scars, smoke).

Perhaps the most fundamental problem to AVHRR fire detection is that analysis is limited to relatively cloud-free areas. This can be a serious issue in tropical and sub-tropical regions. Cloud cover can cause an underestimation in the extent and frequency of burning, and limits the ability to track vegetation parameters. This issue is not limited to the NOAA satellite system. Dense clouds will prevent detection of the surface by all visible and infrared sensors. A satisfactory methodology for estimating the amount of burning missed through cloud obscuration has yet to be developed.

Within these limitations, it is possible, due to the characteristics of the NOAA meteorological satellites described, to collect near real-time information to support fire management activities.

Automatic fire alerts

A prototype software has been developed in Finland for automatic detection of forest fires using NOAA AVHRR data. Image data are received by the Finnish Meteorological Institute. From each received NOAA AVHRR scene, a sub-scene covering as much as possible of the monitoring area is extracted (approximately 1150 square km). The processing includes: detection and marking of image lines affected by reception errors, image rectification, detection of "hot spots", elimination of false alarms, and generation of alert messages by e-mail and telefax. The prototype system has been tested in four experiments in 1994-1997 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. Nearly all detected fires were forest fires or prescribed burnings (73).

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. In the experiments in 1994-97, most of the detected fires that were in areas where verification was possible, were real fires. This shows that space-borne detection of forest fires has potential for fire control purposes.

Atmospheric pollution warning

The drought and fire episodes in Southeast Asia between 1992 and 1998 resulted in severe atmospheric pollution. The regional smoke events of 1992 and 1994 triggered a series of regional measures towards cooperation in fire and smoke management. In 1992 and 1995 regional workshops on "Transboundary Haze Pollution" were held in Balikpapan (Indonesia) and Kuala Lumpur (Malaysia). This was followed by the establishment of a "Haze Technical Task Force" during the Sixth Meeting of the ASEAN Senior Officials on the Environment (ASOEN) (September 1995). The task force is chaired by Indonesia and comprises senior officials from Brunei Darussalam,

Indonesia, Malaysia, and Singapore. The objective of the work of the task force is to operationalize and implement the measures recommended in the ASEAN Cooperation Plan on Transboundary Pollution relating to atmospheric pollution, including particularly the problem of fire and smoke (24, 74-76).

The first regional cooperation plans include the use of satellite data to predict smoke pollution from wildfires based on detection of active fires and smoke plumes and the forecast of air mass trajectories. In addition, some Southeast Asian countries have developed an air quality index for early warning of smoke-generated health and visibility problems.

In Singapore, air quality is monitored by 15 permanent stations and reported using the Pollutant Standard Index (PSI), a set of criteria devised by the US Environmental Protection Agency (EPA). The PSI value of 100 equals legal air quality standard (or limit) and is based on risk to human health (primary standard) or non-human health (animals, plants; secondary standard). Under this system, the levels of key pollutants like sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3) and respirable suspended particles (PM_{10}) are used to come up with a single index, the PSI. The PSI is a standard index, averaged over a 24-hour period, on a scale of 0-500.[3]

Another potentially useful tool for analyzing fire-generated smoke sources, as detected or monitored by spaceborne sensors, is the rose-diagram technique (77). In conjunction with trajectory analysis, this spatial analysis technique allows the establishment of the relationships between smoke pollution and the potential sources, e.g. wildfires vs. industrial pollution.

Climate-change/fire risk modelling

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has recently concluded that "the observed increase in global mean temperature over the

[3] A PSI value <50 is good (no health effects; no cautionary actions required); 50-100 is moderate; 100-200 "unhealthy" (irritation symptoms; no vigorous outdoor activities recommended); 200-300 is "very unhealthy" (widespread symptoms in population with heart or lung diseases; elderly and sick persons should stay indoors); and PSI >300 is "hazardous" (aggravation of symptoms, premature death; elderly and sick persons stay indoors and keep windows closed, general population to avoid outdoor activities). Malaysia is using a similar system for early warning of smoke-caused health problems (Air Pollution Index [API]).

last century (0.3-0.6°C) is unlikely to be entirely due to natural causes, and that a pattern of climate response to human activities is identifiable in the climatological record" (78). In west-central and northwestern Canada and virtually all of Siberia, for instance, this pattern of observed changes has taken the form of major winter and spring warming over the past three decades, resulting in temperature increases of 2-3°C over this period (79).

Numerous General Circulation Models (GCMs) project a global mean temperature increase of 0.8-3.5°C by 2100 AD, a change much more rapid than any experienced in the past 10,000 years. Most significant temperature changes are projected at higher latitudes and over land. While GCM projections vary, in general, summer temperatures are expected to rise 4-6°C over much of Canada and Russia with a doubling of atmospheric carbon dioxide. In addition, changes in the regional and temporal patterns and intensity of precipitation are expected, increasing the tendency for extreme droughts associated with an increase of fire risk and severity.

In the lower latitudes and in coastal regions, the expected changes in temperatures, precipitation and dry season length will be less pronounced than in higher latitudes and in continental regions. However, the manifold interactions between changing climate and human-caused disturbances of ecosystems may result in change of fire regimes in the densely populated regions of the tropics and subtropics (80) (see section on “Assessing impact of climate change and human population growth on forest fire potential in the tropics”, p. 38).

Modelling climate change and forest fire potential in boreal forests

Despite their coarse spatial and temporal resolution, GCMs provide the best means currently available to project future climate and forest fire danger on a broad scale. However, Regional Climate Models (RCMs) currently under development (81) with much higher resolution, will permit more accurate regional-scale climate projections. In recent years, GCM outputs have been used to estimate the magnitude of future fire problems. Flannigan and Van Wagner (82) used results from three early GCMs to compare seasonal fire weather severity under a doubled CO_2 climate with historical climate records, and determined that fire danger would increase by nearly 50% across Canada with climate warming. Wotton and Flannigan (83) used the Canadian GCM to predict that fire season length across Canada would increase by 30 days in a doubled CO_2 climate. An increase in lightning frequency across the northern hemisphere is also expected under a doubled CO_2 scenario (84, 85). In a recent study (86), the Canadian GCM was used, along with recent weather data, to evaluate the relative occurrence of extreme fire danger across Canada and Russia; a significant increase in the geographical expanse of the worst fire danger conditions in both countries under a warming climate was demonstrated.

In a recent study (87), Canadian and Russian fire weather data from the 1980s, the warmest decade on record in Canada (88) were used, in conjunction with outputs from four recent GCMs, to compare the spatial distribution of current seasonal levels of fire weather severity across both countries with those projected under a doubled CO_2 climate.

Daily May - August weather data were collected in the 1980s from 224 Russian and 191 Canadian climate stations. Local noon measurements of temperature, relative humidity, windspeed and precipitation were used to calculate the component codes and indices of the Canadian Fire Weather (FWI) System (89) for each station. Daily FWI values were then converted to Daily Severity Rating (DSR) values using a technique developed by Williams (90) and modified by Van Wagner (91). This severity rating technique permits the integration of fire severity over periods of various lengths, from daily (DSR) through monthly (MSR) to seasonal (SSR) values. In this analysis, both MSR and SSR values are used. The FWI System provides an assessment of relative fire potential based solely on weather observations, and does not take forest type into consideration.

As an example of possible conclusions, the monthly progression of modelled MSR under a doubled CO_2 climate indicates an earlier start to the fire season, with significant increases in the geographical extent of extreme fire danger in May. The month of June shows the most significant increase, however, with virtually all of Siberia and western Canada under extreme fire danger conditions during that period. A more modest increase is observed in July and August. The seasonal pattern changes indicate an earlier annual start of high to extreme fire severity, and a later end to the fire season across Canada and Russia as a whole, although there are important regional variances from this pattern.

Changes in the area in each fire danger class are perhaps more important than absolute value changes in MSR. Dramatic changes in the area extent of high to extreme fire danger in both countries under a doubled CO_2 climate were observed. In general, there is a decrease in moderate MSR and SSR levels, and a significant increase in the area experiencing high to extreme MSR and SSR levels under a warmer climate. This is particularly true in June and July, but increases in the area under extreme fire danger (and therefore greatest fire potential) are common to all months. Significantly, two to three-fold increases are projected for Russia during the June-July period.

Although hampered somewhat by coarse spatial and temporal resolution, the four GCMs utilized in this study show similar increases in fire danger levels across much of west-central Canada and Siberia under a warmer climate. While shifts in forest types associated with climate change were not considered in this analysis, these increases in fire danger alone will almost certainly translate into increased fire activity, and, as fire management agencies currently operate with little or no margin for error, into large increases in area burned. The result will be more frequent and severe fires, shorter fire return intervals, a skewing of forest age class distribution towards younger stands, and a resultant decrease in the carbon storage of northern forests (92).

A warmer climate, in combination with severe economic constraints and infrastructure downsizing, which will decrease the effectiveness and thus the area protected by fire management agencies, means a new reality in forest fire impacts is on the horizon. There is a strong need to continue modelling future climates, using higher-resolution models as they become available, so that future development of long-range early warning systems and fire management planning can be accomplished.

Assessing impacts of climate change and human population growth on forest fire potential in the tropics

With growing population pressure and accelerating change of land use in tropical vegetation, i.e. conversion of tropical forested ecosystems into farming and pastoral ecosystems, fire is being used increasingly. While certain tropical dry forests and savannas have been adapted to anthropogenic fire use for millennia and show typical features of sustainable fire ecosystems, the opening and fragmentation of tropical evergreen forests has increased the risk of wildfires that will have destructive impacts on biodiversity and sustainability of these forest ecosystems.

A recent assessment of potential impacts of climate change on fire regimes in the tropics based on GCMs and a GCM-derived lightning model (80) concluded that there is a high degree of certainty that land use and climate features under conditions of a doubled CO_2 atmosphere will influence tropical fire regimes. The conclusions are elaborated below:

- Tropical closed evergreen forests will become increasingly subjected to high wildfire risk because of land-use changes (opening and fragmentation of closed forest by logging and conversion), increasing fire sources (use of fire as land clearing tool), and climate change (prolongation of dry seasons, increasing occurrence of extreme droughts, increase of lightning as fire source). Tropical dry forests and savannas in regions with predicted reduction of average total annual precipitation and average prolongation of dry seasons will be subjected to higher fire risk. However, the reduction of net primary production (NPP) and the increasing impacts of farming and grazing systems will lead to formation of open and sparse vegetation cover with restricted capability to support the spread of fires (discontinuity of fuelbed).

- Tropical dry forests and savannas in regions with predicted increase of average total annual precipitation and average reduction of dry season length will be subjected to higher fire risk due to the fact that increased NPP will lead to the build-up of more continuous fuelbeds that may carry more frequent and larger-sized wildfires.

Long-range forecasting of fire potential: conclusions

The models and assumptions described in this section clearly exceed the time horizon of early warning systems. However, the IDNDR Working Group strongly suggests that relevant follow-up processes, in conjunction with other international activities, programmes and agreements, should consider this extended time horizon. The disaster management community needs to be prepared for managing situations which in the near future may require the development of innovative technologies and the preparedness of administrations to accomplish tasks that may differ from today's situation. While warning of potential disaster implies a high level of confidence, a second level, or alert level, with lower level of confidence is useful from the standpoint of strategic or contingency planning. This alert level is intended to convey the message that the potential for disaster has increased, but that actions would be limited to planning.

Towards a global wildland fire information system

A demonstration concept

One demonstration project is the Canadian Wildland Fire Information System (CWFIS), developed by the Canadian Forest Service. The CWFIS is a hazard-specific national system envisioned as a prototype system that is adaptable to other countries. Establishing and linking a number of compatible national systems could provide the nucleus of a global fire information network. Following the conceptual design of CWFIS, future early warning systems would have three goals:

- Facilitate information sharing among all agencies through a national network.

- Facilitate interagency sharing of resources by providing national fire information.

- Facilitate the application of fire research results through an interoperable platform.

The CWFIS incorporates several functions: weather observations, weather forecasts, fire danger, fire behaviour, fire activity, resource status, situation reports, decision support systems, technology transfer, and information exchange.

Weather observations

The system automatically downloads weather observations from a national satellite network. Although Canadian weather data are not mapped, exported systems [e.g. USA (Florida) or ASEAN region] provide this capability. Data needed for daily fire-danger calculations are extracted from a larger set of hourly weather observations. Most countries operate national weather observing networks. The World Meteorological Organization maintains a global network of synoptic weather stations which is accessible through satellite downlinks. Nationally, research is underway to produce automated spot fire-weather forecasts using a Regional Atmospheric Modelling System (RAMS). When operational, users will be able to submit coordinates for a specific fire and obtain computer- generated hourly forecasts for that location.

Weather forecasts

At global and national scales, forecasts are important because large-scale mobilization requires one or more days to accomplish. The CWFIS accesses 3 days of numeric forecast data generated by the Canadian Meteorological Centre (CMC). In Florida, a RAMS is used to forecast weather on a finer scale than that available nationally. Many countries operate similar national weather forecasting systems. Alternatively, the CMC (or other major national agencies) can generate a numeric weather forecast for any region on earth (see also section on “Fire weather forecasts”, p. 30).

Fire danger

Weather data are transformed into components of the Canadian Forest Fire Danger-Rating System. Station data are converted to national contour maps with an ARC/INFO GIS processor. The maps are converted to GIF images and stored on a World-Wide Web server. Daily maps overwrite those from previous days and date indices are automatically updated. Fire-danger maps are retained for seven days to provide backup.

Fire behaviour

Digital fuel and topographic databases enable absolute fire behaviour potential such as rate of spread, head-fire intensity, fuel consumption, and fire type to be calculated. The CWFIS uses a 16-class satellite-derived land-cover classification to approximate a national fuel map which is not directly available. The fire-behaviour maps are in a cell format, reflecting the

underlying fuel database. Satellite-based land cover classifications should be derivable for most countries. The system provides seven days of history, current observations, and three days of forecasts.

Fire activity

Fundamental to any fire information system is compiling and disseminating fire statistics such as number of fires and area burned. Although this currently requires manual reporting, tabulation, and graphing, it could be automated by having data entered directly into a remote database. A project has been proposed to develop an automated national satellite monitoring and mapping system for fires with an extension of more than 200 hectares. This system would transmit large-fire maps and associated statistics directly to the CWFIS for distribution via the web server. (Currently, it is partially functioning through the Global Fire Monitoring Center, p. 48).

Resource status

It is important to continuously monitor the disposition of suppression resources. This includes the location and status of individual resources as well as potential availability for interagency mobilization. Manual systems are in place for monitoring resource status at agency and national levels; this information could be displayed by the CWFIS.

Situation reports

It is useful to provide public information on the status of individual fires on the world-wide web. Providing an alternate media access point reduces the workload of public information officials during fire emergencies. Nationally, an overall synopsis of the current situation and prognosis for the near future is useful for senior executives, policy analysts, and governments. Reports are prepared manually and distributed through the internet.

Decision support systems

Decision-support systems (DSS) are often used for complex tasks, such as resource prepositioning, detection route planning, fire prioritization, and dispatch. Most agencies in Canada operate such systems.

Technology transfer

A web-based fire information system provides an interoperable platform to inform users about scientific results and technological developments. It also allows users to test and evaluate new systems. Accessibility through the web allows system developers to focus on underlying technology while avoiding system-specific idiosyncrasies. The CWFIS accomplishes this through a link to the Canadian Forest Service Fire Research Network, where emerging technologies such as hourly and seasonal fire growth models can be tested.

Information exchange

The most important aspect of the CWFIS may be its use as an example and a platform that enables fire management agencies to exchange information among themselves. The CWFIS also provides a national node that links individual fire agencies to the global fire community and vice versa. Similar national nodes in other countries could be readily linked to form a global forest fire information network. For example, FireNet (Australia) has proven invaluable as the principal server for a global fire community discussion group.

Canadian experience has shown that exchanging information among fire agencies is a precursor to developing mutual understanding. This, in turn, fosters agreements to exchange resources as no agency or nation can be an island in fire management. Prior interagency and intergovernmental agreements are the key to avoiding bureaucratic delays that can preclude effective resource exchanges. The process begins slowly and increases gradually as mutual trust develops among agencies. Implementing resource exchanges also fosters common standards for equipment and training; exchanging people fosters technology transfer. The overall result is enhanced fire management effectiveness and efficiency among all participants.

Global fire monitoring

It is currently technically feasible using the described earth observation and information systems (see sections on “Use of satellite data to help assess fire potential”, p.27 and “Active fire detection by satellite sensors”, p 32) to collect, analyze and share information on wildfire throughout the world on a daily basis. The Monitoring of Tropical Vegetation Unit of the Space Applications Institute at the EC Joint Research Centre has

been working on a global fire dataset based on the NOAA AVHRR products (83, 93, 94). The "Global Fire Product", in its first phase, is generating a dataset for the 21 months of global daily coverage from April 1992 to December 1993. Because of the significance of the dataset for global change studies, the latest state-of-the art report was produced under the umbrella of the International Geosphere-Biosphere Programme Data and Information System (IGBP-DIS) (95).

Malingreau (96) proposed the creation of a world fire web in which a network of centres with facilities to receive and process fire observation data from satellites, will be connected via the World Wide Web (WWW). This concept is meanwhile available through the Global Fire Monitoring Center (GFMC) (see p. 48). Through the GFMC, scientists, managers, and policy makers have instant access to local, regional and world data; they can exchange experience, methods and trouble-shoot each other. The GFMC web, in conjunction with the spaceborne evaluation of vegetation dryness and fire-weather forecasts, will provide a powerful early warning and disaster preparedness and management tool once it covers systematically all continents.

RECOMMENDATIONS

The recommendations given by the IDNDR Early Warning Working Group on fire and other environmental hazards build on a series of previous international efforts which addressed the needs of international collaboration in providing and sharing information and technologies and creating institutional mechanisms necessary to fulfil the overall goals of the IDNDR as related to fire disasters. The recommendations are in agreement with and legitimated by international initiatives at science, management and policy levels. They address a broad scale of fire management issues which will be mentioned here because they are prerequisites for operational early warning systems. Summary recommendations of the IDNDR Early Warning Working Group will be given the end of this chapter.

International initiatives and non-binding international guidelines

The methodologies, systems, and procedures in early warning of fire and atmospheric pollution, as described in page 19/20, are not equally available worldwide. Furthermore, some information systems, such as the global fire dataset, global coverage of fire-weather prediction, or real-time monitoring of active fires are still in the phase of being tested and further developed.

Several recent international initiatives in fire science and policy planning have developed concepts and visions for collaboration in fire science and management at international level. The recommendations of the UN FAO/ECE seminar on forest, fire, and global change, Shushenskoe, Russian Federation, August 1996 (97), acknowledged by the resolution of the International Wildland Fire '97 Conference, Vancouver, British Columbia, Canada, May 1997 (40, 98), and presented at the 11th World Forestry Congress, Antalya, Turkey, October 1997 (99), underscored the need of providing international agreements. These recommendations include the following:

- Quantifiable information on the spatial and temporal distribution of global vegetation fires relative to both global change and disaster management issues is urgently needed. Considering the various initiatives in recent years of the UN system in favour of global environmental protection and sustainable development, the ECE/FAO/ILO seminar on forest, fire and global change strongly urges the formation of a dedicated UN unit specifically designed to

use the most modern means available to develop a global fire inventory, producing a first-order product in the very near future, and subsequently improving this product over the next decade. This fire inventory data will provide basic inputs into the development of a Global Vegetation Fire Information System (100). The FAO should take the initiative and co-ordinate a forum with other UN and non-UN organizations working in this field, e.g. various scientific activities of the International Geosphere-Biosphere Programme (IGBP), to ensure the realization of this recommendation [see also recommendations of the ECE/FAO and the international fire science community (99)].

- The development of a satellite dedicated to quantifying the geographical extent and environmental impact of vegetation fires is strongly supported.

- A timely process to gather and share information on ongoing wildfire situations across the globe is required.

- Mechanisms should be established to promote community self reliance for mitigating wildfire damages, and to permit rapid and effective resource-sharing between countries as wildfire disasters develop. It is recommended that the UN be entrusted to prepare the necessary steps. The measures taken should follow the objectives and principles of the IDNDR.

- The unprecedented threat of consequences of fires burning in radioactive-contaminated vegetation and the lack of experience and technologies of radioactive fire management requires a special internationally concerted research, prevention and control programme.

The International Tropical Timber Organization (ITTO) took the first step to develop "Guidelines on Fire Management in Tropical Forests" (101). The document provides a comprehensive guidance targeted at the situation in the economically less developed regions of the tropics. Among others, the guidelines state:

> "Assessment, prediction and monitoring of fire risk and means of quantification of forest fires and other rural fires are prerequisites for fire management planning purposes. Statistical datasets can also be used to call attention of authorities, policy makers and the general public. In the tropics, such information is difficult to be gathered by

ground based-methods. Air- and space-borne sensors offer possibilities to monitor less accessible and sparsely populated land areas with inadequate ground-based infrastructures."

Accordingly, ITTO recommends that:

- Access to meteorological information from ground stations and space-borne systems should be sought, and this information be utilised for fire intelligence (fire risk assessment).

- Existing orbital remote sensing systems for fire detection and prediction which provide real-time information on the geographical location of fires should be used.

- ITTO member countries should join others in supporting the development of international mechanisms to predict wildfires (early warning systems).

- The UNCSD (United Nations Commission on Sustainable Development) should ensure that in the implementation of Agenda 21 for forests, due attention is given to forests fires in relation to arrangements that may be developed to harmonize and promote international efforts to protect the world's forests. A UN-sponsored Global Fire Research and Management Facility which includes a Global Vegetation Fire Information System and the capabilities to provide support on request to any nation in fire management and prevention and management of wildfire disasters should be considered by the UNCSD.

The ITTO guidelines provide general recommendations which must be fine-tuned to specific national requirements. In Indonesia, for instance, ITTO is sponsoring the development of the "National Guidelines on Protection of Forests against Fire", which were finalised in December 1997. This initiative is particularly important in light of the repeated smoke episodes in Southeast Asia caused by land-use fires and wildfires. Other countries, like Namibia and possibly Mongolia, aim to base their national programmes on the ITTO guidelines.

The first regional initiative is underway among member states of the Association of South East Asian Nations (ASEAN). The ASEAN Conference on "Transboundary Pollution and the Sustainability of Tropical Forests:

Towards Wise Forest Fire Management" (Kuala Lumpur, December 1996) (102) "recognised the International Tropical Timber Organization (ITTO) Guidelines on Fire Management in Tropical Forests which has been adopted by most of the ASEAN member countries"; and recommended that: "A collaborative meteorological and air monitoring information network and workable partnership in ASEAN should be further explored. The network would make use of up-to-date remote sensing and communication technologies in order to provide regional assessment of fire risk, fire and smoke events and early warning systems. The related existing national and regional institutions should form a core group of agencies that could be co-ordinated by a regional centre. This centre will take the lead in the organisation of such a network, and to assist the ASEAN Senior Officials on Environment (ASOEN) Haze Technical Task Force, as required in the ASEAN Cooperation Plan on Transboundary Pollution."

Another regional initiative is underway in the Baltic Region. The First Baltic Conference on Forest Fire (May 1998, Poland) was designed to improve the cooperation in early warning of fire and fire management among the countries bordering the Baltic Sea. The recommendations of the Baltic fire forum, among others, recommended that the problem of forest fires should be handled in compliance with the "Action Plan BALTIC 21". The international framework for the "BALTIC 21", among other, are the UNCED Forest Principles and the Agenda 21, and the Intergovernmental Panel on Forest (IPF 1995-1997), the results of the Ministerial Conferences on the Protection of Forests in Europe (Strasbourg 1990, Helsinki 1993, Lisbon 1998).

At the time of finalising this chapter (December 1998), various UN agencies have responded to the fire and smoke events in 1997-98. The UN Secretary General asked the UN Environmental Programme (UNEP) to co-ordinate the UN response to Indonesian fires. As a result of an international meeting in Geneva (April 1998), the joint unit of UNEP and the UN Office of the Coordination of Humanitarian Affairs (OCHA) has proposed an internationally supported fire suppression action in Indonesia and a global fire initiative.

While these recommendations are still under discussion, the World Meteorological Organization (WMO) convened a workshop on "Regional Transboundary Smoke and Haze in South-East Asia" (Singapore, June 1998) for the preparation of an internationally supported plan to enhance the

capabilities of national meteorological and hydrological services in transboundary haze issues.

The World Health Organization (WHO) has prepared a document entitled "WHO Health Guidelines for Vegetation Fire Events" which focuses on fire emissions and human health issues; the workshop for the preparation of the guidelines was held in Lima, Peru (October 1998).

The Food and Agriculture Organization (FAO) has responded by an expert consultation on "Public Policies Affecting Forest Fires" (October 1998) (103). Information on the activities of the FAO in preparing a global fire inventory and an update of the FAO international fire glossary can be found on the internet (see below).

Meanwhile, the Office of Humanitarian Affairs of the German Foreign Office financed the establishment of the Global Fire Monitoring Center (GFMC) as a contribution to the IDNDR. The scope of the GFMC is to establish a global real-time monitoring system on all fire-related information (environmental, ecological, economic, policies, international collaboration). It is envisaged that the scope of work of the GFMC will be expanded towards a Global Fire Management Facility. The GFMC is public domain and can be accessed through the internet (http://www.uni-freiburg.de/fireglobe). For details: see also ANNEX J of the main volume of the WHO Health Guidelines on Vegetation Fire Events.

Science and technology development

Fire research and technology development have received considerable stimulation by scientific projects conducted under the umbrella of the International Geosphere-Biosphere Programme (IGBP) and other programmes devoted to global change research (3, 29, 30, 94, 103, 104). While the scope of global change research is not necessarily directed towards requirements of operational management systems, e.g. early warning of natural hazards, the spin-offs of basic science nevertheless have a considerable potential for management solutions.

However, the application of existing technologies, methods, and procedures of information gathering, processing and distribution has revealed that many of the existing systems must be further developed in order to meet the requirements of precise and real-time application for early warning and management of fire and other environmental hazards.

Communication systems for early warning information dissemination are generally advanced since they rely on the technological progress in the civilian telecommunication sector. Space-borne sensing and collection of real-time data for early fire warning purposes generally depend on systems which were not specifically designed for sensing fire precursors, active fires, and fire effects. Thus, a short overview is given on the most important sensors which are currently designed or the construction is in progress.

New spaceborne sensors for early warning of fires and atmospheric pollution

In accordance with the analysis of Kendall *et al* (49), it is obvious that the remote sensing fire community, in addition to continuing experimentation and refinement of methods, needs to provide the operational monitoring dataset, at regional and global scales, to contribute to early warning of fire hazard, fire and smoke management and earth system studies. The development of operational automated monitoring techniques and the provision of consistent long-term dataset is a challenge that the remote sensing community is now facing. Issues associated with prohibitive data costs, computing resources, data management, data archival, and distribution need to be addressed.

Dataset development is being undertaken with satellite sensing systems which were not designed for fire monitoring purposes. The current suite of sensors suitable for fire monitoring have problems such as calibration, saturation, spatial resolution, orbital overpass time and coverage, which need to be taken into account in the data processing and dataset compilation. It is critical that the user community fully understands the limitations of the data and its utility. New sensors are being designed and built which will reduce or eliminate some of these problems, but they will introduce new, and in some cases unanticipated, problems. The development of new satellite dataset is an iterative process and has to be undertaken in close collaboration with the user community. The planned sensing systems will certainly provide a challenge to the remote sensing community in terms of data volume. The challenge will be to render the raw data to a volume and information content suited to the user community.

Some of the sensing systems which are in the planning and/or construction phase are facing financial constraints. As the user community

requires new spaceborne technologies for early warning applications, palled satellite programmes need to be materialised.

MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) is planned for launch as part of NASA's Earth Observing System (EOS) in 1998. This system will provide new capabilities over the currently utilized coarse resolution sensors. Thirty six spectral bands between 0.4 μm and 14.3 μm at resolutions ranging from 250 m to 1000 m are planned. Currently, two MODIS instruments are planned with the first platform providing a 10:30 am and pm overpass and the second providing a 2:30 am and pm overpass. For fire monitoring, the one kilometre infrared channels at 3.96 μm and 11.0 μm bands will have increased saturation levels, 500 K and 335 K, respectively, which will permit improved active fire monitoring. Full resolution MODIS fire products will have 1km resolution, and the data will be summarized for coarser grids. In the post-launch period, emphasis will be placed on validating the fire product and developing and testing automated burn scar detection techniques. The improved spatial and radiometric resolution of MODIS at 250 m in the visible and near-infrared bands will permit more accurate area estimate of burn scars.

BIRD

BIRD will be a small satellite mission for early warning of vegetation conditions and fires. Starting from their FIRES proposal (105), the DLR (Deutsche Forschungsanstalt für Luft- und Raumfahrt) had proposed a new approach in the design of a small satellite mission dedicated to hot spot detection and evaluation. The new approach is characterized by a strict design-to-cost philosophy. A two-channel infrared sensor system in combination with a Wide-Angle Optoelectronic Stereo Scanner (WAOSS) shall be the payload of a small satellite (80 kg).

The primary objectives of the planned BIRD mission are:

- test of a new generation of infrared array sensors adapted to earth remote sensing objectives by means of small satellites;

- detection and scientific investigation of hot spots (forest fires, volcanic activities, burning oil wells or coal seams); and

- thematic on-board data processing, test of a neuronal network classificator in orbit.

The unique combination of a stereo camera and two infrared cameras gives the opportunity to acquire:

- more precise information about leaf mass and photosynthesis for the early diagnosis of vegetation condition and changes; and

- real time discrimination between smoke and water clouds.

FOCUS on the international space station

The European Space Agency (ESA) recommended that the earth observation from the International Space Station be focussed on areas and processes, where non-sun-synchronous missions have the potential to make unique contributions to ESA's Earth Observation Programme.

The FOCUS instrument of the German Agency for Aeronautics and Space (DLR) was initially proposed to ESA in reaction to the announcement of opportunity for externally mounted payloads during the early utilisation

period of the space station. It contains the following unique features which are neither available on MODIS on EOS AM1 nor on FUEGO (see below):

- a forward-looking imaging IR sensor with a direct link to on-board intelligence dedicated for the autonomous seeking, detection and selection of hot spots, and

- a high-resolution spectrometer part for the remote sensing of the hot event plume.

The autonomous detection capability to be demonstrated by FOCUS on the International Space Station may contribute significantly to the improvement of a forest fire earth watch mission, which is considered by ESA.

The general utilisation objectives are ecology- and environment-oriented:

- spectrometric / imaging remote inspection and parameter extraction of selected high temperature events, such as vegetation fires and volcanic activities, and

- assessment of some environmental consequences of these activities, such as aerosol and gas emission from forest fires and volcanoes and from the thermal biomass conversion.

Furthermore, FOCUS has the important operational utilisation aspect of the autonomous hot spot detection and identification procedures, including:

- fore-field sensor data based hot spots detection;

- fire classification based on the fore-field sensor signals;

- selection of the target/area of interest;

- tilting of main sensor field of view to the area of interest and dynamic range control;

- selection of relevant hot spot data (thematic data reduction); and

- geocoding of thematic reduced data (maps).

The Intelligent Infrared Sensor System FOCUS has to perform a prototype function for operating a worldwide high temperature environmental disaster recognition system.

FOCUS is considered as a demonstration experiment with regard to the verification and validation of the autonomous detection and identification procedures of hot spots.

The FUEGO programme

The FUEGO programme aims at developing a satellite system for forest fire detection and monitoring system for the Mediterranean area, or other area with its respective latitude. The FUEGO system consists of a constellation of small satellites (nine to eleven) and a decentralised ground receiving station network with data processing facilities. The FUEGO satellites will look at prescribed risk areas to provide early alarm of a fire to the fire management authorities locally, regionally or nationally, depending on the structure of the civil protection administration in the country in question.

Next generation geosynchronous satellites

The next generation of geosynchronous satellites will provide improved fire monitoring capabilities with continued high temporal coverage. This means that a better understanding of the diurnal cycle of fire in a range of ecosystems will be possible. For monitoring North and South America, the GOES NEXT (I-M) series of satellites was launched in 1994. The new GOES satellites offer greater radiometric sensitivity and spatial resolution along with improved geolocation. Preliminary results from GOES-I data indicate enhanced capabilities in the identification of fires and the quantification of associated haze. Geosynchronous coverage of Africa and Europe will also be improved in the coming years as the METEOSAT Second Generation (MSG) satellites are launched in 1998. MSG will offer a significant improvement in biomass burning monitoring capabilities through increased spectral coverage. The new sensors will provide 3 km scale coverage every fifteen to thirty minutes with a spectral range similar to that provided by the NOAA-AVHRR. With the addition of a middle-infrared channel (3.8 μm), an opportunity for thorough investigation of the diurnal cycle of fire in African ecosystems will be feasible at last.

Challenges: multispectral and multitemporal sensing of early warning parameters

Early warning, monitoring and inventory of wildfire needs to be accompanied by monitoring and inventory of those ecological characteristics that lead to fire. Disturbances, such as insect or disease outbreak, wind throw of trees, forestry and other land use are frequently precursors to fire events, fire patterns and severity. Insects and disease stress ecosystems, resulting in partial mortality and production of dead materials, particularly foliage and other fine materials which are critical to fire ignition and behaviour. Post-fire vegetation recovery is important to predict fire-return intervals.

Advanced early warning systems will need to integrate these parameters into multi-layer fire information systems. Geographic information systems (GIS) technology, combined with decision support systems (expert systems), offer feasible, cost-efficient, and user-friendly solutions.

A review of some potential applications of the space techniques in fire management has been conducted under the auspices of the Disaster Management Support Project as a part of the Integrated Global Observation Strategy (IGOS) of the G7 Committee on Earth Observation Satellites (CEOS). Within the project, a number of hazard-specific teams have been created: drought, earthquake, fires, flooding, oil spill, tropical cyclone, and volcanic ash. These teams have coordinated the development of statements of user requirements. One of the documents is an outcome of the international working group with experience in the field of space technologies applied to fire management. The document can be found on the internet (e.g. via the GFMC website).

International fire research programmes

The fire research programmes conducted under the International Geosphere-Biosphere Programme (IGBP) offer a suitable mechanism to provide the scientific perspectives for the related programmes such as those under the UNEP, WHO, WMO, IDNDR, etc. As it is anticipated that the consequences of global change in general and climate change in particular will increase global natural hazards, the merging of joint interests between the IGBP and the UN communities seems to be advisable.

Previous and current international fire experiments under the IGBP scheme are regularly announced in the pages of the UN-ECE/FAO International Forest Fire News (IFFN) and published in scientific media (29, 30, 104) (see also section on "Use of satellite data to help assess fire potential", p. 27).

Recommendations by the IDNDR Early Warning Working Group on Fire and other Environmental Hazards

In accordance with the conclusions and recommendations given by the various international initiatives, the IDNDR Early Warning Working Group on Fire and other Environmental Hazards in 1997 recommended the priority activities listed below. (The author of this paper has edited or updated these recommendations by some remarks given in brackets).

- In order to provide a basis for early warning systems, a global fire inventory must be designed and implemented, producing a first-order product in the very near future, and subsequently improving this product for standardized application over the next decade. This fire inventory data will provide the basic inputs into the development of a future relational (geo-referenced) global fire database within the proposed Global Vegetation Fire Information System (GVFIS). The FAO should take the initiative and coordinate a forum with other UN and non-UN organizations working in this field; e.g. various scientific activities of the International Geosphere-Biosphere Programme (IGBP) and the mechanisms of the Intergovernmental Panel on Climate Change (106). [Remark: The FAO is working on the global fire inventory.]

- A timely process to gather and share real-time information on ongoing wildfire situations across the globe is required. This would follow the proposal to create a "world fire web" in which a network of centres with facilities to receive and process fire observation data from satellites will be connected via the World Wide Web (WWW). Through the world fire web, scientists, managers, and policy makers can have instant access to local, regional and world data; they can exchange experience, methods and trouble-shoot each other. The web, in conjunction with the spaceborne evaluation of vegetation dryness, fire-weather forecasts, and the possibility of forecasting fire danger and fire behaviour, may provide a powerful early warning and disaster preparedness and management tool at national, regional and global

scales. The information network should include the resource status by continuously monitoring the disposition of suppression resources. This includes the location and status of individual resources as well as potential availability for interagency and international mobilization. [Remark: The Global Fire Monitoring Center has taken over the initial role of the world fire web.]

- Technology transfer and information exchange on early warning and fire management decision support systems must be provided through international collaborative agreements or aid programmes. Such programmes must support countries in fire-prone regions of the tropics and subtropics where advanced fire management systems are not yet available.

- The development of spaceborne sensor technologies devoted to the specific tasks of recognizing wildfire disaster precursors, fire activities, and the impacts of fire (ecological, atmospheric chemical) must receive high priority. [Remark: The development of the DLR sensors and platforms BIRD and FOCUS is underway.]

- More fire research is needed in those regions where existing early warning systems cannot be applied due to the particular relationships between vegetation conditions, local/regional weather and the socio-economic and cultural conditions which cause wildfires and secondary damages like atmospheric pollution. South East Asia is one of the less explored regions in which fire research must receive adequate attention as postulated by the ASEAN Transboundary Haze Pollution initiative and the IGBP global-change oriented science programmes such as the South East Asian Fire Experiment (SEAFIRE) and the SARCS Integrated IGBP/IHDP/WCRP Study on Land-use Change in SE Asia. [Remark: After the 1997-98 smoke-haze episode, several research initiatives are operational.]

- Policies and agreements on environmental protection at international levels; e.g. the work of the United Nations Commission on Sustainable Development (CSD), should ensure that in the implementation of Agenda 21 for forests, due attention is given to forests fires in relation to arrangements that may be developed to harmonize and promote international efforts to protect the world's forests.

- Regardless of the technological possibilities of decentralized gathering, processing and dissemination of early warning and fire management information, it is recommended that the suggestion of ITTO to establish a UN-sponsored facility for global fire research and management be followed. This would facilitate the proposed Global Vegetation Fire Information System and the capabilities to provide support on request to any nation in early warning, prevention, management and mitigation of wildfire disasters. [Remark: The Global Fire Monitoring Center has been established.]

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It can be seen that two years between the initial report and this updated chapter, a remarkable progress has been made in international cooperation in the field of fire and related environmental, humanitarian, and public health aspects. This progress was mainly due to an increased interest by international organizations and policy makers in the aftermath of the extended smoke-haze episode in Southeast Asia, the large burning activities in Brazil and the wildfires in the USA, the Mediterranean and the Russian Federation in 1998.

The establishment of the Global Fire Monitoring Center in 1998 was a consequent step towards the implementation of the proposals made by the IDNDR fire group in 1997. Details of the operating mode and services offered can be taken from Annex J of the main body of the WHO Health Guidelines on Vegetation Fire Events (Global Fire Monitoring, Data

Archiving and Information Distribution: Location and Access to the Global Fire Monitoring Center) or directly on the Internet (http://www.uni-freiburg.de/fireglobe).

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Background papers

SMOKE FROM WILDLAND FIRES

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INTRODUCTION

Biomass burning is a major contributor of toxic air pollutants, particulate matter (PM), and greenhouse gases, but unlike some anthropogenic sources, poorly quantified. On a global basis, the net effect on human health and impact on climate change has not been adequately determined. The temporal and spatial distribution of these emissions is very difficult to estimate and the interannual variability of smoke production can range by an order of magnitude or more. With the advent of sensors operating over a temporal scale of hours, progress in estimating smoke emissions should be advanced. Still, the exposure of people to smoke emissions on a regional scale will continue to be very difficult to quantify.

Measurement techniques such as open-path Fourier transform infrared (FTIR) spectroscopy have allowed for measurements of oxygenated compounds and other more reactive compounds *in situ* rather than sampling for later analyses. Many different vegetation types have been examined for the release of CO_2, CO, and CH_4. Mass concentrations of products of incomplete combustion including particles less than 2.5 µm in diameter ($PM_{2.5}$) can generally be correlated with CO and CH_4. For example, Hao *et al* (1) reported the concentrations of many aliphatic hydrocarbons of C_6 and lower carbon number as being correlated with the concentration of CH_4. Some compounds such as those sulphur and nitrogen-based compounds depend both on the efficiency of the combustion process and the chemical composition of the vegetation burned by the fires. Utilizing ratios of air toxic compounds to CO, CH_4, and/or $PM_{2.5}$ allows reasonable estimates of

exposure to a number of other compounds based on the characterization of one or two compounds. Of course, this assumes that the emissions are from biomass burning or that the contribution of biomass burning can be apportioned.

FACTORS AFFECTING INCOMPLETE COMBUSTION

Combustion efficiency is defined as the ratio of carbon released as CO_2 to total carbon. For convenience, we use modified combustion efficiency which is the ratio of carbon released as CO_2 divided by the sum of CO_2 and CO. The smouldering combustion phase, which is generally a very low-intensity combustion process, produces high emissions of particulate matter, CO, and other products of incomplete combustion. Fuel properties can markedly affect the amount of smouldering combustion and the overall mixture of combustion products. The mixture of products of combustion produced by a fire in a particular vegetation type may result in 90 per cent of the vegetation being consumed through flaming combustion (e.g., savanna ecosystems), and this would be quite different from a fire burning in a vegetation type where 90 per cent is consumed through smouldering combustion (peat, rotten logs, deep duff, etc.).

DISCUSSION OF PRODUCTS OF COMBUSTION

In the study of smoke related to its effect on the health of wildland firefighters, Ward *et al* (2) discussed several combustion products and classes of combustion products. These substances are categorized as follows:

1. Particulate matter
2. Polynuclear aromatic hydrocarbons
3. Carbon monoxide
4. Aldehydes
5. Organic acids
6. Semivolatile and volatile organic compounds
7. Free radicals
8. Ozone
9. Inorganic fraction of particles

Particulate matter

Particulate matter from wildland fires is highly visible, affects ambient air quality, and has various effects on human health. Particles are abundantly produced by forest fires with source strengths exceeding 0.6 tonnes per second on some large fires (3). The mass of particles can be separated into two modes: (i) a fine-particle mode generally considered to be produced during the combustion of organic material with a mean-mass diameter of 0.3 micrometres; and (ii) a coarse particle mode with a mean-mass diameter larger than 10 micrometres. Research, both from ground-based sampling (4) and airborne sampling systems, shows the bimodal distribution with a small fraction of the total mass (less than 10 per cent) between 2 and 10 micrometres (5). Smouldering combustion releases several times more fine particles than flaming combustion. The fine particles account for up nearly 100 per cent of the mass of particulate matter. The percentage of fine particles produced through flaming combustion ranges from 80 per cent to 95 per cent depending on the turbulence in the combustion zone and other factors. The smaller fine particles consist of 60 to 70 per cent organic carbon (4). Many known carcinogenic compounds are contained with the organic carbon fraction. Roughly, another 2 per cent to 15 per cent is graphitic carbon and the remainder is inorganic ash material (6). Particles are also known to carry adsorbed and condensed toxic gases and possibly free radicals.

Polynuclear aromatic hydrocarbons

Polynuclear aromatic hydrocarbons (PAH) is one class of compounds contained in the organic fraction of the fine particle matter. Some of the PAH compounds associated with the particles are carcinogenic. Benzo[a]pyrene, for example, is a physiologically active substance that can contribute to the development of cancer in cells of humans. Examples of PAH compounds are listed in Table 1 for prescribed fires in logging slash, laboratory fires of pine needles, fireplaces, and woodstoves. Not all of the compounds listed in Table 1 are of equal carcinogenicity. More data have been developed for benzo[a]pyrene than other PAH compounds for smoke from wildland fires. Ward *et al* (2) found for benzo[a]pyrene that emission factors increased proportionally to the density of live vegetation covering the prescribed fire units. This has not been verified for other ecosystems with live vegetation involved in flaming combustion.

PAH compounds are synthesized from carbon fragments into large molecular structures in low-oxygen environments, such as occurs inside the flame envelope in the fuel-rich region of the flame structure. If the temperature is not adequate to decompose compounds upon exiting from the flame zone, then they are released into the free atmosphere and condense or are adsorbed onto the surface of particles. Many different combustion systems are known to produce PAH compounds, and the burning of forest fuels is documented as one of these sources. Little is known about combustion conditions on wildfires, but recent experiments would suggest that emissions are not that different from prescribed fires when burning conditions are similar. Evidence suggests that for low-intensity backing fires, the ratio of benzo[a]pyrene to particulate matter is higher by almost two orders of magnitude over that for heading fire (7). For wood stoves, a relationship was established between burn rate and PAH production. Specifically, as the burn rate increased, total organic emissions decreased, but the proportion that was PAH compounds increased. DeAngelis *et al* (8) found the PAH emission rate to be highest over a temperature range of 500°C to 800°C. This would be consistent with the low-intensity backing fire results of McMahon and Tsoukalas (7).

Carbon monoxide

Carbon monoxide is a colourless and odourless toxic gas. It is produced through the incomplete combustion of biomass fuels. CO is second in abundance to CO_2 and water vapour. Carboxyhaemoglobin is created in the blood of humans in response to the exposure to CO, which replaces the capacity of the red blood cells to transport oxygen. Generally, a level of 5 per cent carboxyhaemoglobin results from three to four hours of exposure to CO of concentrations of 35 ppm and may result in people showing signs of disorientation or fatigue.

CO is produced more abundantly from smouldering combustion of forest fuels. Immediately following the cessation of flaming combustion, maximum levels of CO are produced. This phenomenon coincides with suppression activities, especially where direct attack methods are being used. As the flames subside, CO is released at the highest rate and, typically, continues at a high rate during the first few minutes of the die down period. For fires burning under high drought conditions, the smouldering combustion can be self-sustaining and consume deep into the duff and in some cases, soil where the organic component of the soil makes up more than 30 per cent of the total. Tremendous amounts of smoke can be produced under severe conditions which is some times sustained for days and weeks.

Aldehydes

Aldehydes are compounds of which a few are extremely irritating to the mucous membranes of the human body. Some, such as formaldehyde, are potentially carcinogenic and in combination with other irritants may cause an increase in the carcinogenicity of compounds like the PAH compounds. Formaldehyde is one of the most abundantly produced compounds of this class and is released proportional to many of the other compounds of incomplete combustion. Formaldehyde is transformed rapidly to formic acid in the human body with formic acid being removed very slowly.

Acrolein is also known to be produced during the incomplete combustion of forest fuels. Acrolein is known to effect respiratory functions at concentrations as low as 100 ppb. Studies of pathogenesis in rabbits exposed to smoke from low-temperature combustion of pine wood suggest that low-molecular-weight aldehydes, including acrolein, are the most likely agents of injury. The ability of scavenger cells in the lung to engulf foreign material of bacteria is decreased through exposure to aldehyde compounds, which may accentuate infections of the respiratory system. Acrolein may have a high likelihood of making a discernible addition to the irritant character of smoke near firelines, and its concentrations could be as high as 0.1 to 10 ppm near fires.

Aldehydes as a class of compounds have been difficult to quantify for forest fires and there are still many issues to be worked out. Some recent research by Reinhardt *et al* (9) suggest that acrolein is produced proportional to formaldehyde. On the other hand, Yokelson *et al* (10) using a very straight forward analytical technique were not able to identify acrolein in as high a

concentrations as those reported by Reinhardt *et al* (9) and in much less abundance than formaldehyde.

Organic acids

Organic acids are known to form from the combustion of biomass fuels. Yokelson *et al* (11) and McKenzie *et al* (12) have recently made significant progress in characterizing some of the emissions of organic acids including acetic and formic acid finding molar ratios to CO of 7.4±6.2 and 1.5±1.5, respectively. Through the application of the molar ratios of different air toxic compounds to CO, McKenzie *et al* (12) reported possible exposure levels that were well below the allowable time weighted averages (TWA's) based on a peak exposure of firefighters of 54 ppm [based on Reinhardt's *et al* (9) data for peak exposure]. No single compound is present at a hazardous level except for vinyl acetate and 2-furaldehyde, which are suspected carcinogens (Table 2). It should be noted however, that the synergistic effects of some or all of these compounds and others have not been determined.

Semivolatile and volatile organic compounds

Semivolatile and volatile organic compounds in smoke contain a wide variety of organic compounds, many with significant vapour pressures at ambient temperatures. Some compounds are partitioned between the gaseous and liquid or solid phase at ambient temperature; e.g., benzene, naphthalene, toluene. Fires are known to produce a variety of these types of compounds, but little characterization work has been done. The phenolic compounds are important because they contain compounds that are very strong irritants and are abundantly produced from the partial oxidation of cellulosic fuels. Various phenolic compounds are used as starting materials in the manufacture of resins, herbicides, and pharmaceutical products. Other PAH compounds of low-molecular weight are contained with the semivolatile class of compounds. Because of the volatility and in some cases reactivity of these compounds, special sampling protocols are required including charcoal adsorption, porous polymer adsorption, and whole-air sampling. These materials are difficult to sample, and surrogate methods are needed for correlating exposures of the more volatile materials with the semivolatile components. Methane and carbon monoxide gases are often produced proportional to other products of incomplete combustion and may serve as indicators of their abundance.

Free-radicals

Free-radicals are abundantly produced through the combustion of forest fuels. The concern lies with how long these materials persist in the atmosphere and their reactivity when in contact with human tissues. Most of the chemical bonding is satisfied through recombination of free-radical groups by condensation within the few seconds of time it takes for the mixture of gases to exit from the flame which should reduce the overall toxicity of the smoke. However, some free-radicals persist up to 20 minutes following formation and may be of concern to people exposed to fresh aerosols. How much of the organic material remains in a reactive, free-radical state is unknown.

Ozone

Ozone concentrations close to fires that are high enough to be concerned about would not be expected. Ozone is formed photochemically near the top of smoke plumes under high sunlight conditions. Generally, ozone is formed in situations where smoke is trapped in valleys or under temperature inversion conditions of the atmosphere, or both. Fire crews working at high elevation locations may encounter elevated levels of ozone. Any effort to characterize exposure of people to smoke from vegetation fires must account for the potential exposure to ozone in areas where personnel are working at elevations close to the top of the atmospheric mixing layer.

RATIOS OF TOXIC AIR POLLUTANTS TO CO, CH_4, AND $PM_{2.5}$

In performing a risk assessment and establishing the relative importance of different compounds from a human health standpoint, a method is needed to estimate the exposure levels based on the measurement of CO and/or PM. Many of the compounds discussed are very difficult to measure which makes breathing space sampling nearly impossible for most of the toxic air compounds. Correlations of toxic air compounds to CO, CH_4, and $PM_{2.5}$ has proven to be an effective way of estimating the release of a number of compounds (11-13).

If this method is to be used, then it is important to give “safe-side” estimates or to use very specific information for the phase of combustion producing the smoke of concern. For example, ratios of benzo[a]pyrene to CO and/or to PM for different fuel types show a significant difference

between flaming and smouldering combustion and fuel type (Table 3). There is almost an order of magnitude difference between emission ratios of benzo[a]pyrene to CO for flaming in comparison to smouldering ratios. An average weighted emission ratio can be calculated based on the percentage of fuel consumed by phase of combustion producing the emissions contained within the breathing space. This can be done by assuming, for example, that the emissions along the fireline consist of 10 per cent from vegetation consumed during the flaming phase, 70 per cent for the first smouldering phase and 20 per cent for the final smouldering phase. The results are illustrated in Table 3. On the other hand, emissions released through flaming combustion are generally accompanied by the release of significant heat which lofts the emissions through convective forces acting on the smoke plume. Most of the emissions near the surface may be produced through smouldering combustion. It is recommended that emission ratios for smouldering combustion be used for assessing exposure, except for those conditions where 75 per cent to 80 per cent or more of the fuel is consumed through flaming combustion.

CONCLUSIONS

1. The mixture of particles, liquids, and gaseous compounds found in smoke from wildland fires is very complex. The potential for adverse health effects is much greater because of this complex mixture.

2. The particles are known to contain many important organic compounds some of which condense to form tarry droplets over a substrate material of ash or graphitic carbon or both.

3. The size distribution of smoke particles is such that a large percentage are respirable.

4. Gaseous compounds in the air adjacent to fires in association with the particles include carbon monoxide, methane, oxides of nitrogen and many organic compounds - some of which are carcinogens and many of which are irritants.

5. Other semi-volatile compounds have a significant vapour pressure at ambient temperature and pressure which results in a gas phase emission and many of these compounds to be important from a health standpoint, but have not been adequately quantified.

6. With the data available today, we still do not know what the overall toxicity of smoke is from wildland fires or how this toxicity varies from fire to fire.

7. The large variance in the concentration of smoke needs to be evaluated to assess the level of exposure and risk to humans.

8. The new USEPA $PM_{2.5}$ air quality standard is designed to protect human health and suggests that health is most at risk from particles less than 2.5 µm in diameter.

9. Along with the combustion products is the dust, heat, and remoteness of many of the wildland fires making exposure to humans difficult to assess. The fire, fuel, and weather vary continuously, which changes the fire dynamics and the dilution occurring over time and space.

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Table 1
Comparison of polynuclear aromatic hydrocarbons from four sources: (i) prescribed fires in logging slash in western Washington and western Oregon (2); (ii) pine needle litter fuel of southeast Pinewood (7); (iii) fireplace emissions tests with green southern pine wood (8); and (iv) woodstove emissions tests with green southern pine wood (8). Carcinogenicity is from National Academy of Sciences (23) and is coded as follows: "-" is not carcinogenic; "±" is uncertain or weakly carcinogenic; and "++" or "+++" is strongly carcinogenic

Compound	Logging slash (mean±SD)	Pine needles (mean±SD)	Fire places	Wood stoves	Carcino-genicity
	(µg of compound per g of particulate matter)				
Anthracene/phenanthrene	42±29	185±72	575	6345	-/-
Methylanthracenes	61±38	NA	692	3147	NA
Benz[a]anthracene/chrysene	17±8	43±25	117	2276	+/+
1,2-benzanthracene	17±8	NA	NA	NA	+
Chrysene/triphenylene	29±11	NA	NA	NA	NA
Dibenzanthracenes/ Dibenzophenanthrenes	NA	NA	4	3	NA
Fluoranthene	47±23	51±29	125	1153	-
Benzofluoranthene	NA	11±11	133	865	NA
Benzo (ghi) fluoranthene	11±5	NA	NA	NA	-
Benzo (a) fluoranthene	7±4	NA	NA	NA	NA
Benzo (b) oranthenes	26±9	NA	NA	NA	++
Benzo (j) oranthenes	26±9	NA	NA	NA	++
Benzo (k) oranthenes	26±9	NA	NA	NA	-
Pyrene	42±24	73±46	133	1153	-
Benzo(a)pyrene	13±14	3±2	NA	NA	+++
Benzo(e)pyrene	13±5	6±3	NA	NA	-
Benzopyrenes/perylene	NA	NA	117	578	NA
Perylene	3±2	2±2	NA	NA	NA
Indenopyrene	13±14	NA	NA	NA	NA
Indeno(1,2,3-c,d)pyrene	NA	NA	NA	NA	+
Anthanthrene/dibenzopyrene	6±8	NA	8	1	-
Benzo[ghi]perylene	15±19	NA	117	288	-

NA: Not available

Table 2
Listing of ratios of toxic air pollutants to CO determined for a variety of fuel types. The bold type values in column 3 are the ratios recommended for use in making risk assessments and are calculated from the highest 1 to 3 values listed for each compound in column 2.

	Literature values	Values to be used for risk assessment
	mean molar ratio to CO (x10^{-3})	**mean molar ratio to CO (x10^{-3})**
	1.50±0.93[12]	**1.50**±0.93[12]
5-methylfuraldehyde	0.30±0.19[12]	**0.30**±0.19[12]
2acetylfuran	0.33±0.16[12]	**0.33**±0.16[12]
Phenol	0.32±0.2[12]	**0.32**±0.2[12]
o-cresol	0.27±0.13[12]	**0.27**±0.13[12]
m/p-cresol	0.52±0.25[12]	**0.52**±0.25[12]
Guaiacol	0.17±.081[12]	**0.17**±.081[12]
4-methylguaiacol	1.00±0.83[12]	**1.00**±0.83[12]
Vanillin	0.50±0.57[12]	**0.50**±0.57[12]
Acetol	1.20±1.7[12]	**1.20**±1.7[12]
Vinyl acetate	1.70±2.1[12]	**1.70**±2.1[12]
2-cyclopenten-1-one	0.20±0.13[12]	**0.20**±0.13[12]
Acetic acid	7.40±6.2[12]; 22.6[11];8.70±6.1[15]; 1.60±2.4[16];8.00±4[17]; 3.20±0.4[15];2.60±6.8[17]	7.40±6.2[11] 22.6[11]; 8.70±6.1[15] **12.1**
Formic acid	1.50±1.5[12];1.6[14]; 9.1[11]; 2.60±2[15]; 0.17±0.27[16]; 20.0[17] ; 35.00±22[17]	9.1[11] ;35.00±22[17]; 1.6[14]; **15.2**
Propanoic acid	0.39±0.19[12]; 0.66[14]	**0.66**[14]
3-oxobutanoic acid	0.41±0.44[12]	**0.41**±0.44[12]
Methanol	11.00±9[12]; 18.0[11]	11.00±9[12]; 18.0[11]
Methane	29.00±11[12]; 55.00[13]; 83.4[11]; 45.00±13[18] ; 140.00±93[19]; 58.00±18[20] ; 71.00[13]; 91.00±3.1[21]; 76.00±13[22]	83.4[11]; 140.00±93[19]; 91.00±3.1[21]; **104.8**
Ethane	2.50±1.2[12]; 9.4[11]; 4.00±1.4[18] ; 6.80±5.2[21]	9.4[11]; 4.00±1.4[18] 6.80±5.2[21] **6.7**
Ethene	12.00±9[12] ; 13.5[11] ; 17.00±9.1[18]; 12.00±8.7[21]	12.00±9[12] ;13.5[11] 17.00±9.118 [18] **14.2**

Table 2(continued)

	Literature values	Values to be used for risk assessment
	mean molar ratio to CO (x10^{-3})	**mean molar ratio to CO (x10^{-3})**
Glycol	10.8[11]	**10.8**[11]
Formaldehyde	17.3[11]	**17.3**[11]
Ammonia	26.0[11]	**26.0**[11]
HCN	4.0[11]	**4.0**[11]
1,3-butadiene	1.10[1]	**1.10**[1]
Benzene	2.13[1]	**2.13**[1]
Toluene	1.79[1]	**1.79**[1]
o-xylene	0.24[1]	**0.24**[1]
m,p-xylene	0.43[1]	**0.43**[1]
n-hexane	0.06[1]	**0.06**[1]
Pyruvic aldehyde	6.2[14]	**6.2**[14]
Crotonic acid	0.21[14]	**0.21**[14]

Table 3
Example of application of data for prescribed fires in the Pacific Northwest used as an estimate of emissions exposure of 10 per cent flaming, 70 per cent primary smouldering, and 20 per cent secondary smouldering. The ratios can be multiplied by the concentration of CO to calculate either B[a]P or PM exposure. If only PM exposure is available, CO can be calculated and B[a]P estimated along with other air toxics found in Table 2.

Phase of combustion	CO (ppm)	PM (µg/m^3)	B[a]P (µg/m^3)	B[a]P/CO (µg/m^3/ppm)	B[a]P/PM (µg/g)	PM/CO (µg/m^3/ppm)
F	140	15740	0.1284	0.0009	8.2	112.4
S1	113	8391	0.1608	0.0038	42.8	74.3
S2	26	1214	0.1024	0.0067	126.4	46.7
Weighted	98	7690		0.0040	56.1	78.2

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

ANALYTICAL METHODS FOR MONITORING SMOKES AND AEROSOLS FROM FOREST FIRES: REVIEW, SUMMARY AND INTERPRETATION OF USE OF DATA BY HEALTH AGENCIES IN EMERGENCY RESPONSE PLANNING

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EMISSION AND TRANSPORT

Forest fires result in emission of range of gases and aerosols which can travel thousands of kilometers from the fire. A pair of field experiments conducted in 1992 serve to illustrate both the emissions and the species received downwind of the fire: the South Tropical Atlantic Regional Experiment (SAFARI) was conducted in Africa from mid-August to mid-October; the Transport and Atmospheric Chemistry Near the Equator--Atlantic (TRACE-A) mission was conducted from mid-September to late October over Brazil, Africa, and the South Atlantic (1).

Anderson et al (2) discuss aerosols emitted from biomass burning in Brazil and Africa. Measurements were made using a passive cavity aerosol scattering probe in the range from 0.1 to 3 microns, which is the range of most interest in terms of human health effects. Near Ascension Island in the South Pacific, fine aerosol number concentrations were found to be 200-300 per cm^3 in the lower 2 km. Nearer the source regions, fine aerosol number concentrations greater than $1000/cm^3$ were recorded. Aerosols may be the greatest health risk from biomass burning at downwind locations.

Blake et al (3) give concentrations for a number of hydrocarbons near biomass burning sites in both Brazil and Africa. While the concentrations for each hydrocarbon are relatively low in the boundary layer, the aggregate for hydrocarbons is relatively high.

Cheng et al (4) measured CO, NO, NO_2 and O_3 in Edmonton, Alberta in early June 1995 from a fire 300 km north of Edmonton. They found significant enhancements of all species above their seasonal climatological means, with O_3, for example, reaching 92 ppb compared with a climatological mean of 24 ppb. These readings are especially significant given the fact that the back trajectory calculations indicate that the smoke travelled about 1000 km to reach Edmonton. Among the hydrocarbons, alkanes had the highest concentration.

Browell et al (5) used an airborne UV differential absorption lidar (DIAL) system to measure ozone and aerosol profiles above and below the NASA DC-8 used in TRACE-A. The African plumes had both aerosols and ozone, while the long-distance Brazilian plumes had only ozone, since the process of convective lofting of the plumes stripped the aerosols out.

Gregory et al (6) discuss the chemical characteristics of tropical South Atlantic air masses arising from biomass burning. They point out that ratios of short- to long-lived species can be used to determine the approximate age of the air mass. For example, the ratio of acetylene (C_2H_2) to CO is >3 for air less than 1 day from the source, approximately 1.5 for 3-5 days, and <1 for >5 days. Such information might be of use in determining the source region for forest fire plumes.

Hao et al (7) measured the emissions of CO and various hydrocarbons from fires in savannas in Zambia and South Africa. They found CO to have 19 times the emission rate of methane, and ethene to have 23 per cent of the emission rate of methane. Other hydrocarbons were emitted at less than 10 per cent of the methane rate, with ethane (C_2H_6), ethyene (C_2H_4), and propene (C_3H_6) each being emitted about 7 per cent of the methane rate. This information is useful in determining which hydrocarbons to measure, should hydrocarbons be of interest.

Singh et al (8) discussed the impact of biomass burning emissions on the reactive nitrogen and ozone in the South Atlantic troposphere. They found ozone mixing ratios enhanced by about 20 ppb above the marine boundary layer (MBL). The South Atlantic is different from land masses in that the

MBL is relatively stable while the BL over land masses is turbulent and more rapidly mixes with air aloft. Thus, enhancement of ozone should be considered an important consequence of biomass burning.

INSTRUMENTS

The measurements of interest are the following:

1 - meteorological parameters;

2 - aerosols:
- a - aerosol loading at the surface
- b - visibility
- c - aerosol loading above the surface

3 - molecular species
- a - CO
- b - ozone
- c - hydrocarbons

Meteorological parameters

It is important to include meteorological information in any analysis regarding the transport of smoke from forest fires and other biomass burning. Such factors as wind speed and direction at a number of altitudes, the existence of low- and high-pressure regions, cloud cover, precipitation, temperature (surface and profile), etc., all play important roles in the transport and transformation of aerosols and gases from burning regions. Most likely, meteorological stations already exist throughout much of the regions that are of interest. The existing stations should be identified and compared with the network required that would best provide the information useful in studying transport, and any gaps identified.

Campbell Scientific, Inc. manufactures weather stations. Didcot Instrument Company Ltd. also manufactures a small automatic meteorological station. It measures wind, solar radiation, air temperature and humidity, net radiation, and rainfall.

Handar manufactures weather stations with a number of sensors. Met One Instruments manufactures weather stations with a number of sensors.

Their system is called MicroMet Data System, and includes MicroMet Plus software; and sensors are available that measure wind velocity, solar radiation, temperature, relative humidity, dew point, precipitation, evaporation, barometric pressure, soil water potential, and leaf wetness.

Vaisala manufactures an automatic weather station (MAWS). It can measure wind, relative humidity, temperature and pressure; and sensors are also available for measuring global solar radiation. It has a mass of 15 kg, can be set up on a tripod, and has a RS-232 output port for transmitting data to a remote location.

Visibility

One additional factor of particular interest is visibility. Most likely, it is determined by manual observations. However, such measurements are not possible at night. There are electro-optic techniques for measuring visibility, generally involving lasers, which could be installed at a few sites if deemed important enough.

Belfort Instruments manufactures a visibility sensor, Model 6210. It is a point monitor that uses a xenon flashlamp and measures forward scatter from aerosols to determine visibility. It can measure visibility over a range of 5 m to 50 km.

Handar manufactures a visibility sensor with a visibility range from 0.25 to 30 km.

Vaisala manufactures the PWD11 which emits laser radiation and senses forward scattering a few cm from the laser. It can measure visibility in the range from 10 m to 2000 m, as well as amount and type of precipitation with a sensitivity of 0.1 mm/hr. They also manufacture the FD12P Weather Sensor which is a larger version of the PWD11, and can measure visibility up to 50 km and detect precipitation down to 0.05 mm/hr.

Aerosols - *in situ*

AIRmetrics manufactures a MiniVol Portable Air Sampler. It is lightweight and compact and can run off a battery or AC power. It can sample ambient air for particulate matter [total suspended particulates (TSP), particle mass concentrations for particles less than 10 microns (PM_{10}) or 2.5 microns ($PM_{2.5}$) in diameter] and non-reactive gases such as CO and NO_x. The system makes up to six "runs" at a time over a period of up to 24 hours or a week. Ambient air is pumped through the unit at a rate of 5 liters/minute. For TSP, filters are used. For PM_{10} and $PM_{2.5}$, impactors are used. For gases, 6-liter Tedlar bags are used. The advantages of this instrument include that it is lightweight and portable, can operate using a battery, and is relatively inexpensive. The disadvantage is that the material obtained by the unit must be collected and analyzed in a laboratory with the proper analytical equipment, such as highly accurate balances. This instrument may be more suited to industrial site evaluations than to monitoring of forest fire emissions.

Met One Instruments, Inc. manufactures aerosol mass monitors. The Beta-Attenuation Mass Monitor, BAM 1020, uses beta rays from ^{14}C (60 $\mu g/m^3$) to measure the amount of aerosol collected on a filter tape in the instrument. This model was shipped to Malaysia for installation at various sites. Another particulate monitor, Model GT-640, is a portable monitor that can be used to measure TSP, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$. A laser optical sensor is used to detect and measure particulate concentrations up to 1 mg/m^3 on a continuous flow basis. It is more commonly used than the BAM 1020.

Rupprecht and Patashcnick manufacture a line of aerosol samplers in their Partisol line. The Model 2000 is manual, and can measure PM-10, -2.5, -1 and total suspended particulates (TSP). The Model 2025 automatically changes the filter.

Aerosols - remote

Handar manufactures a ceilometer that measures cloud heights to 8 km, and can, most likely, be used for aerosol plume measurements as well.

Vaisala manufactures a laser ceilometer, Model CT25K. It transmits a laser beam and detects backscatter up to 7.5 km above the surface. The wavelength employed is 905 nm, and it is an eye-safe system. While it is generally used at airports to detect cloud bottom heights, it can also be used to measure aerosol profiles such as those associated with forest fire plumes, and to monitor the transport of smoke plumes.

There are also lidar systems operating in such countries as Indonesia. A lidar system is installed in Jakarta, where it has been used to monitor the atmospheric boundary layer (9). Another advantage of lidar systems is that they can give the top of the boundary layer as one of the measurement parameters. This permits a determination of the total depth of the boundary layer, which can be used to estimate the concentrations of pollutants trapped in the layer: the thinner the layer, the higher the concentrations, other things being the same. Of course, during the day, the top of the boundary layer increases during daylight hours and decreases during non-daylight hours due to solar heating.

Solar radiation

As mentioned above, a number of companies manufacture solar radiation sensors, including Didcot, Met One Instruments and Vaisala.

Yankee Environmental Systems manufactures several instruments which may be of interest in monitoring emissions from forest fires. Their best known product is probably their ultraviolet pyranometer, used for monitoring solar UV-B radiation reaching the surface (10). There are two reasons why this instrument might be of interest here. First, smoke plumes from biomass burning reduce UV-B radiation reaching the surface, so monitoring UV-B is one way to determine whether smoke plumes are passing overhead. Of course, such measurements would have to be augmented with other factors such as time of day and cloud cover. Second, UV-B radiation kills microorganisms, and there is reason to believe that reduced UV-B radiation leads to increased disease incidence in the tropics (11).

A second Yankee instrument of interest is the multi-filter rotating shadow-band radiometer (12). This instrument is useful for monitoring global, diffuse, and direct solar irradiance. It includes a rotating sun blocker

which, when between the sun and the detector, blocks direct solar irradiance, leading to a measurement of diffuse solar irradiance. The presence of an aerosol plume would reduce the direct solar irradiance while increasing the diffuse solar irradiance. Such a device might be quite useful in determining the amount of aerosols overhead as well as determining the presence of clouds. Broken or scattered clouds show up in the increased variability of irradiance (13). The signals at the various wavelengths from 415 to 940 nm can be used to determine the coarse aerosol size distribution. This would be useful, for example, in separating out crustal material aerosols, which tend to be large, from biomass burn aerosols, which tend to be small, especially near the source region. This radiometer is fully automated and the data obtained using it can be transmitted to a central location over a phone line.

Solar Light Co. also makes a sun photometer, which is a five-band instrument, and does not include the rotating shadow band. Thus, it is less expensive. The instrument is similar to that used by Forrest Mims III, since he developed the prototype. In his report on using a 4-band sun photometer (14), he describes a transect through a diffuse smoke plume obtained by driving along a mountain road in Wyoming. The shortest wavelength (376 nm) measured over 4 times the optical depth (0.22) as did the longest wavelength (1020 nm). Since the ratio of wavelengths was only 2.7, this indicates the presence of fairly small particles, as expected from fresh biomass burning aerosols. Had the optical depth scaled inversely with wavelength, it would have indicated the presence of large aerosols.

Cimel Electonique manufactures the Cimel CD 318-2 Sun Photometer. It is a direct solar-viewing photometer with filters at 440, 670, 870, and 1020 nm for measuring atmospheric aerosol optical thickness. It has a filter at 936 nm for measuring atmospheric water vapour. It also has 3 polarized filters at 870 nm. It does not separate direct from diffuse radiation, but is thought to be quite accurate for aerosol measurements. It has been used quite successfully to invert data to obtain aerosol volume size distributions from 0.1 to 8 μm with good accuracy (15). It has been adopted in the AERONET programme (15), and is used in 167 locations worldwide as of 1997. All sites are listed at the AERONET web site (http://spamer.gsfc.nasa.gov). An advantage of adopting Cimel CD 318-2 Sun Photometers is the ability to participate in the AERONET network and take advantage of algorithm developments, etc., from others participating in the network.

Point monitors

Dasibi Environmental Corp. manufactures UV photometric ozone analyzers. They use the 254-nm mercury line to monitor absorption through a cell with ambient air, then compare these measurements to those with ozone removed from the ambient air stream. They make two models, the Series 1003, which is the basic instrument, and the Series 1008, which is a microprocessor-based instrument.

Thermo Environmental Instruments makes a number of analytical instruments that are useful for monitoring smoke emissions from forest fires. One is a methane, non-methane analyzer. It uses the principle of gas chromatography to separate the hydrocarbons, then a flame ionization detector (FID) to measure the amount of hydrocarbons present. Methane, being the lightest hydrocarbon, is the first one to emerge from the column. After methane is measured, a valve is closed to reverse direction of flow in the column, back-flushing the other hydrocarbons to the FID. This instrument is useful in regions closer to anticipated forest fire regions, since many of the hydrocarbons are removed during transport. Hydrocarbons are of interest for several reasons: they are indicators of forest fires, they have minor health impacts, and they are precursors of ozone. However, in the tropics with so many trees, photochemical production of ozone is probably limited by NO_x rather than hydrocarbons (16).

Another instrument manufactured by Thermo Environmental is a chemiluminescence NO-NO_2-NO_x analyzer. It can measure over the range from sub parts per billion (ppb) to 100 parts per million (ppm). Ozone is generated to react with NO and produce a characteristic chemiluminescence. NO_2 is converted to NO in order to enable its measurement. It monitors continuously with 10- to 300-sec averaging times, and can be accessed remotely over telephone lines.

Thermo Environmental Instruments also manufactures a UV photometric ozone analyzer. It monitors continuously with a 20-sec response time, and has a precision of 1 ppb. Use of the mercury line at 254 nm has become the standard way of monitoring ozone.

Finally, Thermo Environmental Instruments manufactures a gas filter correlation CO analyzer. The gas filter has two components, one containing CO, the other, N_2. When the CO cell is between the infrared source and detector, a background signal is obtained, independent of CO. When the N_2

cell is inserted, the signal increases, with greater increases corresponding to lower CO concentrations. CO has a comb-like absorption band in the 4.6-micron region which enables this approach to work well. The precision is one per cent of the reading or 0.05 ppm, and the response time is 60 sec. It monitors continuously and can be accessed over a phone line.

Vistanomics, Inc. manufactures ozone badges that can be used to measure personal exposure to ozone. The badge has a paper coated with an iodine compound that changes colour upon exposure to ozone, similar to the old potassium iodide wet chemistry approach for measuring ozone. After a 1- or 8-hour exposure, the colour of the paper can be compared with the colour set provided with the badge to determine the average ozone concentration during that period. The badge measures in 40-ppb steps, so is a bit coarse. However, since human health effects begin at levels above about 80 ppb, the badge would be useful in determining whether levels adverse to health had been reached. Geyh et al (17) describe a similar instrument that used nitrite which reacts with ozone to form nitrate.

Network

Thus, there are a number of instruments which can measure pollutants and meteorological parameters both in situ and remotely. There is probably some redundancy, possible in the use of various instruments. Forest fires generally have emission factors for various pollutants that are closely linked to each other; i.e., if one pollutant emission rate is known, a number of others can be estimated fairly closely. As a result, not all of the instruments would be required, and certainly not at each monitoring station. However, having several, including redundant ones, would enable continuous monitoring even when one or more instruments failed.

The value of monitoring increases considerably when the instruments are integrated into a network of stations located between the likely fire regions and population centres. This way, both the transport of the pollutants and the concentrations or column loading of the pollutants can be determined. In addition, by operating the stations prior to the burning season, background levels can be determined, and the instruments can be brought back into working order.

Networks of stations with meteorological instruments and some pollution monitoring instruments are already set up in some southeast Asian countries. Each country could be contacted to learn what is already in place.

INTERPRETATION AND USE OF MONITORING DATA BY HEALTH AGENCIES

As discussed above, there are a number of analytical instruments that can be used to obtain both in situ and remotely-sensed data on molecular species and particulates associated with forest fires that pose various degrees of health risks, as well as meteorological parameters. By having a network of instruments, the emissions can be followed as they are transported towards highly populated regions. By using a combination of sightings of fire and plume locations and meteorological information that can be used for forecasting future air mass motion as a function of altitude, the time of arrival at the population centres can be estimated. Also, the loading can be estimated so that more serious health risks can be assessed. By continuing to monitor the molecular species and particles between the fire locations and the population centres, information leading to estimates of the anticipated changes in pollution loading in the population centres can be obtained.

Once the health agencies have the information, what can they do with it? First, they will have both real-time and advance information on the concentrations of pollutants in the populated regions. They may also have information regarding the expected duration and magnitude of the source fires. They can assess which pollutants pose the most serious threat to health and safety based on concentrations, expected doses, and health effects vs. concentration and dosage. Since different pollutants have different impacts on people; some acting through the lungs, with various short- and long-term effects, and some affecting the eyes, the health agencies could determine which impacts are most likely. Armed with information about the health impacts of various pollutants as a function of concentration and duration, they will be able to make estimates of how much pollution the people should experience before, say, long-term adverse consequences ensue.

Second, they could make decisions to reduce the impacts of the pollution. Perhaps, simple particle masks could be distributed. Perhaps people should stay indoors if possible. Perhaps, they should not do strenuous physical activity. Perhaps, as a long-term measure, buildings should be equipped with air purifiers. Perhaps, airports should be closed if visibility goes below safe levels. Perhaps, fossil fuel combustion in vehicles and for power generation should be reduced in order to reduce total pollution levels. All of these decisions would be made in an economic framework; i.e., if serious adverse impacts were to ensue by shutting down production for two weeks, the policy makers would probably elect not to shut down.

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Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

THE ROLE OF THE ATMOSPHERE IN FIRE OCCURRENCE AND THE DISPERSION OF FIRE PRODUCTS

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SUMMARY

The large-scale atmospheric controls on the spatial and temporal distribution of fires are discussed and related to a hierarchy of smaller scales. Interactions between scales and between the fire and the atmosphere are important in determining transport pathways and concentrations of fire-generated products. Climatic change on a range of time scales is considered in determining fire distributions. Sudden changes in climate are of particular concern.

Long-range, large-scale transports of fire-generated products can be calculated for prototypical conditions and used as guidelines for preparation and emergency planning. Methodology for the computation of trajectories and transports of particulates and trace gases are provided within a meteorological framework of synoptic states. Both direct and indirect recirculated products and concentrations are considered. A hierarchical classification of global fire regimes is proposed as a basis for developing an emergency response plan.

INTRODUCTION

An objective of this paper with respect to the WHO Health Guidelines on Episodic Vegetation Fire Events is to provide both background as well as

predictive information about the occurrence of large fires and the transport of their products.

Atmospheric processes which influence the temporal and spatial distribution of rainfall through the balance between precipitation and evaporation, directly influence the occurrence, distribution and nature of fires and their products. The occurrence of fire not only depends upon climatic and more immediate weather conditions, but is strongly influenced by the quantity and nature of the fuel available to the fire. This fuel is in turn, and in part, dependent upon climate. Feedback loops such as herbivory intensify the interaction between climate, fire, and vegetation (1).

Fire occurs within the atmospheric fluid system. An intense heat source, such as a fire, at the base of a fluid can create its own “storm”. The resulting heat-driven turbulence and convective motions interact with the atmosphere’s fields of motion prevailing over the fire. The result can be nonlinear and unexpected. Prediction of where and how fast the products of a fire will go requires as complete an understanding of these complex interactions as is possible.

Fire and the distribution of products from a fire, therefore, require an understanding of processes in the atmosphere which range in scale from motions occupying a significant fraction of the planet to motions on a scale smaller than that of the fire itself. The large scales of motion in the atmosphere such as the semipermanent subtropical anticyclones, occupying most of a given continent, such as northern or southern Africa for much of a season, represent potentially predictable, near steady state conditions. Similarly, the large seasonal oscillations of the Australian monsoon represent predictability in time and space of conditions both favourable and unfavourable to fire.

Fire at a given location, however, within these large-scale atmospheric circulations, is dependent both at inception and in its subsequent behaviour, on the interactions of a number of atmospheric scales of motion which range downwards from the large planetary scale, through storm, sub-storm (squall line), to convective (thunderstorm cloud), and turbulent scales. All of these scales interact with each other and with the fire itself. Predicting or even determining behaviour of a fire and its products depends on our ability to understand these nonlinear processes. To do so precisely is not now possible, nor likely to be so at any point in the future. Part of the behaviour of the fire-atmosphere system will remain indeterminate, chaotic, and

unpredictable. An attempt in this chapter will be to seek out the more deterministic and predictable aspects of this complex fire-atmosphere system.

CIRCUMSCRIPTION OF THE OCCURRENCE OF FIRE AND THE DISPERSION OF FIRE PRODUCTS

Spatial identification of fire-prone regions

Few fires produce the widespread and serious conditions to human and environmental health as did the fires over the Indonesian region in 1997. The need exists to detect the occurrence of fires which are likely to pose hazardous environmental health problems. The first step towards detecting serious fires is to identify globally vulnerable areas.

Fosberg and Levis (2) model fire upon climate in a framework shown in Figure 1. Climate, in turn, can be described in terms of the large-scale circulation fields of the globe. Figures 2 and 3 show the dominant large-scale meridional and zonal circulation patterns of the atmosphere. When these large-scale circulation fields are compared to global meridional pressure and rainfall fields (Figure 4 a & b) near coincidence is seen between

- upward motion, low surface pressure, and high annual rainfall; and
- downward motion, high surface pressure and low annual rainfall

(note that a paucity of measurements in high southern latitudes fails to show the high zonal pressure over Antarctica). The wet regimes of Figure 4b correspond to cyclone tracks along the corridors of the polar fronts in both hemispheres and to the equatorial trough about the meteorological equator. The dry regions correspond to the subtropical high pressure belts and the polar highs. Based on these simple meridional fields alone, we would not expect serious fires in either the wet or dry zones of the globe. Serious fires are most likely in the margins of these zones where changes in precipitation can be the greatest.

An important departure to this simple meridional model is to be found in the zonal Walker circulations which are subject to reversal. The Low Phase of the Southern Oscillation, with an accompanying El Niño, results in either the diminution of upward motions over the Maritime Continent, and

over the Amazon and Zaire Basins or actual reversal of the vertical velocity fields. A strong El Niño event such as that of 1996/1997 may reverse the upward motions of the La Nina creating sinking motions, persistent high pressures, inversions, and drought conditions.

All of these conditions point to serious fire hazards and pollution events, serving as a prototype example of fire-prone regions. Such fire-prone regions are typically regions where:

- the standard deviation from the mean of the rainfall is high;
- dry or extremely dry periods can occur and wet years are infrequent;
- biomass and fuel levels can be high;
- dry conditions are persistent in time, accompanied by large scale sinking in the atmosphere;
- large-scale sinking produces adiabatic warming and drying;
- cloud cover is reduced or absent, solar insulation is high, and with reduced water, conversion of solar radiation at the surface to sensible heat results in high surface temperatures;
- high daytime surface temperature produces enhanced buoyant mixing and deep mixed layers;
- large-scale sinking produces temporally persistent and spatially extensive capping inversions which trap and concentrate fire products;
- polluted layers under persistent inversions elevate temperatures in the layer, intensifying the inversion further; and
- stratification of the atmosphere may lead to strong low-level nocturnal winds which transport fire products over long distances.

Fire climatology documenting the distribution of large fires which pose health and environmental hazards should be compiled and compared with the above climatologically defined fire-prone regions. Satellite-based remote sensing of fires can be employed to provide a global view of fire occurrence and distribution. Figure 5 shows an example of the detail now available from satellite remote sensors. Methodology will have to be devised to identify the large fires which pose serious environmental threats, separating these from the many smaller and less serious fires.

Global rainfall distributions provide an initial indication of the transitional zones identified above as potential fire regions. Rainfall variability in terms of departures from the mean represents a guide to regions where serious fires are likely. Similarly, distribution of drought-prone regions provide additional guidance to fire-prone locations. In each case (rainfall, rainfall variability, and drought regions), consideration of fuel loads are crucial to the actual fire potential of the region.

Time-Dependent Fire Regimes

Climate change research has identified a range of periodicities in the system which have potential impact on the occurrence of fire (3, 4). The absence of adequate understanding of the cause or even clear existence of such periodicities should induce caution but not abstention from the use of these indicators.

Long-term (thousands to millions of years) temperature and rainfall records have been reconstructed for the earth (5). Inferences from such records can also be drawn regarding the strength and direction of surface winds and the associated transports. These records leave little doubt that the earth has undergone major changes in climate ranging through wet, dry, cold, and warm conditions. A model of an expanding and strengthened circumpolar vortex with a corresponding weakening of the tropical easterlies has been used to explain cool, dry conditions over the summer rainfall regions of southern Africa (6, 7). A weakening of the polar vortex would have the opposite effect. These changes in rainfall regimes occur on a global scale appearing in all of the continents and in the maritime regions.

Davis et al (8) have found a statistically significant oscillation in the strength of the Atlantic anticyclone over the past 100 years. Strengthening of the anticyclone corresponds to strong zonal (E-W, W-E) flow resulting in wet conditions in the tropics and subtropics and dry conditions in midlatitudes. A weakening of the anticyclone implies the opposite response in rainfall. These periodicities must be clearly reflected in the temporal changes of fire in temperate and tropical regions. Documentation of such temporal trends could provide useful guidance for planning any response to fires.

While much of the early climatological research suggested that climate changes occur gradually over long periods of time, recent research shows sudden discontinuous shifts from one level (of energy) to another (3, 4). Such sudden shifts in climate occurring in time intervals of less than a decade must be taken seriously in any plan to respond to serious fires.

Climate changes occurring on intermediate time scales ranging from annual to about 100 years are becoming increasingly well documented. Tyson (9) has documented a near 18-year periodicity in summertime rainfall which is seen to occur in the subtropics on a global scale. The approximately nine years of below and nine years of above average rainfall can depart from the mean by as much as ± 50 per cent. Such extended dry and wet periods provide a valuable guide to the probability and nature of fire in each period.

Similar periodicities have been suggested for the strong El Niño events (10, 11). While uncertainties exist on whether and what periodic functions may exist during the strong El Niño events, observational systems (particularly remotely sensed sea surface temperatures) provide excellent day-to-day documentation of the temperature fields and their temporal and spatial changes across the tropical Pacific Ocean. These data provide the basis for predicting potential fire conditions months in advance. Such guidance should clearly be incorporated as part of the overall response plan.

Droughts which last for periods of less than one season can have substantial influence on the occurrence of fire. Failure of the onset of rains in a region with strong seasonal cycles trigger outbreaks of fire. Failure of the onset of the summer rains in monsoon regions brings the risk of fire and crop failures. Regions of the globe and times of the year of well-known increased fire risks can be systematically documented. In cases of lack of rain, conditions which amplify the risks of serious fire include:

- vegetation is already dry;
- precursor cloud convection is frequently accompanied by severe lightning;
- clear (cloudless) skies and low moisture content enhance nocturnal inversions and the occurrence of strong low level nocturnal winds; and
- inversions in the atmosphere are strong, widespread and persistent.

Particulate matter transport models

The transport of particulate matter as well as trace gases produced by a fire is a highly scale-dependent phenomenon. The antecedent conditions prior to the fire and potentially surrounding the fire after onset are governed by large and synoptic scale atmospheric conditions. These conditions not only influence rainfall, but control the three-dimensional velocity fields and the thermodynamic structure of the atmosphere. The existence or absence of vertical shear of the horizontal wind and the presence, intensity, height, and thickness of temperature inversions influence where and in what concentrations fire products will be transported.

Interactions of intense turbulent and convective circulations created by the fire with the surrounding atmospheric environment will ultimately dictate the transport patterns of a range of particle sizes. Large particles (> 100 µm) will be elevated by the fire into the lower atmosphere. Transport away from the fire will depend not only on the velocity and thermodynamic fields of the atmosphere but also on the time of day or night. In the presence of nocturnal jets with speeds in excess of 20 m s^{-1} at altitudes of 500 m or less, particles of considerable size will be transported away from the fire. Similarly, plumes of smaller particles can be transported up to 1000 km during a 10-hour night in the presence of a nocturnal jet of 25 m s^{-1}.

Vertical velocities within the fire can range between 20 and 40 m s^{-1}. A 20 m s^{-1} upward velocity operating over 10 min will elevate material to 12 km. While a number of factors such as dilution by entertainment of air outside of the active fire plume into the plume will dilute and reduce such upward transports, considerable uncertainty exists as to the mean or modal height to which most of the fire products will be transported. Knowledge of what this height is, is critical to determining where the fire plume will go. The uncertainties are such that the best approach is to choose a range of

heights above the fire and to calculate forward trajectories. Based upon those heights, a comparison between the trajectories and the observed (satellite) smoke plume will provide an indication of the height of the core transport.

Long-range, large-scale transports

Calculation of long-range, large-scale transports from a fire depend upon knowledge of the properties of the surrounding atmosphere. In many locations where serious fires occur, information on the structure of the atmosphere is likely to be lacking.

From the above discussion, it is recommended that the general structure (wind and thermodynamic fields) be characterized according to the dominant synoptic systems of the region [see Tyson et al (12); Garstang et al (13, 14) for the procedures]. Such models of the dominant synoptic systems will provide generalized information on the horizontal velocity fields as a function of height and the vertical thermodynamic structure (presence of inversions) of the atmosphere. Locations (heights) of the dominant inversions should be considered when choosing the heights at which the calculation of forward trajectories should be initiated.

Prototype trajectory calculations prior to and in the absence of fires could be run for fire-prone regions at the times of year when fire hazards are greatest. The "time of year" will dictate the most likely dominant synoptic situation. Choice of such synoptic conditions will provide the framework for trajectory calculations based upon actual meteorological conditions. These prototype trajectories will provide guidance on the most likely transport pathways, average transport velocities, plume heights and sizes, and potential concentration levels of particulate material along the transport pathway. The occurrence and character of inversions present under the archetypical synoptic conditions will be important in determining concentrations and plume heights. Circulation patterns associated with the archetypical synoptic system will govern the degree to which recirculation takes place. Recirculation will influence the concentration, particle size distribution, and elemental composition of the plume.

Kinematic trajectory calculations are recommended over other (isobaric, isotropic, constant absolute vorticity) methods of calculating trajectories (15). The kinematic technique (as do all other methods) depends upon knowledge of the existing meteorological fields. Provision would have to be made to acquire large-scale numerical model generated wind fields,

such as those produced by the European Center for Medium Range Weather Forecasting (ECMWF). Such fields would be required for at least five levels in the atmosphere (875, 850, 700, 500 and 200 hPa) every six hours. A point of origin (geographic coordinates) would be chosen over the fire and forward trajectories at each chosen level would be calculated for as long as the fire presented a hazard. Initial conditions would be chosen some five days before the fire. Trajectories would then be calculated for those five days using the principle of Lagrangian advection. Horizontal (u,v) and vertical (w) wind components at the starting point are used to compute a new downstream location every 15 min. New trajectories would be started at least once per day for every day considered. As time progressed beyond the starting time of five days before the fire, trajectories would be accumulated. Vertical planes normal to the trajectory pathway such as illustrated in Figure 6, should be constructed. The construction of the core transport is based upon a contour enclosing 95 to 98 per cent of all of the trajectories striking a given plane as illustrated in Figure 7.

Once the 95 or 98 per cent transport area has been identified on the x,z planes normal to the trajectory pathway, a volume transport can be calculated by multiplying the area in the plane by the transport velocity. Volume fluxes may be converted to mass fluxes using information available on concentrations in the plume. If successive measurements of concentrations are available along the trajectory pathway then deposition rates can be estimated.

Vertical distribution of the temperature and velocity fields surrounding a fire will govern the degree to which recirculation of fire-generated products will occur. Fire-prone regions and times of occurrence of fires are likely to coincide, dominated by anticyclonic circulation fields in the atmosphere. Semipermanent anticyclones dominate fire-prone regions in the subtropics. Transient but often persistent high pressure systems are typical of dry or drought and fire-prone states in mid-latitude forests. As described above, sinking and warming air characteristic of high pressure systems produces strong, widespread and persistent inversions. Under such conditions, fire products are concentrated in stratified layers and trapped into recirculating gyres which frequently bring fire products back to the vicinity of their origin.

The trajectory methods described above and presented in greater detail in Garstang et al (16) and Tyson et al (17) are capable of keeping track of the recirculated material. The individual trajectories originating at the prescribed

heights above the fire are tracked through each of the vertical planes erected normal to their transport. The spatial and temporal location on the plane (x,y,z,t) of each trajectory strike is noted. Forward trajectory strikes are distinguished from return trajectory strikes (see Figures 6 and 7). The fraction (per cent) of return trajectories is easily determined. An ensemble of trajectories calculated for a given fire over a period of time will allow the percent return flow to be calculated. Extreme pollution events are often characterized by such trapping and recirculation. It is thus, important to determine whether such processes are at work.

Long-range, large-scale trajectory calculations will provide general guidance to the transport of material from the fire providing information on the plume width, plume height, plume level, plume direction, and concentration along the plume. If sufficient observations of concentrations are available, the trajectory calculation will also provide an estimate of deposition. The trajectory calculation will work best under conditions in which atmospheric circulations are persistent or changing only slowly. Clearly, the trajectory calculation depends upon the existence of observations and a model-generated database. The large-scale trajectory calculation will not be reliable under conditions in which marked weather changes are occurring (thunderstorms, squall lines, cyclones, etc.). However, these weather conditions may not be likely in locations where serious fires develop or alternatively, if they occur, the fire will be extinguished. Because the trajectory calculation is based upon large-scale meteorological data, it cannot depict smaller local scale processes. If, for example, because of say marked terrain, local conditions dominate the situation, the above method is not applicable.

Short-range mesoscale transports

Short-range mesoscale transports are dealt with in greater detail elsewhere in this volume. Various transport models such as the HYbrid Single-Particle Langrangian Integrated Trajectory (HYSPLIT) model are available to calculate transport and deposition from point sources such as fires (18, 19). The trajectory model depends upon meteorological fields which are generated from a separate mesoscale model. Choice of the mesoscale model depends upon the location and observational data base surrounding the fire and the local computational facilities available. Models such as the RAMS (20) can be operated in complex terrain with sophisticated inputs including the effects of vegetation. Other mesoscale models are less complex but may not be capable of adequate simulations in complex terrain.

CONCLUSIONS AND RECOMMENDATIONS

The thesis developed in this chapter is that climate and weather play important roles in the initiation, kind and consequences of a fire. To the extent which this hypothesis is true, considerable advantage can be taken of existing global climatological and meteorological knowledge.

It is recommended that

- a hierarchial classification of global fire regimes should be constructed to identify fire-prone regions;
- the classification should follow an atmospheric scale of motion format from the planetary scale to the fire-generated perturbation;
- global rainfall statistics be combined with the atmospheric circulation fields and fire distributions to identify fire-prone regions and times;
- knowledge of periodic behaviour in climate be utilized to identify time periods and locations of heightened fire risk;
- large-scale trajectory analyses be used to describe transport patterns of fire products, plume size, height, and possibly concentrations.

The purpose of the above recommendations is to provide a procedure which anticipates regions and times of high fire risk, has a pre-constructed framework of the meteorological conditions for any location where serious fires occur, and a procedure for determining the large-scale transports associated with any fire that should occur.

Measurements of fires on the ground, in the fire plume, and from remote platforms are essential if an adequate job is to be done on describing the hazard. Support for ground observations is necessary. Coordination with space agencies capable of monitoring fires from satellites must be organized.

Coordination of global meteorological centres is required to ensure that model generated data fields are available when required and that the calculations using these data can be carried out.

Transport models should be clearly identified on two scales: long-range and short-range. The model software should be acquired and tested.

Increasing human populations increase the likelihood of fires and certainly increase the probability of loss of life and property. Problem regions where fire occurrence and population pressures coincide should be identified. One of the most serious outstanding problems is that of adequate measurements of particulates and trace gases in the immediate vicinity of the fire and in the smoke plume. Support for adequate measurement programmes including any emergency strike force will be difficult to come by.

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Figure 1

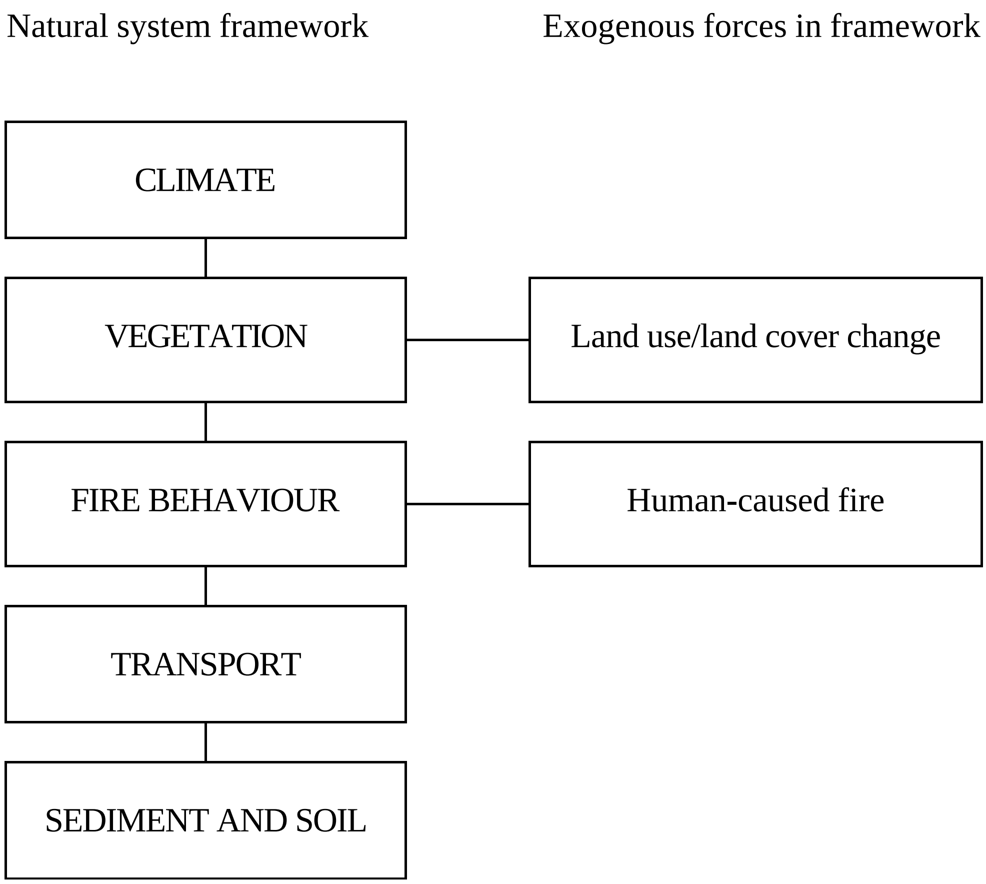

Natural system framework
Exogenous forces in framework
CLIMATE
VEGETATION
Land use/land cover change
FIRE BEHAVIOUR
Human-caused fire
TRANSPORT
SEDIMENT AND SOIL

Figure 2

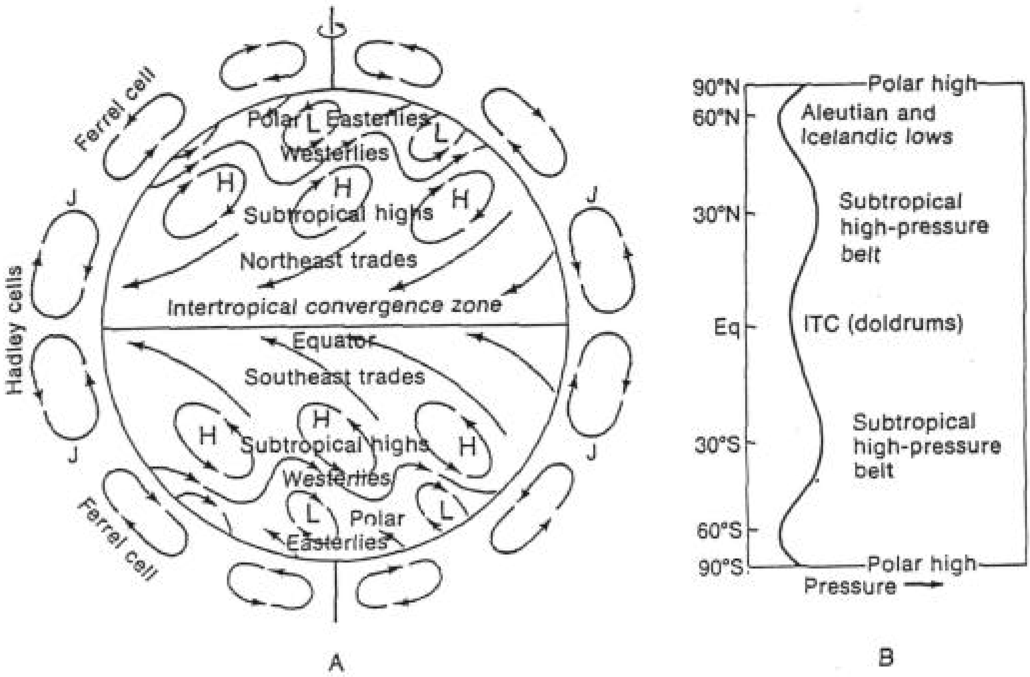

Ferrel cell
Polar Easterlies
L
L
Westerlies
H
H
H
Subtropical highs
J
J
Northeast trades
Intertropical convergence zone
Hadley cells
Equator
Southeast trades
H
H
H
Subtropical highs
J
J
Westerlies
L
L
Polar
Easterlies
Ferrel cell
A
90°N
60°N
30°N
Eq
30°S
60°S
90°S
Polar high
Aleutian and
Icelandic lows
Subtropical
high-pressure
belt
ITC (doldrums)
Subtropical
high-pressure
belt
Polar high
Pressure
B

Figure 3

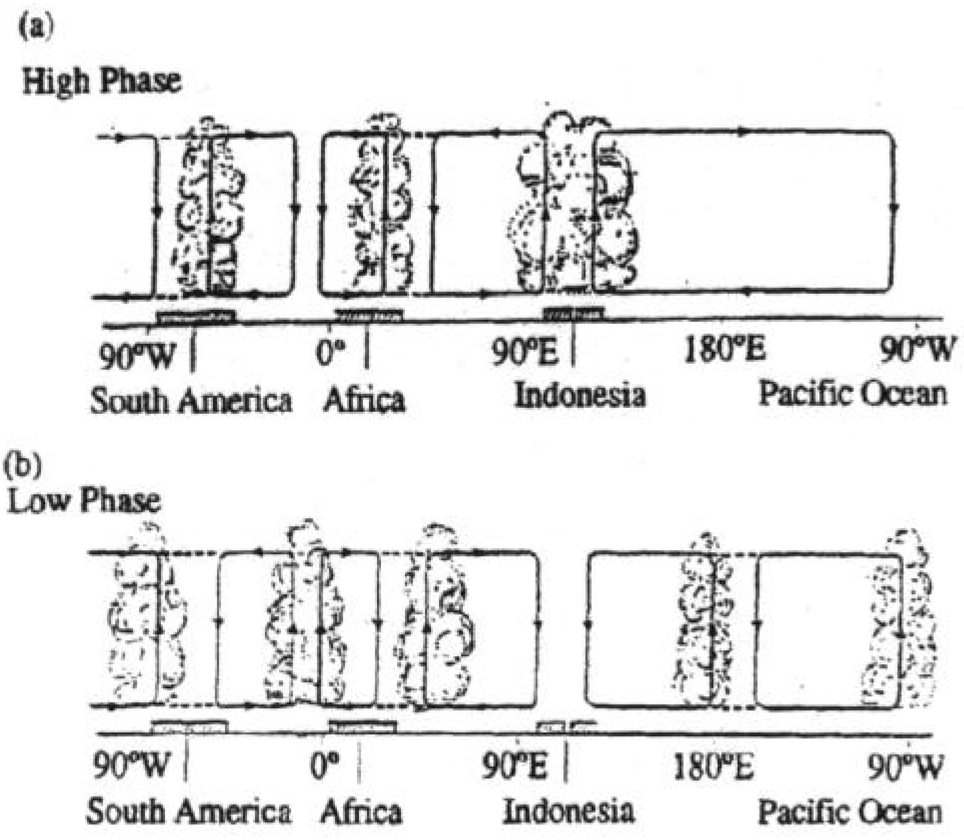

(a)
High Phase
90°W
0°
90°E
180°E
90°W
South America
Africa
Indonesia
Pacific Ocean
(b)
Low Phase
90°W
0°
90°E
180°E
90°W
South America
Africa
Indonesia
Pacific Ocean

Figure 4(a)

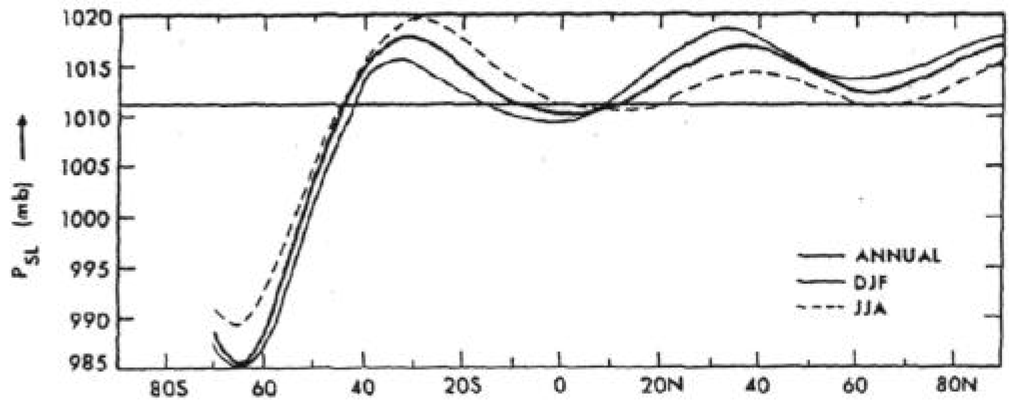


Figure 4(b)

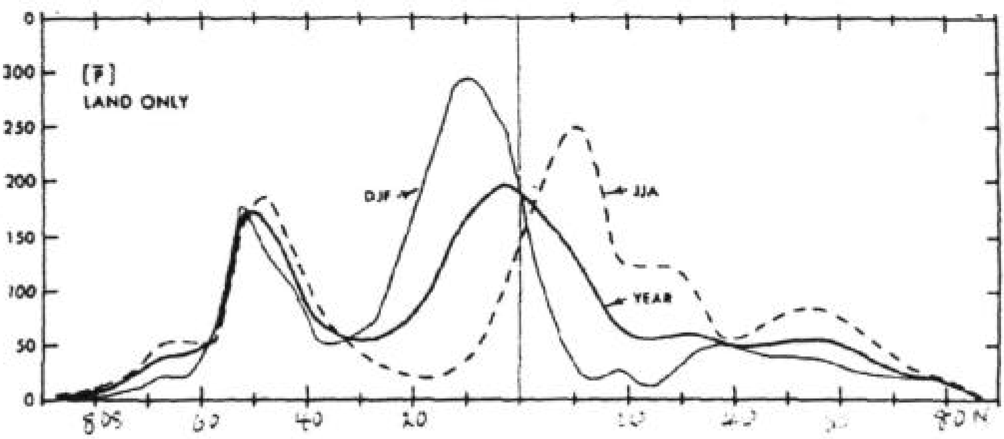


Figure 5

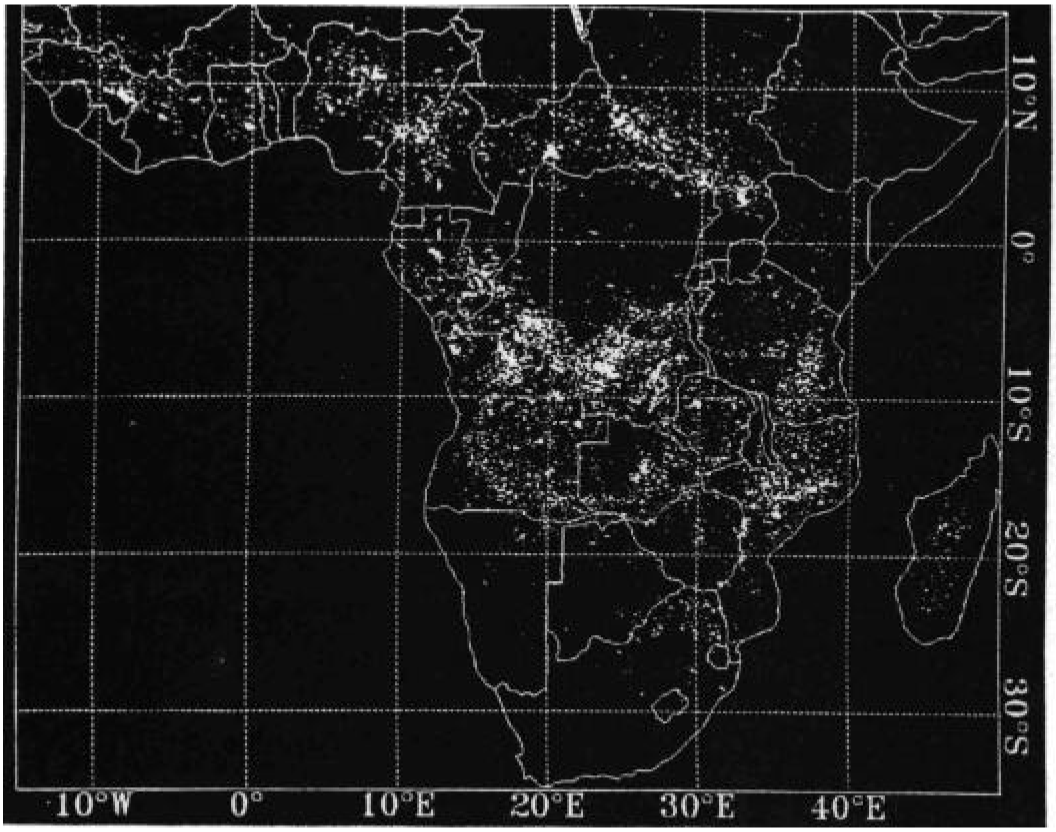


Figure 6

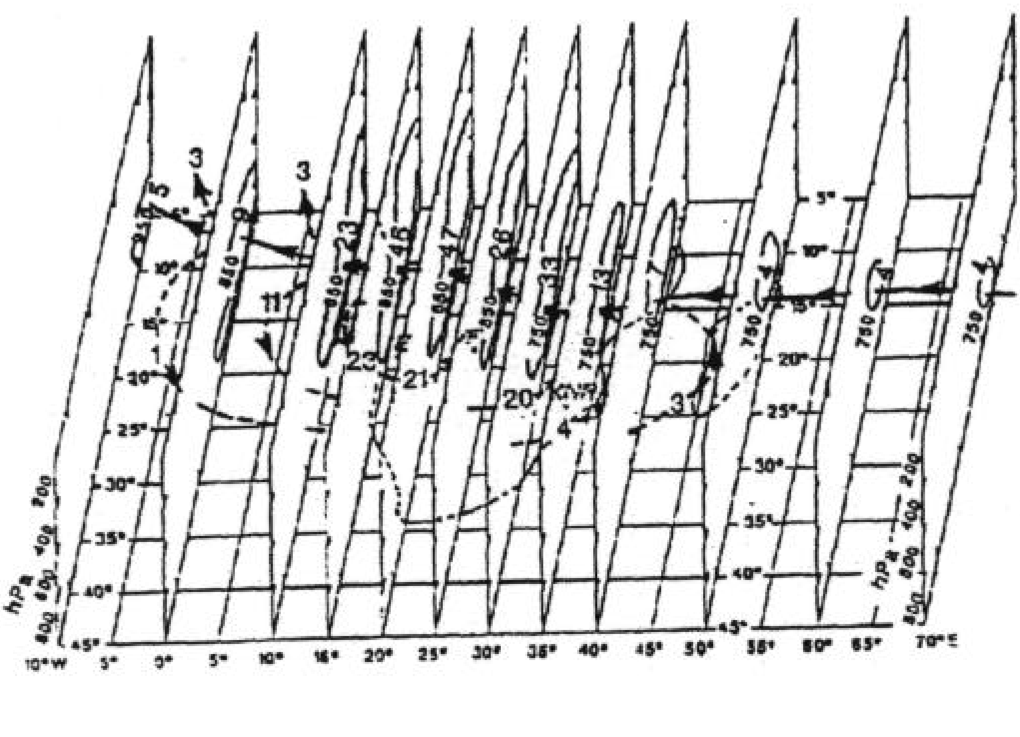
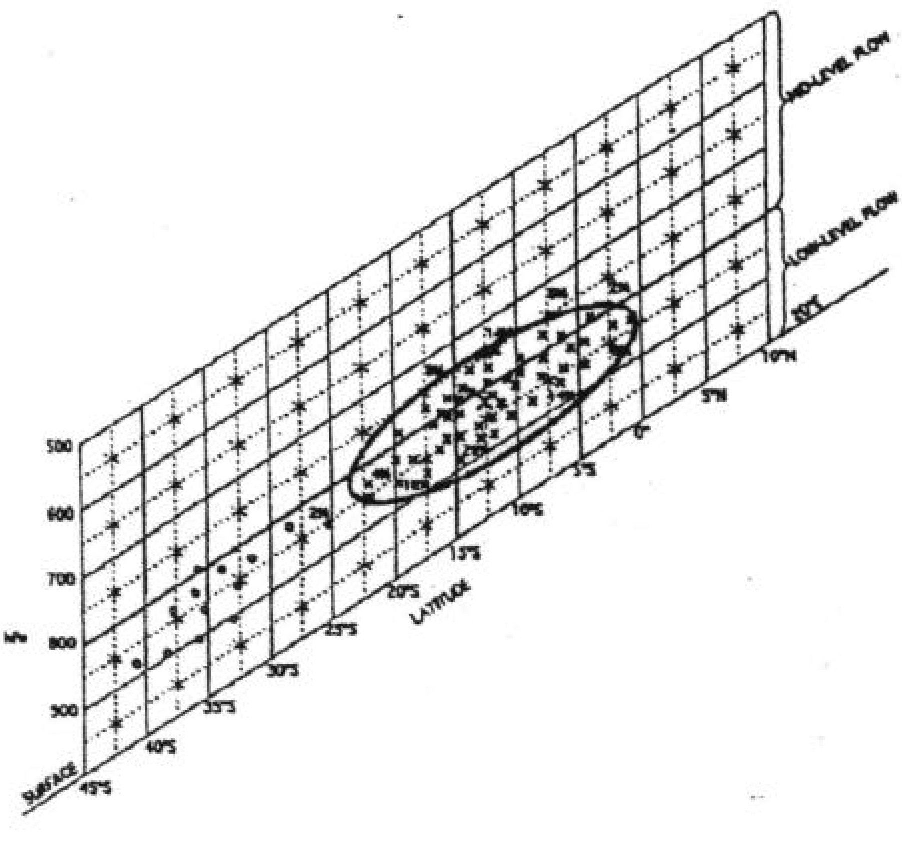


Figure 7


MID-LEVEL FLOW
LOW-LEVEL FLOW
500
600
700
800
900
hPa
SURFACE
45°S
40°S
35°S
30°S
25°S
20°S
15°S
10°S
5°S
0°
5°N
10°N
LATITUDE
FIRE

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

FOREST FIRE EMISSIONS DISPERSION MODELLING FOR EMERGENCY RESPONSE PLANNING: DETERMINATION OF CRITICAL MODEL INPUTS AND PROCESSES

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INTRODUCTION

The last two years have seen many countries in South East Asia, Central and South America severely affected by transboundary smoke haze originating from uncontrolled forest fires, burning mainly in tropical forests severely affected by drought. The magnitude of these events was largely unpredicted and unprecedented, and understandably governments were anxious for advice about health impacts on their populations along with steps that could be taken to mitigate the problems. In the absence of global guidelines for dealing with such emergencies, the WHO is currently faced with the difficult task of developing workable guidelines for dealing with forest fire emissions and their impact on human health and well-being.

Almost certainly, implementation of guidelines relating to health effects of exposure to emissions from biomass burning will involve the use of atmospheric transport models (ATMs) that allow the ability to predict impact areas and pollution concentrations downwind of forest fire source areas. Current ATMs utilising numerical weather prediction (NWP) model outputs have been developed to a high level of sophistication and can be initialised and run at a range of resolutions for any location on the globe. They can be used in the analysis and understanding of past events as well as in forecasting. Many countries affected by regional smoke haze from forest

fires lack meteorological and air quality monitoring and modelling infrastructure. Atmospheric transport modelling based on NWP is clearly the most useful approach to determine the local and regional impacts of forest fires, particularly if the predictions are made readily accessible, most likely through specialized meteorological centres located strategically around the globe.

Since the Chernobyl nuclear accident in 1986, there has been a growing interest in the long-range transport and dispersion of atmospheric pollutants. The International Atomic Energy Agency (IAEA) coordinates the response to nuclear accidents or radiological emergencies. Meteorological support for these environmental emergencies is given through a network of centres of the World Meteorological Organization (WMO), known as Regional Specialized Meteorological Centres (RSMCs). There are now eight centres (Toulouse, France; Bracknell, UK; Montreal, Canada; Washington DC, USA; Melbourne, Australia; Tokyo, Japan; Beijing, China; and Moscow, Russian Federation). Each centre is responsible for the provision of advice in the form of a basic set of products, which includes the prediction of trajectories for releases at specified heights, atmospheric exposure and surface deposition.

Volcanic ash is an environmental problem that is a significant hazard to aircrafts. In a similar fashion to the response for nuclear emergencies, the prediction of the long-range transport and dispersion of volcanic ash is performed at centres coordinated by the International Civil Aviation Organization (ICAO).

Within the next year, all of the RSMCs will be able to respond to an emergency situation located anywhere in the world. In addition to these centres with global or hemispheric capability, there are many more centres that can respond regionally, that is, use limited area meteorological models to provide input data for ATMs, and an even larger number of organisations that possess ATMs. For example, the European Tracer Experiment (ETEX) (1) evaluated 47 models, while in a previous evaluation, 22 ATMs were applied using Chernobyl data (2).

A recent WMO Workshop (3) identified a range of meteorological and other requirements to support the forecasting of smoke and haze that could be divided into long-term and short-term. Long-term forecasts are associated with improved predictions of climate variability, such as that due to the El Niño Southern Oscillation (ENSO). Short-term forecasts are

closely linked to daily and shorter time-scale smoke trajectory and dispersion forecasts. A number of limitations on the short-term forecasting of smoke from ATMs were identified at that meeting; many of these are elaborated later in this paper.

In this paper, we will focus on meteorological and emissions data available during forest fire episodes for input to ATMs, the output of which could be made available to health agencies for emergency response planning and decision making. Although ATMs can handle gaseous emissions, we concentrate here on the particulate matter emitted from forest fires since this apparently provides the greatest environmental and health impacts. It is emissions from tropical forest fires that have been most problematic in recent years.

Nature of current atmospheric transport models (ATMs)

The work of the RSMCs has demonstrated the value of two modelling techniques for planning purposes (4). The first technique is to compute the trajectories of air parcels. A "trajectory" is the path that an air parcel takes as it is transported by the winds. The computation assumes that the three-dimensional wind field is known accurately from NWP models, and that the parcel follows the wind (that it is neutrally buoyant). Earlier work relied on rawinsonde (instrumented balloons providing vertical soundings of atmospheric thermodynamics and winds) data alone, but the accuracy of the computations has been improved by the better temporal and spatial resolution of NWP models. The use of NWP models to provide the data input for ATMs also permits forecasts of trajectories whereas the use of rawinsondes does not. The trajectory technique is conceptually simple and requires only modest computer resources. Trajectories can be run forward in time to determine receptor areas, or backwards in time to determine the pollutant source areas. In general, multiple trajectories are required because of the variability of the wind field (e.g. the presence of vertical wind shear). RSMCs use trajectories released at three heights (500 m, 1500 m and 3000 m) above the source location. In regions of sparse data or atmospheric complexity, the determination of the wind field is uncertain. The spread of the end points of a number of trajectories released under nearly identical (spatial and temporal) initial conditions is a measure of atmospheric predictability. The larger the spread, the less predictable the atmosphere is.

The second technique is to use an ATM. This type of model is based on the conservation of mass for the pollutant. The movement of the pollutant

through the atmosphere as a result of the mean wind field (provided by the NWP model) and turbulent mixing processes (parameterized in the ATM) is balanced by the difference between the emission inputs and pollutant losses due to deposition by wet (precipitation) and dry processes (also parameterized in the ATM). For species other than smoke, losses could also include radioactive decay or change of chemical species.

There are two main modelling approaches used in ATMs; Lagrangian models that follow the trajectories of segments, puffs or particles and Eulerian models which solve the diffusion equation at every point on a fixed grid. In Lagrangian models, the dispersion is accomplished by Gaussian (or an equivalent probability function) diffusion for segments and puffs and by Monte Carlo (Langevin-Markov) techniques for particles. For Eulerian models, the dispersion is usually performed by first order turbulent closure (transfer down the gradient), but higher-order turbulent closures could be used.

For long-range transport, both the Lagrangian and Eulerian modelling techniques provide similar results. The accuracy of the predictions is highly dependent on the NWP model input, particularly the moist convection and precipitation fields, atmospheric stability (the intensity of turbulent mixing depends on this quantity), the boundary-layer height (the value of this quantity reflects the spatial distribution of turbulent mixing), and surface roughness and topographical influences. Improving the NWP model data input, initialization and physical parameterizations improve these factors. In addition, the transport model requires good knowledge of the area of emissions, the amount of material released, the initial height over which the release occurs, and the equivalent particle size. For more sophisticated modelling, knowledge of the emissions of a spectrum of particle sizes would be required as well as information about coagulation and other physical processes affecting deposition processes in complex ways.

For emergency applications, ATMs are run off-line. For daily predictions of events which have emissions over a long period of time, such as the fires in SE Asia in 1997 and 1998, the ATMs may need to spun-up for initialization. Questions of what spin-up time to use for the initialization of the ATM and what averaging time to use can only be determined empirically through model calibration and verification.

The use of limited area NWP models (LAMs) allows increases in the model resolution of wind field. In general, meteorological centres possess a suite of models of different domain sizes and resolutions. Increased model resolution input data for ATMs can produce better results, provided that the frequency of input data is increased as well as its spatial resolution. For very high-resolution NWP models, the physics of ATM turbulent mixing processes change as the atmosphere goes from being quasi two-dimensional in nature to three-dimensional. Also, the treatment of the rainfall changes from being parameterized at larger spatial scales, to being explicit at smaller spatial scales. A third change in moving to higher horizontal resolution is that the LAM must then account for vertical accelerations and become non-hydrostatic.

Verification of the general smoke pattern predicted by ATMs can be performed using satellite and aircraft data. This is sufficient for relative (qualitative) modelling. However, for health applications, quantitative modelling may be needed. In this case, determination of emission rates as a function of particle size, emission area, height extent and measurements of airborne concentrations and surface depositions need to be performed, in addition to smoke patterns derived from satellite measurements, in order to initialize, calibrate and verify the model. Typical forest fire smoke deposition velocities should also be determined experimentally.

Meteorological inputs for ATMs

The input necessary to drive ATMs comes from NWP models. These data are available on grids at regular temporal intervals in the form of direct-access, fixed-length records, one record per variable per level. Some pre-processing of the data is required. The data usually arrive in a compressed form and must be unpacked. The map projection and the vertical coordinate systems of the ATM and the NWP models often differ and interpolation to the ATMs coordinates may be required.

The basic fields required are the wind components (u, v, w) (although the vertical velocity could be derived from the continuity equation if it was missing, for example if rawinsonde data were used instead of NWP data), temperature, height or pressure, and the surface pressure. For smoke applications, it is also necessary to have the moisture and rainfall fields to be able to compute the wet deposition. Other fields that are desirable, but not essential, are the surface fluxes of momentum, heat and moisture.

Additional information is required to initialize the ATM. The starting time, run duration time, number and location of sources, height of emissions, emission rate, hours of emission, averaging interval, and the diameter, density and shape factor of the particles or their deposition velocity are all required. For applications other than smoke, a number of other quantities may also need to be specified.

NWP models rely on data from a variety of sources, including the synoptic surface network (wind, temperature, humidity, pressure, precipitation), the ship surface network, pilot balloons, rawinsondes, dropsondes, buoys, pilot reports (AIREP), wind and temperature profilers, automatic sensing of winds and temperatures from commercial aircraft (ACDAR, ASDAR, AMDAR), satellite-derived temperatures (SATEM, TOVS), moisture (HUMSAT), cloud-drift winds (SATOB), scatterometer winds (ERS-2) and sea surface temperatures (SATOB-SST).

A data assimilation and analysis procedure is then employed which accounts for the raw observations, their reliability (instrument error) and representativeness and the state of the atmosphere (all the atmospheric variables must be mutually compatible and must satisfy certain balance conditions). The data are then analyzed onto a regular spatial grid at fixed times. Even with all of these sources of data, there are still regions of the atmosphere that are sparsely covered, such as at the equator. The introduction of pseudo-observations (PAOBS) and tropical cyclone bogussing offers some help here.

The RSMCs, outside the South East Asia - Western Pacific region, have the following suite of models that could be used to drive ATMs (1, 5, 6). It should be noted that:

1. Model resolution is not a static quantity; Centres will increase their model resolution as computer resources improve.

2. Specification of the resolution for spectral models is ambiguous. We have used a linear grid estimate and have given the equatorial resolution for the non-stretched global spectral models.

Canada:
Global, 21-level, T199 spectral model (resolution about 0.90 degrees, or about 100 km); LAM, 28-level, variable resolution, uniform resolution of 0.33 degree (or about 35 km) over North America and adjacent oceans; ATM (7), Eulerian model, 11-levels, 150 km, 50 km and 25 km resolution options.

China:
Global, 19-level, T106 spectral model (resolution about 1.7 degrees, or about 189 km); LAM, 19-level, 1 degree model (resolution about 91 km); ATM, details not available.

France:
Global, 3-10 day forecasts, 31-level, T213 spectral model (resolution about 0.84 degrees, or about 93 km); Global, 0-96 hour forecasts, 27-level, variable resolution, T521.5 spectral model over France (about 20 km), T42.5 over New Zealand (about 250 km); LAM, 27-level, E66 model (resolution about 10 km); ATM (8), Eulerian model, 15-levels, 0.5 degrees (resolution about 40 km).

Japan:
Global, 30-level, T213 spectral model (resolution about 0.84 degrees, or about 93 km); LAM, 36-level, 20 km resolution; ATM (6), Lagrangian particle model, resolution about 0.84 degrees, or about 93 km.

Russian Federation:
Hemispheric, 15-level, T40 spectral model (resolution about 4.5 degrees, or about 350 km); LAM, 11-level, 50 km resolution; ATM, details not available.

United Kingdom:
Global, 19-level, 0.83 degrees latitude and 1.25 degrees longitude or about 111 km; LAM, 19-level, 0.44 degrees (resolution about 31 km); LAM, 31-level, 0.15 degrees (resolution about 11 km); ATM (9), Lagrangian particle model, variable resolution.

United States:
Global, 28-level, T126 spectral model (resolution about 1.43 degrees, or about 159 km); Global, 42-level, T170 spectral model (resolution about 1.06 degrees, or about 117 km); LAM, 38-level, 48 km resolution; LAM, 50-level, 29 km resolution; ATM (10), hybrid Eulerian-Lagrangian model using particles and puffs, variable resolution. (This model can be run via the internet: http://www.arl.noaa.gov/ready/ hysplit4.html)

Australia

The Australian modelling suite is illustrated in Figure 1. The NWP models available include the global model (GASP), which is a 19-level, T79 spectral model (resolution of about 2.25 degrees, or about 250 km at the equator); the tropical limited area model (TLAPS) which is a 19-level finite difference model with resolution of 0.75 degrees, or about 83 km at the equator; the mid-latitude limited area model (LAPS) which is a 19-level finite difference model with resolution of 0.75 degrees, or about 83 km at the equator; and mesoscale limited areas models (meso-LAPS) which are 19-level, finite difference models with a resolution of 0.25 degrees, or about 25 km.

Because of increased computer resources from October 1998, the resolution of all of the above models will be increased substantially. GASP will become 29 levels, T239 (resolution about 0.75 degrees, or about 83 km at the equator); TLAPS and LAPS, 29 levels, 0.375 degrees (resolution about 42 km at the equator); and meso-LAPS, 29 levels, 0.125 degrees (resolution about 12 km). The domain of meso-LAPS will be expanded to include all of Australia in a single forecast (55 S - 0 S latitude, 90 E - 170 E longitude).
The ATM used in the Melbourne RSMC is a hybrid Eulerian-Lagrangian model which uses puffs in the horizontal and particles in the vertical, and it can be driven by any of the operational models described above (9). The

resolution of the output concentration grid can be varied to suit the application.

In addition to the RSMCs, a number of other countries possess global meteorological models or LAMs. Some of these include:

The common ECMWF model:
Global, 31-levels, T213 spectral model (resolution about 0.84 degrees, or about 93 km)

The common Nordic-Dutch-Irish-Spanish model called HIRLAM:
LAM, 31-levels, 0.5 degrees resolution, or about 50 km

Germany:
Global, 19-level, T106 spectral model (resolution about 1.7 degrees, or about 189 km); LAM, 20-level, 0.5 degree (about 50 km); LAM, 30-level, 0.125 degrees (about 12 km)

Brazil:
Global, 28-level, T62 spectral model (resolution about 2.9 degrees, or about 322 km); LAM, 42-level, 40 km

South Africa:
Global, 28-level, T62 spectral model (resolution about 2.9 degrees, or about 320 km); LAM, 17-level, 80 km

India:
LAM, 16-level, 0.5 degrees (resolution about 50 km)

Republic of Korea:
Global, 21-level, T106 spectral model (resolution about 1.7 degrees, or about 189 km); LAM, 23-level, 40 km resolution

Hong Kong:
LAM, 13-level, 1 degree (resolution about 100 km)

Singapore:
Global, 16-level, T63 spectra model (resolution about 2.8 degrees, or about 312 km); LAM, 12-levels, 127 km resolution; 13-levels, 63.5 km resolution

Emission rate inputs and deposition rates for ATMs

Previous sections of this paper discussed the meteorological inputs for ATMs in some details. To provide reasonable predictions of particulate concentrations for assessment of health impacts, ATMs also require knowledge of the area and location of emissions, the amount of material released, the height of that release, and the equivalent particle size. In addition, for more detailed understanding of health impacts and processes such as settling velocity for deposition calculations, detailed particle size distributions should be obtained. Unfortunately, it is in these areas that the greatest uncertainty in air quality modelling for forest fires occurs.

Since the discovery of the importance of biomass burning, particularly in the tropics, for global atmospheric chemistry (11), there has been a great deal of work done on the nature and impacts of biomass burning in many parts of the world. This is reflected in the very comprehensive review edited by Joel Levine (12). Much of the work has been concerned with characterizing emissions, emission factors, impacts and measurement systems at the global, sub-global (eg. tropics), regional (eg. Amazonia, Southern Africa) and local level. However, there is very little discussion of emission rates from biomass burning in the literature. Our ability to reliably predict ground level particulate concentrations using ATMs running with NWP input is likely to be severely constrained without such information. Whilst it is possible to broadly characterize area emission rates based on published estimates of total emissions over a period of time (for example a season or year) and area burnt, this is likely to be very imprecise. Unfortunately, there are major difficulties in overcoming this because emission rates are hard to characterize, being dependent on many factors including fuel type, climatic conditions and fire intensity (13).

Recently, the NOAA Air Resources Laboratory (ARL) (Web page mentioned above under the United States ATM) has used published data for tropical biomass burning (14,15) to calculate the amount of particulate emitted per hectare of forest burning. This was then used in the HYSPLIT_4 ATM (10) for prediction of particulate concentrations downwind of fires in South East Asia, Mexico and Florida. When the ARL ATM is operated for a

major fire, source locations and areas are updated on a daily basis from satellite imagery. ARL acknowledges the uncertainty of emission rates and calibrate their ATM predictions of concentrations by balancing their emission rate and their deposition velocity (particle size, density and shape) assumptions to give approximately the same order of magnitude for predicted concentrations as those determined by PM_{10} (sub-10 micron sized particles which are of significance for human health) measurements at 10 m height. They also compare predicted patterns and concentrations to satellite-observed quantities. The quantitative predictions by ARL are the only use of forest fire emission rates in a regional ATM that we know of.

Although local burning experiments (16-18) can provide more precise emission characteristics and rates, such information is of only limited use for atmospheric modellers wishing to predict air quality downwind of a forest fire, anywhere on the globe, in real time. The development of new satellite remote sensing techniques based on improved sensors provides probably the best possibilities for developing real time estimates of particulate emissions. Kaufman et al (19) describe a promising method for estimating the rate of emission of aerosol and trace gases from fires based on the thermal radiation emitted from the fires. It is assumed that the emitted thermal radiation is proportional to the biomass consumed, and hence also to the emission rates of aerosols and trace gases. The method therefore can distinguish between smouldering and flaming fires, processes that are known to have different emission ratios (13).

There is relatively little experimental information available about the time evolution of particles in smoke plumes, including processes such as coagulation and deposition. Hobbs et al (18) provided some results from airborne remote sensing of a prescribed burn in the Pacific Northwest of the USA. Taking HYSPLIT_4 as an example of a state-of-the-art ATM, the dry deposition is determined either by a deposition velocity, or for particles, it may be computed as being the equivalent to the gravitational settling velocity, or it may be computed using the resistance method and information about the surface (10). In the simulation of the South East Asian fires, they used a deposition velocity of 0.004 m/s, typical of a 2.5 micron particle. Wet removal for soluble gases and particles is also defined in HYSPLIT_4, where particle wet removal is defined by a scavenging ratio within the cloud and by an explicit scavenging coefficient below cloud base.

EXAMPLES OF THE USE OF ATMS IN REGIONAL FIRE SITUATIONS

During August-October 1994, significant wildfires burning in Borneo and Sumatra produced heavy smoke haze across much of Borneo and Peninsular Malaysia, including Singapore. Particularly large fires occurred in the area around Pangkalan Bun in Indonesian Kalimantan. Figure 2a shows a composite of daily trajectories (each starting at 00Z) for the period 10 September - 15 October, initialized at 950 hPa (500 m) above Pangkalan Bun. These trajectories show the 3-day forward motion of individual parcels of air, with no attempt to show smoke dispersion or concentration patterns. There appears to be two families of trajectories, with~50 per cent of the total moving northwest over Singapore, Peninsular Malaysia and Sumatra, and the remainder recurving in monsoon flow towards the Philippines. It would appear that smoke entrained above Pangkalan Bun had a significant impact on the observed severely degraded air quality of Singapore, Peninsular Malaysia and Sumatra, although the latter location had forest fires of its own at this time. Equivalent backward trajectories from Singapore (Figure 2b) provide confirmation that the trade wind circulation is bringing smoke-laden air from fire regions, with more than 50 percent of trajectories passing over Kalimantan during their 3-day track.

Plots such as those produced in Figure 2 suggest that monthly or seasonal trajectory climatologies could be of value for risk assessment in regions known to suffer regularly from forest fire smoke (eg. South East Asia, Amazonia), especially if they could be tied to cyclical drought occurrences such as that due to the El Niño Southern Oscillation (20).

In Figure 3, we present a calculation of the transport and dispersion of smoke from the fires burning in Kalimantan, Sumatra, Irian Jaya and Papua New Guinea during October 1997. This figure is intended to show the kind of forecast that can be made when little information about the initialization is known. The emissions rate and the height over which the emission occurred were unknown. The emissions rate was set to unity (thus the resulting concentrations will be relative, not absolute values). The smoke was assumed as being released uniformly from the surface to 1000 m. The sources were located by determining "hot spots" from images of the fires produced by the NOAA-14 satellite. A deposition velocity of 0.001 m/s was used. No spin-up was employed, but instead the concentrations were averaged over 48 hours. The ATM was driven by the LAPS NWP model data.

Figure 4 shows a schematic diagram produced by the Singapore Meteorological Service, resulting from their analysis of the smoke pattern given by NOAA-14. The satellite images differentiate between the smoke and convective (water/ice) clouds to some degree, but often it takes careful analysis by an experienced person to see the smoke pattern clearly. Comparing the patterns given in Figures 3 and 4 shows agreement in the major patterns. This agreement occurs in spite of the fact that the calculations were averaged over 48 hours and the satellite scan was of the order of 20 minutes. The pattern of the surface deposition of smoke particles was similar to that for the airborne concentrations and is not shown.

Another comparison of predicted and observed smoke patterns is shown in Figures 5 and 6. In this case, the model was spun-up for a day as part of the intialization process. An attempt was made to produce absolute, rather than relative predictions. The emission rate/hectare was estimated from Levine (15) and the fire area estimated by NASA from satellite imagery. It was assumed that the smoke was released uniformly between the surface and 500 m. The resulting concentrations were averaged over 6 hours. Again, the airborne concentrations and the surface deposition patterns were similar. This time, we present the surface deposition pattern. The ATM in this case was driven by the US global model data. Particles were assumed to be 2.5 micrometers in diameter to simulate $PM_{2.5}$, and Stokian gravitational settling was computed. The predicted smoke concentration at 10 m over Kalimantan was several hundred micrograms per cubic metre. We also show the aerosol index determined by TOMS in Figure 7. The predictions give reasonable agreement with the limited observations that were available to us. The relatively minor differences shown are an artifact of the difference between times of prediction and observation, as well as averaging period differences.

Our last example relates to situations where there is controlled burning to reduce fuel loading. The Australian Bureau of Meteorology provides forecasts twice a day for 18 prescribed sites in Western Australia. The fire authority responsible for the burning wants to avoid smoke impacting on populated areas. In Figure 8, we show the example of the 18 trajectories initiated at 0300 UTC on 10 November 1997. Note in the upper left-hand panel that two trajectories almost coincide, but one continues on to the northwest and the other curves around towards the city of Perth. There is a time difference when their geographical positions coincide that leads to the later divergence of the trajectories. Comparing the two trajectories near the centre of the upper right-hand side and the lower right-hand side panels, it is observed that although they start at nearly the same place, one travels over the

city and the other to the west of the city. In the upper two panels, it is seen that those trajectories that start north of the city travel eastward while all of the others travel north or northwestward. These samples illustrate the non-linearity and chaotic nature of atmospheric flow.

CONCLUSION

In this paper, we have reviewed the current status of ATMs suitable for regional scale modelling and prediction of particulate pollution arising from large-scale forest fire events. We believe that through the RSMCs and the ICAO volcanic ash centres, there currently exists a global infrastructure capable of undertaking smoke modelling in real time, and these centres should be an initial focus of WHO’s effort in this area. Additional modelling capabilities and experience exist in various regional centres, for example in Brazil, South Africa and Singapore. Whilst there is always room for improvement, current ATMs utilizing NWP inputs are well advanced in terms of their meteorology. However, the required level of information on emission rates from forest fires (in particular) and smoke deposition rates for input to the ATMs is lacking. This is an area that must be quickly addressed if a global capability to issue forest fire smoke predictions, which give suitable guidance to health authorities and emergency management planners, is to be rapidly achieved.

We recommend that WHO and ICAO collaborate with WMO to coordinate the modelling effort to forecast the extent and concentrations of smoke from large-scale fires likely to last for periods of several weeks. This would include satellite measurements, surface and aircraft monitoring, in addition to the modelling, in order to be able to initialize, calibrate and verify the models. In South East Asia, the programme to address ASEAN Regional Trans-boundary Smoke (PARTS) under the auspices of WMO is already beginning to develop an integrated approach. It would be helpful if a data set suitable for initialization, calibration and verification of models were collected and made available to the modelling community. Preliminary efforts to develop such a data set have begun [through the WMO Commission for Atmospheric Science (CAS)], but financial support is now required. In their meeting early in 1998, CAS emphasised the importance of the coordinating role of WMO in emergency response activities.

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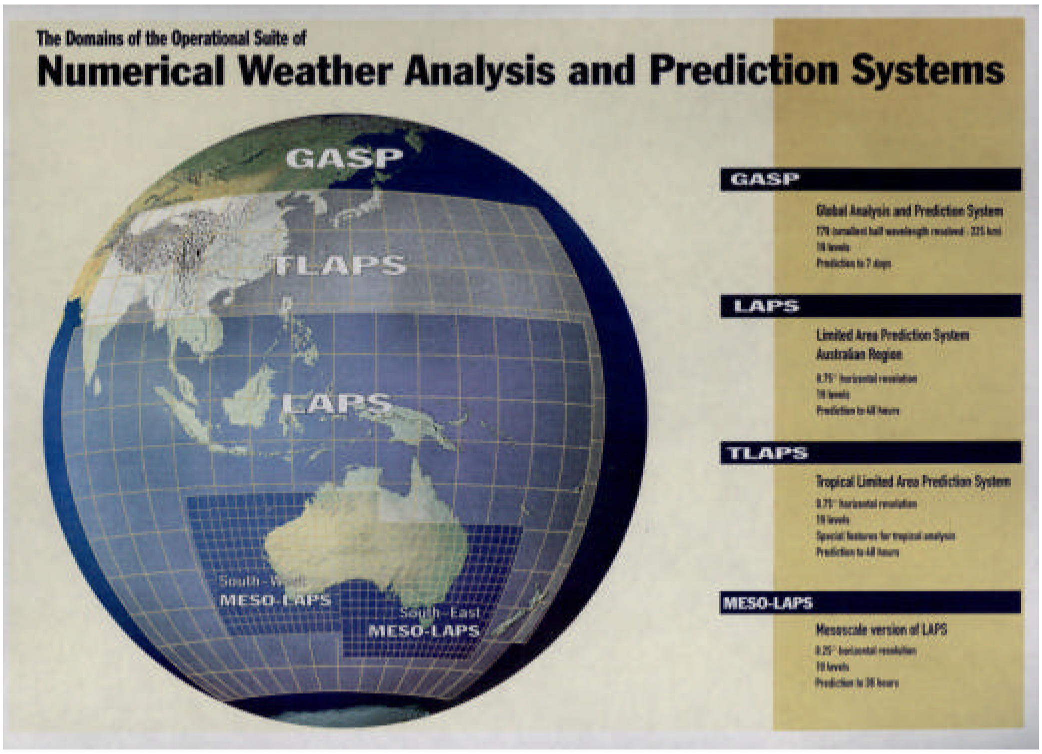

Figure 1. Australian Bureau of Meteorology Numerical Meteorological Products (NWP), September 1998

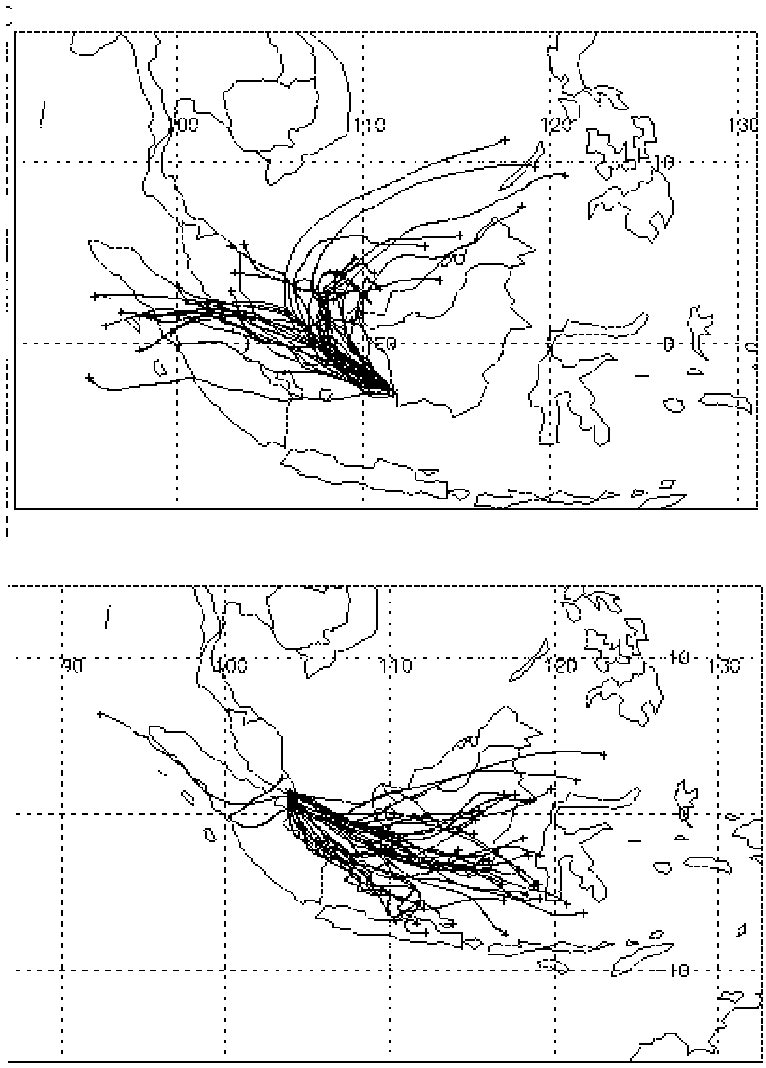

Figure 2. Daily trajectories for the period 10 September-15 October 1994. (a) A composite of 3-day forward trajectories, startingat 950 hPa (500m) Above Pangkalan Bun, Kalimantan. (b) A composite of 3-day backward Trajectories ending at 950 hPa (500m) above Singapore. HYSPLIT_3 Trajectory dispersion model running on Bureau of Meterology TAPS data (20).

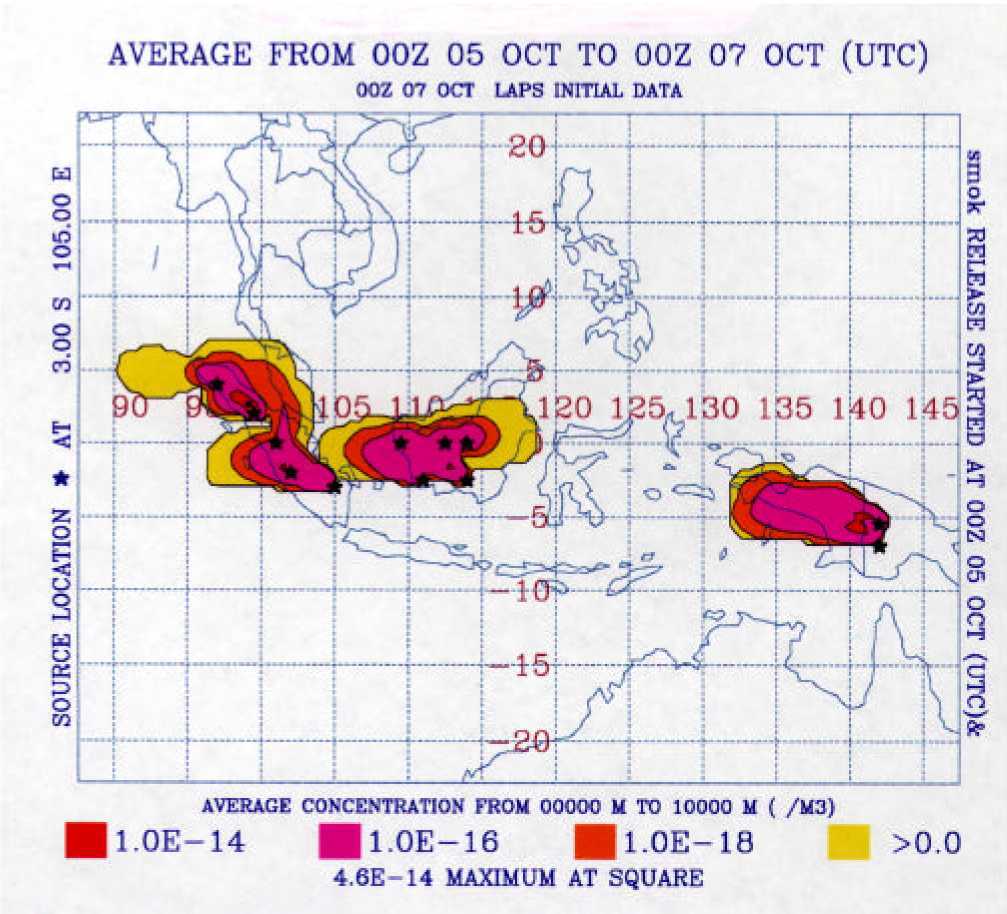

Figure 3. The relative particulate concentrations over South East Asia, 5-7 October 1997. An example of forecasts able to be made with little initialization information. Bureau of Meteorology LAPS data, HYSPLIT_4 trajectory dispersion model.

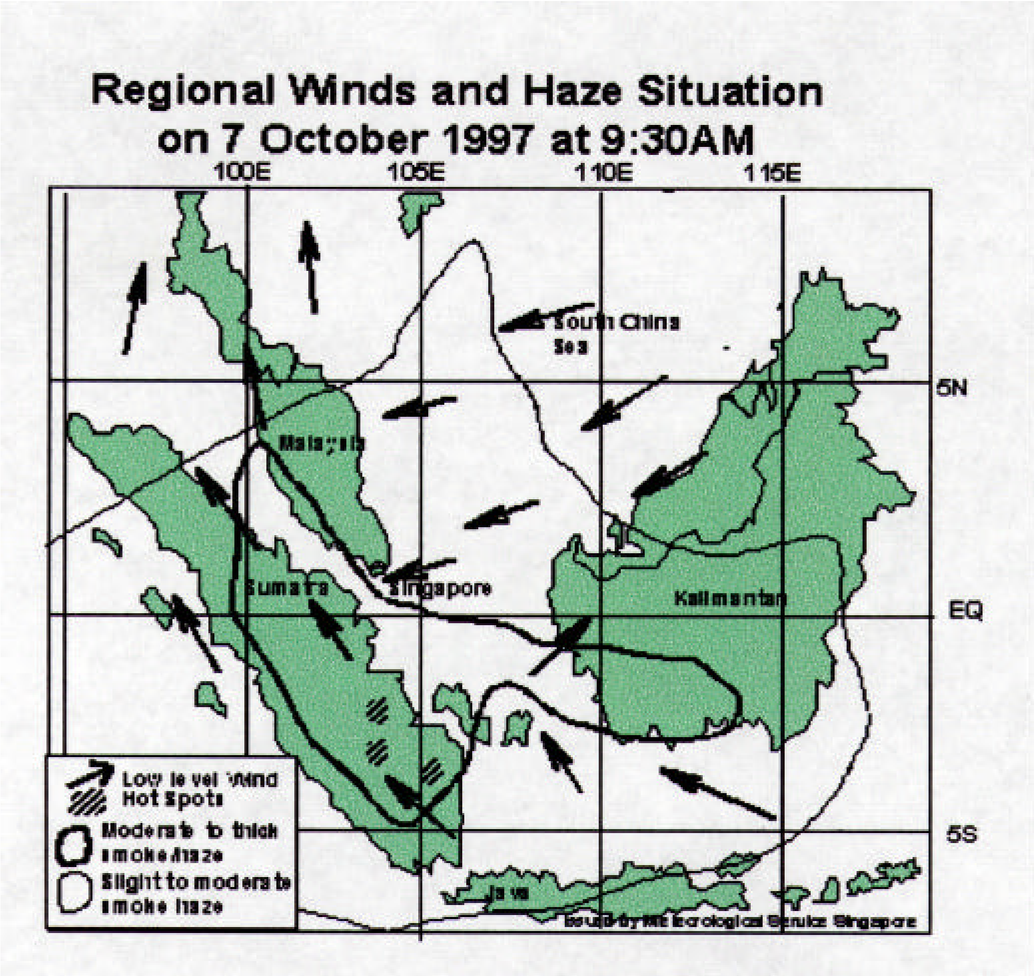

Figure 4. Schematic diagram showing the distribution of smoke haze, 7 October 1997. Diagram produced by courtesy of the Meteorological Service, Singapore.

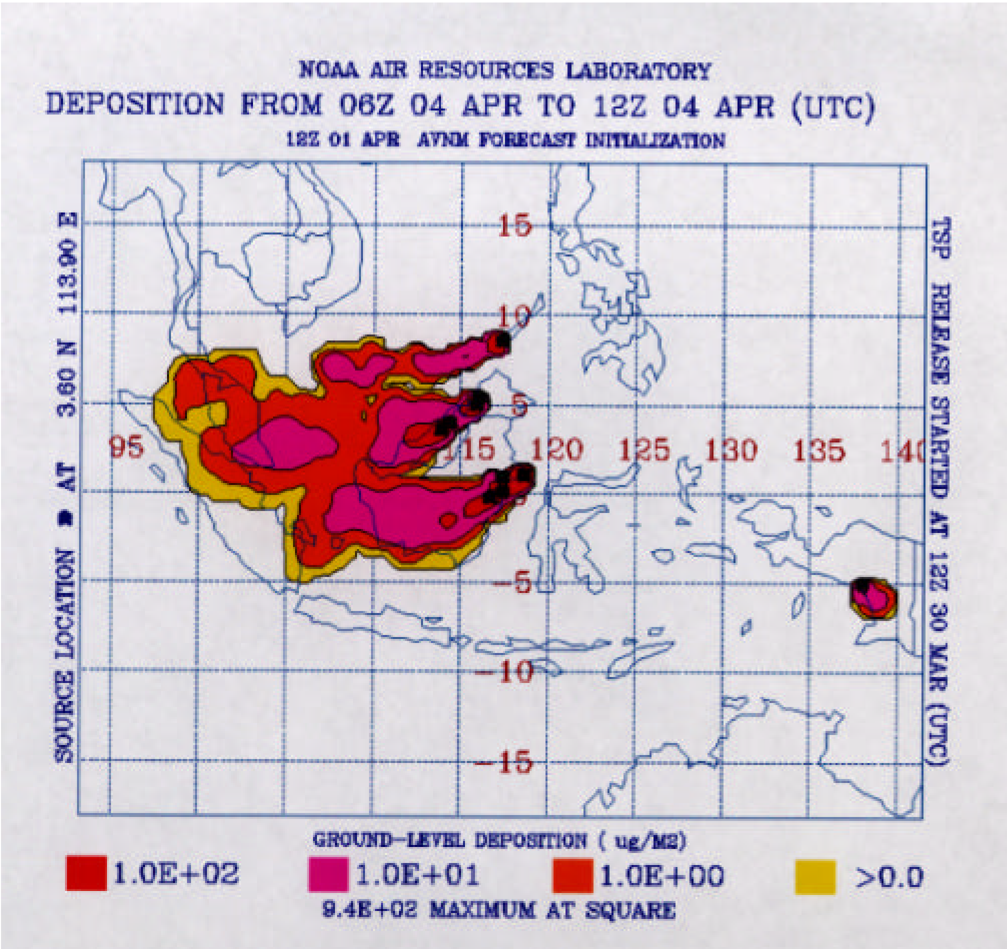

Figure 5. Ground-level particulate deposition over South East Asia, April 1998. US global model data; HYSPLIT_4 trajectory dispersion model; emission rates from Levine (15). Diagram produced by courtesy of NOAA Air Resources Laboratory.

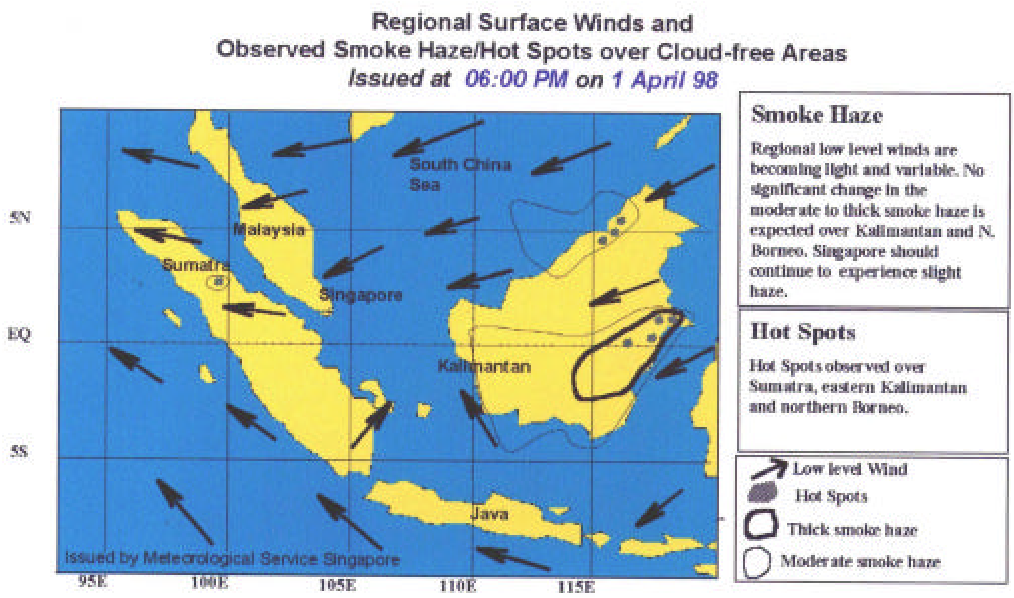

Figure 6. Schematic distribution of smoke haze over South East Asia, 1 April 1998. Diagram produced by courtesy of the Meteorological Service, Singapore.

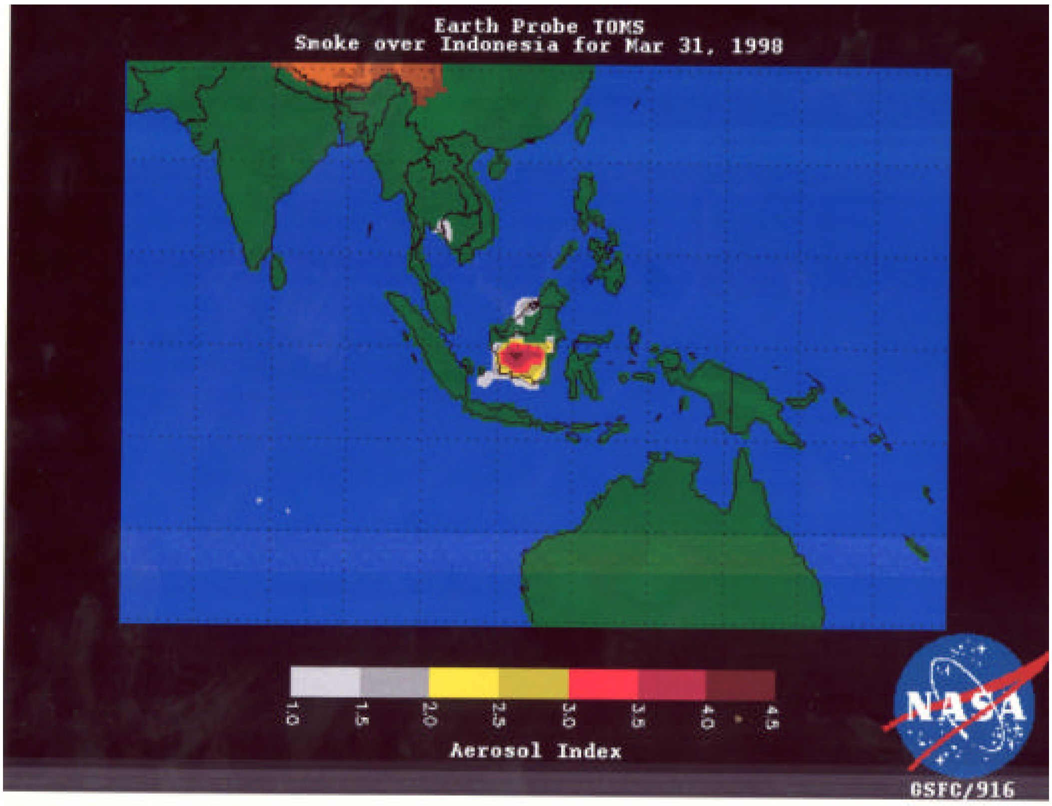

Figure 7. Atmospheric aerosol index over South East Asia, 31 March 1998, produced by TOMS satellite. Diagram produced by courtesy of NASA.

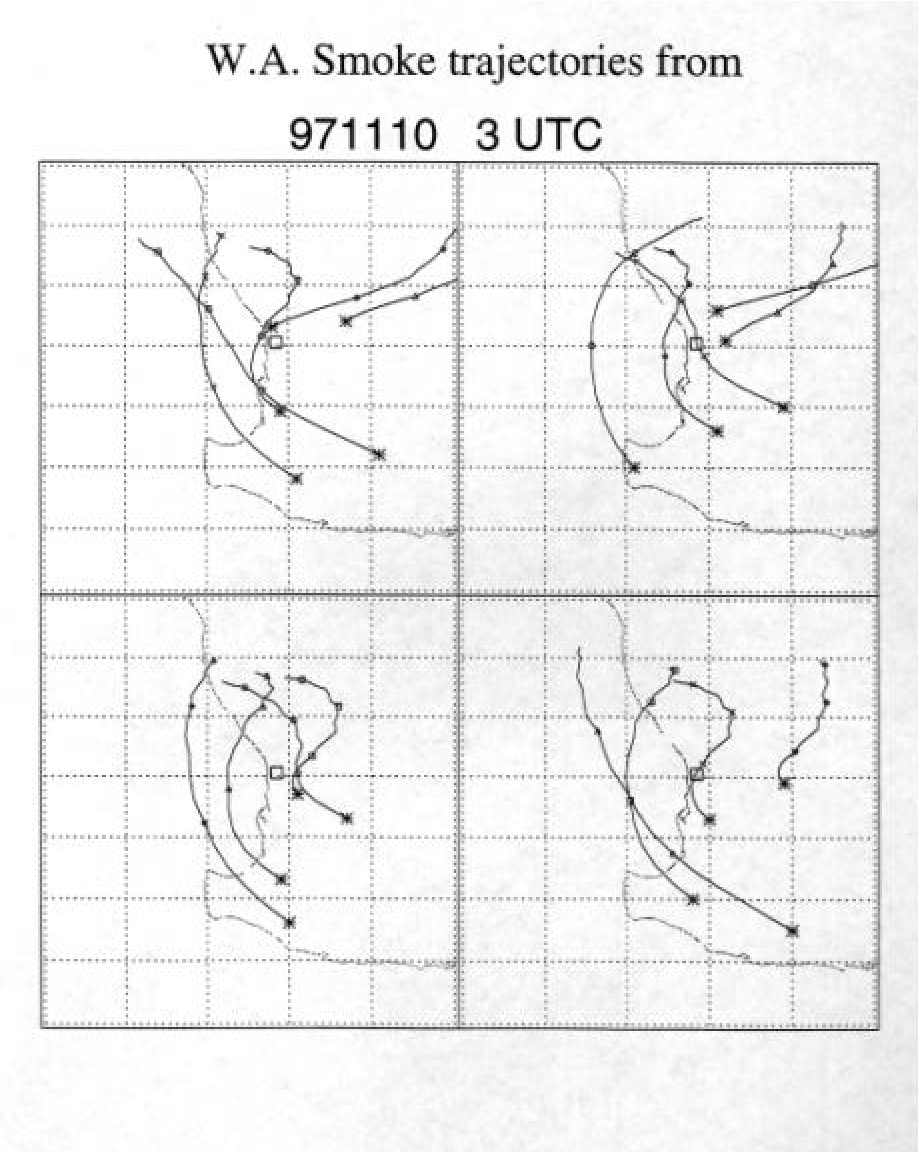

Figure 8. Smoke management using trajectory modelling. Eighteen smoke trajectories initiated at 0300 UTC, 10 November 1997. The small square near the centre of the panels indicates the city of Perth, the asterisks are the starting locations and the other symbols are 6-hourly time markers. The large squares are 1 degree by 1 degree.

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

APPROACHES TO MONITORING OF AIR POLLUTANTS AND EVALUATION OF HEALTH IMPACTS PRODUCED BY BIOMASS BURNING

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INTRODUCTION

Biomass burning is a persistent activity occurring throughout the world. Biomass burning refers to the burning of live or recently living vegetation to clear land for agriculture, plantations, and resettlement; for the disposal of agricultural and domestic refuse; and as fuel for cooking and heating. Intense forest fires can also ignite subsurface organic soil components (e.g., peat), which can continue to smoulder long after the original surface fires are out. In many instances, biomass fires can result in human exposure to high levels of various air pollutants. Among the air pollutants (or their precursors) emitted from biomass fires that are often of most concern for general population exposures are certain widespread pollutants, e.g., particulate matter (PM), sulfur oxides (SO_x), carbon monoxide (CO), etc., typically found in urban air mixes, as well as a variety of other toxic metals and volatile and semi-volatile organic compounds (VOCs).

In general, comprehensive approaches intended to be standardized for use in dealing with potential risks to public health of emissions from biomass fires should include: (a) characterization of the magnitude and composition of the emissions and their transformations during transport; (b) quantification of resulting concentrations of toxic air pollutants in ambient air in populated areas; (c) evaluation of likely exposure scenarios for affected populations (both indoors and outdoors); and (d) assessment of consequent health risks posed by such human exposures.

This paper first highlights, briefly, certain key types of health-related information that can be useful in evaluating the potential health impacts of air pollution resulting from biomass fires. It also provides an overview of general air monitoring approaches and preferred methods for monitoring ambient concentrations of selected key air pollutants useful in evaluating the effects of biomass fire emissions. Lastly, the methods employed and results from a specific monitoring study designed to support assessments of health risks caused by exposure to high air pollutant levels in areas affected by biomass burning emissions (specifically in SE Asia) are also discussed as a case study. This study, carried out in Indonesia and Malaysia during the haze event of 1997 (1), focused mainly on measuring PM_{10} and $PM_{2.5}$ concentrations, and on characterizing the chemical composition of the aerosol. The emphasis on measuring PM components arose because PM levels were by far the most elevated compared to US values and the highest air pollutant alert system values were obtained for PM_{10}, compared to the other pollutants that were measured simultaneously with PM_{10}. Levels of air pollutants in US cities are also presented as part of the case study to give an idea of what typical levels of these pollutants in urban areas are with pollution control measures in place. These data can also be used as background values in estimates of health risks posed by exposure to aerosol components.

This paper does not address issues related to the atmospheric chemistry or transformations of biomass burning emissions, nor on the use of remote methods (e.g., satellite imagery) for monitoring the spread of biomass burning plumes (i.e., as given in item (a) above). These issues will be covered in other reviews. Methods for characterizing total human exposure to biomass burning products and to other pollutants (i.e., as given in item (c) above) in indoor and outdoor environments will also not be covered. However, it should be noted that significant exposures to biomass burning products occur in indoor environments in developing countries where wood and other biomass fuels are burned for cooking and heating in an inefficient manner (2). Thus, fully comprehensive evaluations of total human exposures would also need to consider exposure to indoor sources.

APPROACHES FOR EVALUATION OF POTENTIAL HEALTH IMPACTS

Probably of most use, currently, in evaluating potential health impacts of air pollution derived from biomass fires is the comparison of monitored ambient air concentrations of toxic pollutants against already established pertinent air standards or guidelines and associated air pollution alert system levels, e.g., the US National Ambient Air Quality Standards (NAAQS) and the associated Pollutant Standard Index (PSI) alert system, and/or World Health Organization (WHO) Air Quality Guidelines.

Concern about health and welfare effects of exposure to ambient air pollution levels led to the passing in 1970 of the US Clean Air Act to control the levels of ambient air pollutants in the United States. The Clean Air Act, which was last amended in 1990, requires the US Environmental Protection Agency to set NAAQS for widespread ambient air pollutants considered harmful to public health and the environment. The Clean Air Act established two types of NAAQS. Primary standards set limits to protect public health, including the health of sensitive subgroups of the general population such as the asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against visibility degradation, and damage to aquatic and terrestrial ecosystems, agricultural crops, vegetation, and buildings. The current NAAQS for the various "criteria" pollutants are shown in Table 1. The US Pollutant Standard Index (PSI) alert system has been developed as a way to provide accurate, timely, and easily understandable information to the public about the general health effects associated with different pollution levels, and to describe the precautionary steps that need to be taken if air pollutant levels rise into the unhealthful range. The correspondence between pollutant concentrations, the NAAQS and PSI values is shown in Table 2. It should be noted that the PSI value that is reported does not include the combined effects of different pollutants; instead the highest individual PSI value and the responsible pollutant involved are reported.

Markedly elevated particulate matter (PM) levels are one common feature of air pollution resulting from biomass fires and, hence, the typical need arises to emphasize evaluation of potential PM-related health impacts as a key part of any assessment of public health risks associated with any given biomass fire situation. By far, the bulk of information concerning health effects resulting from exposure to PM air pollution has been collected in urban areas in Europe and North America. Severe air pollution episodes

involving high PM concentrations, e.g., those that occurred in the Meuse Valley, Belgium; Donora, Pennsylvania; and London, England (among others), have been found to contribute to notable increases in mortality and morbidity. The most notable episode in this regard occurred in London from December 5 to 8, 1952 in which some 4000 excess deaths were recorded. During this episode, peak citywide 24-h particle concentration (measured as "British smoke") was 1.6 mg/m^3, and the mean citywide daily smoke level was approximately 1.0 mg/m^3. The mean citywide sulfur dioxide concentration was also over 1 mg/m^3 but the peak 24 h average SO_2 concentration was about 2 mg/m^3. The correspondence between smoke measurements and the mass of suspended particulate matter (PM) is not straightforward (3).

The high PM and SO_2 values that occurred during the above noted air pollution episodes are generally no longer found in industrialized areas in North America and Western Europe, but can still be found in Eastern and Central Europe and in China. Also, high concentrations of PM_{10} of about 1.6 mg/m^3 have been reported in the city of Jambi on Sumatra, Indonesia (4) in the haze produced by biomass burning in 1997, and similar concentrations were obtained in some Florida areas affected by forest fires in June 1998 (5). By comparison, annual average PM_{10} concentrations in the United States range from about 10 ? g/m^3 in very clean wilderness areas to about 50 ? g/m^3 in western US cities which are subject to dust storms and dust suspension by traffic on paved or unpaved roads, agriculture and construction; and maximum 24-h average concentrations are typically factors of two to five times the annual average values.

Although existing guidelines for evaluating the health effects of exposure to PM have been based on data collected in industrialized areas, it should be noted that there are distinct differences in the composition and toxicity of PM produced by biomass burning and fossil fuel burning (6). In addition, the physical conditions which characterized the above-mentioned urban episodes (i.e., acidic fogs and low temperatures) do not necessarily apply to biomass burning episodes. Insufficient data exist to characterize differences in mortality caused by exposures to these two types of PM mixtures but, in general, emissions from fossil fuel burning and industrial operations appear to be more toxic than those from biomass burning (7).

Available data indicate that most of the particulate matter produced by the combustion of either fossil or biomass fuels is found in particles less than 2.5 micrometres in aerodynamic diameter (6). Recent research

summarized in the USEPA report (6) has found evidence for small, but significant, increases in mortality at much lower PM_{10} levels than in the episodes mentioned above.

PM_{10} particles having aerodynamic diameters less than 10 micrometres (also known as thoracic particles) can be inhaled past the nose and throat into lower respiratory tract areas, including the lungs. PM_{10} particles consist of two main groups:

(i) $PM_{2.5}$ particles having aerodynamic diameters less than 2.5 micrometres, and

(ii) $PM_{10-2.5}$ particles having aerodynamic diameters between 2.5 and 10 micrometres.

$PM_{2.5}$ particles are often referred to as "fine" particles, whereas $PM_{10-2.5}$ particles are often referred to as "coarse" particles. They can reach lower regions of the lung, and are of much concern with regard to a variety of potential adverse health outcomes. $PM_{2.5}$ in populated areas is composed mainly of substances derived from high temperature processes (e.g., combustion of fossil or biomass fuels). $PM_{2.5}$ in remote areas may be produced by the oxidation of SO_2 or NO emitted by natural processes. There may also be some addition of crustal materials from the coarse mode mixed into the $PM_{2.5}$ size fraction. Coarse ($PM_{10-2.5}$) particles include substances such as suspended crustal material, plant and insect debris, mould spores, etc., some of which may also be of health concern (e.g., they may exacerbate asthma symptoms). The efficiency of penetration of particles of different sizes deep into the lungs depends on the health status of the individual and his (or her) ventilation rate. Increasing the level of physical activity and switching from nasal to oral breathing results in increased ventilation rates and enhanced delivery of inhaled particles to lower respiratory tract areas.

In addition to evaluating possible acute health risks in relation to the total mass of PM_{10} and/or $PM_{2.5}$ particles, efforts should be made to assess possible chronic health risks associated with specific chemical subcomponents of the aerosols resulting from biomass burning. This may include the assessment of health risks associated with exposures to ambient levels of trace metals and/or benzo[*a*]pyrene (B*a*P) or other polycyclic aromatic hydrocarbons (PAHs) found often in fossil fuel or biomass combustion emissions. Consideration should also be given to the assessment of potential risks associated with other gaseous compounds often directly emitted or formed as transformation products from precursors emitted from biomass fires, e.g., carbon monoxide, nitrogen oxides, ozone, and/or various volatile organic compounds (VOCs) such as xylenes, benzene or toluene (so-called "XBT").

AIR MONITORING APPROACHES AND METHODS

Under ideal circumstances, a monitoring network, which can provide the necessary information about exposures to pollutants emitted by local sources as well as from biomass burning emissions would already be in place in affected areas. There are several general considerations which should be considered in the design of monitoring networks, e.g., the objectives of the monitoring programme, the spatial and temporal resolution of the monitors needed to meet these objectives, the specifications of performance of the monitoring devices, the siting of the individual monitors, the management of data, and the development of a quality assurance/quality control programme. Meteorological parameters should also be monitored along with air pollutants. The criteria used for the placement of monitoring sites vary according to the intended uses of the monitoring data. In many specialized studies designed to evaluate the health effects of exposure to ambient air pollutants, the general approach has been to site monitors within a variety of environments in an urbanized, metropolitan area to obtain a clear picture of the variability in ambient concentrations likely to be encountered by the general population. Large urban areas also have a sufficiently large population to be able to discern differences in health outcomes that are related to variations in air pollutant levels.

Data collected by air monitors are meant to represent variations in ambient concentrations over a range of separate spatial scales. The highest concentrations of pollutants in an urban area are typically found close to highways and major point sources (e.g., power plants, smelters, etc.), and monitors located near these sources collect data meant to be representative over spatial scales ranging from tens to hundreds of metres. Sites designed to characterize exposures of the general population to ambient concentrations in environments ranging from residential-suburban to city centre obtain data meant to be representative over spatial scales ranging from kilometres to a few tens of kilometres.

Finally, sites designed to characterize background concentrations are intended to obtain data meant to be representative over spatial scales ranging from tens of kilometres to hundreds of kilometres. The microenvironmental characteristics of any monitoring site must be evaluated to minimize the effects of potential artifacts caused by nearby sources or by physical features (e.g., overhanging tree limbs, close-by buildings, etc.), which may interfere with the interpretation of the data. Methods are available for determining the optimum placement of monitoring sites to meet the objectives given above while minimizing the artifacts caused by nearby objects (8).

The spatial and time representativeness of the monitoring sites also depends on the pollutant being measured. A number of studies (see e.g. (9)) have indicated that the spatial distribution of $PM_{2.5}$ particles is relatively uniform and the day-to-day variability in their concentrations tends to be similar across a given urban area. This coherence in the $PM_{2.5}$ data results in part from long range transport from distant sources on spatial scales which are much larger than the city under study and from widespread area sources which exhibit similar temporal behaviour (e.g., motor vehicle traffic). $PM_{2.5}$ particles also have an atmospheric lifetime (with respect to removal by wet and dry deposition), which is long compared to the transport time across a given urban area, leading to more complete mixing in urban airsheds. However, coarse mode particles (aerodynamic diameters >2.5µm) have much shorter atmospheric lifetimes than $PM_{2.5}$ particles and, as a result, are less likely to be as evenly distributed across an urban area. These considerations likely form the basis for the health effects associated with exposure to ambient PM, demonstrated by epidemiological analyses using central site monitors in urban areas (6).

For the purposes of examining the effects of distant sources (e.g., biomass burning) on a local population, at least one additional monitor should

be placed at a site which is expected to be affected by the emissions before they reach the urban study area. This monitoring site should be sited to capture the effects of the pollution plume before additions from local sources have occurred. Thus, the contributions from local sources can, in principle, be separated from those of distant sources. Data from such a site can also be used for health studies relating to the non-urban population. The location of this site could be determined on the basis of calculations of the most likely transport routes (i.e., climatological trajectories) from fire prone areas. However, the extent to which data collected by such a site can be used to generate early warnings for the urban area can only be evaluated after the most likely transport routes have been calculated. In addition, monitoring should also be performed at a control site which is unaffected by either the long range transport of the pollutants under study or high levels of local pollution.

A quality assurance plan is essential for ensuring maximum credible use of results of a monitoring effort. Elements which are included in the development of USEPA quality assurance plans (10) relate to understanding the objectives to be met by the monitoring programme, personnel training requirements, sampling methods, sample handling, calibration standards, the frequency of calibration of monitoring devices, external performance and system audits, data acceptance criteria, data management and archiving, data review and evaluation, and reconciliation of data reporting with user requirements.

Monitoring of the pollutants shown in Table 1 is routinely performed throughout the United States: to characterize trends in and the current status of air quality; to determine compliance with the relevant NAAQS; to evaluate the effectiveness of control strategies; to provide data for atmospheric modelling and health studies; and to provide timely warning to the public before potentially hazardous levels of pollutants are reached. Monitoring requirements are met in the United States by using Federal Reference Methods (FRMs) or designated equivalent methods. Methods accepted for measuring PM_{10} are summarized in Table 3. These methods are also used in many monitoring networks elsewhere in the world. Since the announcement of NAAQS for $PM_{2.5}$ on 18 July 1997, four manual FRMs for monitoring $PM_{2.5}$ concentrations have been developed. These are: BGI $PM_{2.5}$ Ambient Fine Particle Sampler (RFPS-0498-116); Graseby Anderson $PM_{2.5}$ Ambient Air Sampler (RFPS-0598-119); Graseby Anderson $PM_{2.5}$ Sequential Air Sampler (RFPS-0598-120); Ruprecht and Patashnik Partisol® FRM Model 2000 Air Sampler (RFPS-0498-117); and Ruprecht and Patashnik Partisol®

Plus Model 2025 Sequential Air Sampler. A list of Federal Reference Methods and designated equivalent methods for the pollutants shown in Table 1 can be found on the USEPA website: *www.epa.gov/ttn/amtic/criteria.html*.

The principal FRMs for monitoring $PM_{2.5}$ and PM_{10} involve the collection of aerosol deposits on filter substrates. PM filter samples are collected based on 24-hour sampling periods. The filters are weighed prior to, and after sampling following equilibration under conditions of fixed relative humidity and temperature for 24 hours. Timely information about ambient levels for reporting to the public or for taking measures to protect the public health cannot therefore be obtained by filter measurements because of the constraints imposed by the long sampling and equilibration times. For purposes of determining compliance with the NAAQS, particle sampling is conducted using a schedule ranging from once per day to once every six days in the United States. However, two automated methods are capable of providing near real time, hourly measurements of PM concentrations and have been designated as equivalent methods, based on their performance in comparisons with FRMs (Table 3). These are the beta gauge sampler (11) and the Tapered Element Oscillating Microbalance (TEOM) method (12). Data collected using these methods are used to calculate PSI values in the United States in metropolitan statistical areas whose populations are over 200,000. Such automated methods represent feasible sampling techniques for operating an effective alert system.

It should be noted that both of these automated methods are subject to artifacts which result from the heating of the inlets to temperatures ranging from 30°C to 50°C (to avoid interference from the condensation of moisture). The heating tends to drive off semi-volatile components such as ammonium nitrate and some organic compounds. The magnitude of error in the mass measurement, therefore, depends on the composition of the particles that are being sampled, which in turn, depends on the nature of contributing PM sources. Under same circumstances, then, the actual ambient PM mass concentration may be underestimated by such methods (unless site-specific calibrations against gravimetric measurements are performed)—thus arguing for caution in ascribing precise quantitative accuracy to the values obtained and associated PSI values.

In addition to determining the mass of particles in the PM_{10} and $PM_{2.5}$ size ranges, the composition of the ambient particles can also be determined for estimating the potential consequences of long-term exposures to toxic trace components. Thus, airborne concentrations of trace elements (e.g.,

potassium, lead, etc.) and concentrations of total organic and elemental ("black" or "soot") carbon in the particles can be measured. Images of particles on selected samples can be obtained by scanning electron microscopy to provide additional insights about the sources of the particles. The concentrations of PAHs in the gas phase and in the particulate phase can also be measured. Methods of sampling and analysis for trace components summarized in Table 4 (as employed in the SE Asia case study presented later) have been used extensively by the USEPA (13-15) and are considered to be EPA recommended methods. However, other sampling and analysis techniques are in use by other governmental and non-governmental organizations in the United States and elsewhere.

Although the foregoing discussion focuses on techniques for sampling and analyzing aerosol components, gaseous components also need to be considered. As part of initial assessments, canister samples of gaseous hydrocarbons of potential health concern (e.g., xylenes, benzene, and toluene) should be obtained.

SOUTHEAST ASIA CASE STUDY

During the summer and autumn of 1997, uncontrolled biomass burning in the SE Asia region (especially in Indonesia) created a widespread, dense smoke haze, which spread as far as the Philippine Islands to the northeast and the SE Asian mainland (including areas of Vietnam, Thailand, and Malaysia) to the north and northwest. As described in earlier reports (16, 17, 18), haze episodes resulting from biomass burning have previously affected Malaysia, Singapore and Indonesia. The 1994 haze event described by Nichol (18) was associated with an El Niño atmospheric pattern, as was the haze event of 1997.

The biomass burning in SE Asia resulted in the exposure of millions of people to potentially dangerous levels of pollutants during the 1997 episode. At the height of the episode in late September 1997, the Malaysian Air Pollution Index (API) reached values of over 800 in Kuching, Sarawak and a peak API of 300 was reached in Kuala Lumpur, Malaysia. The high values of the API were caused in both places by elevated levels of suspended particles in the air (as depicted in Figure 1 for Kuala Lumpur). Malaysian API values are analogous to USEPA Pollutant Standard Index (PSI) values, in that both the API and PSI value of 100 is assigned to the concentration of the 24-h standards in the respective countries. In this case, the Malaysian 24-h PM_{10}

standard is equivalent to the comparable 24-h PM_{10} US National Ambient Air Quality Standard (NAAQS).

Most of the data shown in Figure 1 for Malaysia were collected during the period of the southwest monsoon, which transported pollutants from biomass burning areas in Kalimantan and in Sumatra. The peak PM_{10} level measured by the Malaysian Department of the Environment (MDOE) during late September, probably represents short-term incremental PM contribution from the biomass fires of about 350 $\mu g/m^3$ above background PM levels from sources in Kuala Lumpur, assuming that the urban background level could be represented by the average PM_{10} level observed during November. However, because of enhanced stability in the boundary layer during the haze, the background PM levels resulting from the local, urban sources may have been larger. The transition to the northeast monsoonal regime occurred in November and was associated with lower PM concentrations. The levels of other criteria pollutants during the period of the southwest monsoon were all significantly lower with respect to either exceedences of the relative NAAQS or to their API values. Corresponding values could not be shown for affected areas on Sumatra or Kalimantan because of a lack of reported measurements.

Air pollution monitoring was conducted by USEPA from 2 to 11 November, 1997 in Petaling Jaya, several km to the southwest of central Kuala Lumpur. Particle mass in the $PM_{2.5}$ and PM_{10} size ranges was measured in Malaysia to provide an initial comparison with data obtained by the MDOE. However, measurements of $PM_{2.5}$ only were obtained at Shah Alam. The period of measurement in Malaysia is indicated by the bar labelled "EPA" in Figure 1. Samples were also collected from 4 to 8 November, 1997 in Palembang, and on the campus of Sriwijaya University (30 km to the south of Palembang) in Sumatra, Indonesia, to obtain data in areas affected by the haze in Indonesia and situated closer to the biomass fire sources. Aerosol composition data in both countries were obtained using the methods summarized in Table 4. The mix of sampling sites chosen in Malaysia and Indonesia were similar (i.e., measurements were made in both countries at urban sites and at more rural upwind sites). The upwind measurements were meant to capture the composition of the particles transported from the biomass burning before substantial additions of particles from local, urban sources, while the urban measurements were meant to capture the composition of the particles produced by local sources in addition to those produced by biomass burning. The two sets of monitoring sites were deployed along the prevailing wind direction in both countries (i.e., along the Klang Valley in Malaysia, and south to north in Sumatra from Inderalaya to Palembang in Indonesia). The general locations of the sampling sites and the general meteorological and haze conditions during the period of sampling are shown in Figure 2.

The daily 24-h PM_{10} concentrations obtained at Petaling Jaya with the modified dichotomous sampler, along with data from collocated MDOE -gauge monitoring equipment are shown in Figure 3. The average PM_{10} levels recorded by the MDOE -gauge sampler (82.4 $\mu g/m^3$) were about 11 $\mu g/m^3$ (15 per cent) higher than those obtained using the modified dichotomous sampler (71.1 $\mu g/m^3$). This difference is within the range of more extensive comparisons, although the direction of the discrepancy is opposite to what is expected. A longer record is needed to draw more definitive conclusions (19).

It rained on several days during the sampling period, resulting, in part, in the day-to-day variability seen in the PM_{10} levels shown in Figure 3. Winds were mainly from the northeast during this period (Figure 2), except for a brief time when they had originated in the southwest and may have brought in contributions of the biomass burning particles from Sumatra. Therefore, the results presented here may be viewed mainly as representing

contributions from local sources to the measured ambient particles with some contribution from the Indonesian biomass fires. The mean $PM_{2.5}$ concentration measured at Petaling Jaya was 59.1 µg/m^3. The US Army, Centre for Health Promotion and Preventative Medicine, measured $PM_{2.5}$ concentrations at Shah Alam and at Petaling Jaya. They obtained mean $PM_{2.5}$ concentrations of 59.7 µg/m^3 at Petaling Jaya and 50.1 µg/m^3 at Shah Alam. Data obtained at Shah Alam were highly correlated with those obtained by either method at Petaling Jaya (r>0.98). All of the above considerations suggest that the samplers at Petaling Jaya and Shah Alam were monitoring primarily the urban plume from Kuala Lumpur during the early November sampling period. These findings are also consistent with remarks in the preceding sections about the uniformity of $PM_{2.5}$ levels across urban areas. The measurements made on Sumatra, discussed below, are considered to be more representative of the composition of the biomass burning emissions.

The mean concentrations and composition of suspended $PM_{2.5}$ and $PM_{10-2.5}$ particles measured in Petaling Jaya, Palembang, and Inderalaya (Sriwijaya University) are shown in Table 5. As can be seen from Table 5, $PM_{2.5}$ constituted over 80 per cent of PM_{10} at Petaling Jaya and Palembang. There are many possible sources (e.g., motor vehicles, vegetation burning, plant and animal debris, pollen, fungal spores, organic compounds which condensed onto existing particles) for the carbonaceous constituents that were sampled in Petaling Jaya. The value shown for organic carbon also reflects a rough estimate of the amounts of organic compounds containing hydrogen, nitrogen and oxygen. Selected filter samples were analyzed by scanning electron microscopy to obtain information about the nature of the carbonaceous particles collected on them. Most of the larger particles were mould spores, with a few particles present that are typical of diesel exhaust. The smaller particles were probably generated by combustion by motor vehicles, power plants, and perhaps by vegetation burning. These types of particles are to be expected, given the proximity of the monitoring site to vegetation and to a nearby road. The mean concentration of lead (Pb) in Petaling Jaya was 39 ng/m^3, compared to the US National Ambient Air Quality Standard for lead of 1500 ng/m^3 (1.5 ? g/m^3 90-day ave.). The concentrations of other heavy metals such as nickel (Ni), copper (Cu), and zinc (Zn) were all substantially lower, and cobalt (Co) and cadmium (Cd) were not detected. An example of a typical profile of trace elemental composition of emissions from wood burning is shown in Figure 4. It is again worth noting that organic compounds constitute the major component of biomass burning emissions, thus underscoring the need for detailed evaluations of artifacts which may be produced by heating the inlets in

continuous monitors. The ratio of potassium (K) to $PM_{2.5}$ in the data collected at Petaling Jaya is consistent with biomass burning emissions; however, it is difficult to say how much of the fine particle mass measured in Petaling Jaya was due to local vegetation burning or transport from Indonesian biomass fires. Background levels of K could have been contributed by other sources (e.g., soils, coal burning, etc.) in the Kuala Lumpur area.

Sulfate in aerosol samples collected in the United States is associated typically with the oxidation of sulfur dioxide (SO_2) emitted by power plants and to a lesser extent by motor vehicles. Similar sources may also have contributed to the sulfate seen at Petaling Jaya. Wind blown dust suspended from roads, construction sites, and natural surfaces probably represents the major source of the crustal elements (e.g., Al, Si, Ca, Ti, Fe). Heavy metals originate from a variety of industrial processes such as incineration, manufacturing, smelting, etc. Motor vehicles are also a likely source of Pb seen in the samples collected in Malaysia. As is the case for biomass burning emissions, automotive emissions consist mainly of organic carbon species and they likely contributed to the observed organic carbon levels in Petaling Jaya.

The mean daily (24-hr) PM_{10} concentration at Palembang was 402 $\mu g/m^3$. The mean daily fine particle ($PM_{2.5}$) concentration was 341 $\mu g/m^3$ at Palembang and 264 $\mu g/m^3$ at Sriwijaya University. The concentrations of PM_{10} and $PM_{2.5}$ exceeded the 24-h US NAAQS for both PM_{10} (150 $\mu g/m^3$) and $PM_{2.5}$ (65 $\mu g/m^3$) by large margins on all five days. The PM_{10} average corresponded to a USEPA PSI value of about 300 for PM_{10} levels, with values for several individual days reaching higher levels categorized as “Hazardous”. Approximately 85% of the mass of the particles was concentrated in the $PM_{2.5}$ (fine size) fraction at Palembang. Since the Indonesian government does not routinely monitor airborne particulate matter levels at the Sumatran sites sampled by USEPA, no intercomparisons with their equipment or evaluation of their techniques could be performed.

Scanning electron microscopy (SEM) images of filter deposits collected in Palembang indicate that the particles were composed mainly of hygroscopic carbon compounds. Small amounts of the organic compounds could have also been produced by motor vehicle emissions and the condensation of organic vapours. Mould spores and plant and animal debris were also present in the images.

As can be seen from Table 5, the values for most trace metals in Palembang and Inderalaya (Sriwijaya University) are similar to those obtained in Petaling Jaya, but concentrations of chlorine (Cl) and potassium (K) are much higher at the Indonesian sites. Ratios of K to total mass ranged from 0.5 to 1.0% in the $PM_{2.5}$ samples collected. These values are characteristic of wood burning emissions (Figure 4). As mentioned above, most of the mass of the emissions from biomass burning is typically in the form of organic compounds, and these were elevated at both the Palembang and Sriwijaya University sites. Thus, the organic matter and the overall $PM_{2.5}$ particle composition at both Indonesian sites appear to be dominated by biomass burning emissions. Sources of sulfate, crustal elements and heavy metals are probably similar to those in Malaysia.

The composition of the coarse particles, i.e., particles with aerodynamic diameters between 2.5 and 10 micrometres ($PM_{10-2.5}$), is dominated by soil particles and some biological material, such as mould spores at Petaling Jaya. The composition of the coarse particles at Palembang reflects mainly soil, perhaps suspended by motor vehicle traffic, with additions of biomass burning products.

The composition of particle samples obtained in selected US cities (Los Angeles, CA, Philadelphia, PA, and Roanoke, VA) and in a city in the Czech Republic (Teplice) are shown for comparison in Table 6. The same sampling and analysis methods that were used in SE Asia were also used to collect and analyze samples in Philadelphia and Teplice. These comparisons are shown to help place the air pollution values obtained in SE Asia in perspective in relation to those encountered elsewhere. Los Angeles and Philadelphia were chosen because they are both large urban areas with a somewhat different mix of aerosol characteristics, and Roanoke because it is frequently impacted by wood smoke during the winter. Teplice was chosen because it is a heavily industrialized Central European city, which is subject to frequent air pollution episodes during the winter when lignite (a soft brown coal formed from peat) is widely used for residential heating and results in exposures to elevated levels of many of the same air pollutants derived from biomass fires. During the period from January through March 1993, as shown in Table 6, the overwhelming bulk of suspended aerosol mass in Teplice was found to be due to coal combustion (13).

During a severe episode that occurred in February 1993, a peak 24-h average PM_{10} level of about 1 mg/m^3 was reached. As can be seen from a comparison of Tables 5 and 6, concentrations of the trace metals observed at

the three sites in SE Asia are well within the range of values routinely observed in US cities. However, the concentration of K and the ratio of K to total fine particle mass is elevated in the SE Asian samples compared to the samples collected in Los Angeles and Philadelphia. The ratio of K to total fine particle mass is similar among the samples collected in Roanoke and in SE Asia. In Philadelphia, K is mainly found in the coarse size mode, consistent with wind-blown soil as a major source of K. In contrast, K is mainly found in the fine particle mode in the SE Asian and in the Teplice samples, which is consistent with a combustion source of K.

Levels of sulfate, reported as S, are highly elevated in the samples collected in Sumatra compared to those collected in US cities. They are more reminiscent of the values found in Teplice, a heavily industrialized city, during a winter season marked by several air stagnation-pollution episodes. The ratio of S to total mass in particulate emissions from wood burning is about 0.005 (Figure 4), while the ratio of S to total fine particle mass was about 0.032 in Palembang and 0.026 at Sriwijaya University.

Thus, over 80 per cent of the observed sulfate at the two sites is due to other sources (e.g., the oxidation of SO_2 emitted by power plants and biomass burning and sea spray). Unfortunately, pH measurements were not performed on extracts of the samples collected in Sumatra.

PAHs are produced by the incomplete combustion of biomass, motor vehicle fuels (e.g., diesel fuels are rich sources of PAHs), and other fossil fuels such as coal and oil. They may be present in either the gas phase or attached to particles, depending mainly on temperature. Benzo[*a*]pyrene (BaP) is a PAH found mainly in the particulate phase and is of potential health concern because it is a strongly carcinogenic compound. BaP concentrations found in a number of studies are shown in Table 7. Airborne levels of BaP and other PAHs measured in approximately 60 urban areas around the world since the mid-1970's are reviewed by Menichini (25), to which the reader is referred for further characterization of PAH levels.

POTENTIAL HEALTH IMPLICATIONS

Malaysia

The potential health implications of the air monitoring data collected in Petaling Jaya are difficult to assess because of the very limited data set. Based on data collected by MDOE, the short-term excursions of ambient PM_{10} concentrations to levels notably above the USEPA and Malaysia's daily PM_{10} standards nearly every day during the last two weeks of September, 1997 must certainly be viewed as having posed some increased acute health risks for the general population in the Kuala Lumpur area. This is especially likely, given indications from the USEPA air monitoring efforts that a substantial proportion (~80 per cent) of the PM_{10} mass in the Kuala Lumpur area appeared to be small sized, fine ($PM_{2.5}$) particles. Available epidemiological studies, reviewed in the recent USEPA air quality criteria document for particulate (6) and by WHO (26), indicate that short-term (24-hr) exposures to ambient particles measured as PM_{10} or $PM_{2.5}$ are associated with some increased risk of mortality and morbidity (measured as increased respiratory symptoms, hospital admissions, etc.), especially among the elderly (>65 yrs old) and persons with preexisting cardio-respiratory disease. Some increased risk for exacerbation of asthma symptoms in asthmatic individuals or, possibly, worsening of acute respiratory disease (e.g., in the case of acute respiratory infections or pneumonia), could also occur based on available PM epidemiological studies.

As for the health implications of specific PM constituents (e.g., elemental or organic carbon, crustal materials, heavy metals, sulfate, or PAHs), the EPA monitoring results obtained in Kuala Lumpur were not indicative of much, if any, increase in acute exposure health risks. This outcome is not necessarily very meaningful, however, given that the USEPA monitoring data were obtained during a distinctly lower air pollution period after the peak period of haze from the biomass fires had passed. Also, increased risks of possible cancer and non-cancer health risks associated with the specific compounds measured are typically of most concern in relation to prolonged chronic exposures to ambient air concentrations encountered by the general public (versus usually much higher acute exposure levels often experienced in occupational settings). Such chronic environmental exposure health risks are generally assessed and quantified based on the assumptions of daily (24-hr) exposures over an entire lifetime (70 yrs average) for susceptible individuals—a scenario clearly not met by the relatively brief increased exposures in Malaysia to biomass fire emissions components in 1997. Repeated, more prolonged exposures to biomass fire smoke constituents every few years, however, might result in cumulative doses projected to be associated with increased health risks. Much more extensive data and assessment efforts would be necessary to attempt any more specific estimation of potential health impacts of increased air pollution concentrations in Malaysia due to haze from biomass fires. On the other hand, people with undiagnosed asthma or those progressing toward more severe asthma from mild forms readily amenable to effective medication control, or persons with acute respiratory infections (e.g., pneumonia), could be placed at increased risk for rapid onset of worsening of respiratory systems and lung function declines due to short-term acute exposure to the haze produced by the biomass fires.

Indonesia

The situation in Indonesian areas impacted by haze from the biomass fires, especially those relatively close to “hot spots” where concentrations of PM and certain other air pollutants are likely at their highest, almost certainly posed substantially greater risk for the local general population. Daily PM_{10} levels in Palembang approached or exceeded levels that would be deemed to be “Hazardous” in terms of the USEPA Pollutant Standard Index (PSI) or analogous Malaysian API values shown in Figure 1. Furthermore, given that the USEPA monitoring effort occurred after the extent and intensity of the fires had already been substantially reduced from earlier peak levels, the local population in Palembang and its vicinity were likely exposed on a daily basis

to even higher PM levels during the preceding months of September and October.

Of particular concern is the very high percentages (i.e., 85 per cent) of the PM_{10} mass attributable to $PM_{2.5}$, the "fine particle" size fraction thought to be most clearly implicated in increasing risks of mortality and morbidity due to exposures to PM of ambient origin, as evaluated by both USEPA (6) and WHO (26). Assuming that the average $PM_{2.5}$ mass concentration of 264 ? g/m^3 detected by USEPA monitoring at Sriwijaya University largely reflects the impact of smoke from nearby biomass burning and that similar biomass smoke input levels contributed to the average 341 ? g/m^3 $PM_{2.5}$ mass found by USEPA monitoring in Palembang, it can be estimated that an average increment of about 250 ? g/m^3 $PM_{2.5}$ from the biomass burning haze was added to the daily average of about 75 ? g/m^3 of $PM_{2.5}$ generated from other local sources in Palembang. That increment of haze-related particle exposure in excess of background particle levels due to local sources can be projected based, for example, on quantitative risk estimates published by WHO (26), to have contributed to detectable increases in respiratory symptoms and hospital admissions for respiratory problems among the local general population and, even possibly, some mortality among the elderly and those with preexisting chronic lung diseases or cardiac conditions. Again, much more extensive information and assessment efforts would be needed to attempt even a rough estimate of potential increases in mortality or morbidity among members of the general population in Palembang or other Indonesian areas impacted by the haze from the biomass burning. The public health impacts could be fairly substantial given the PM concentrations involved and the size of the likely affected Indonesian populations in Sumatra, Kalimantan, etc. Even larger, very substantial public health impacts would be projected if Jakarta and other parts of densely populated Java (which was much less impacted by the 1997 biomass burning haze than were Sumatra and Kalimantan) experienced any prolonged periods of haze from biomass burning.

The lack of any well-established, routinely operating air monitoring network in Indonesia precludes having data available by which to attempt analyses analogous to the one presented here based on MDOE PM data for KL during August-November, 1997. Nevertheless, even the brief period of USEPA monitoring in early November at two sites near biomass fire hot spots in Sumatra indicates that ambient levels of both PM_{10} and $PM_{2.5}$ markedly exceeded US PM standards and approached or exceeded 24-h PM_{10} levels designated as "Hazardous" in terms of US PSI values. Most of the particles were in the $PM_{2.5}$ fraction, and the specific composition of the particles and presence of particular PAH compounds are characteristic of wood smoke. The daily (24-h) PM_{10} and $PM_{2.5}$ concentrations measured by USEPA at the Sumatra sites (Palembang and Sriwijaya University) probably posed increased public health risks for the local general population. The USEPA monitoring was conducted after reductions in the number of hot spots seen in satellite images had occurred. Thus, exposures of the general population to even higher PM levels for prolonged periods of time (weeks, months) likely occurred, pointing toward even more substantial public health impacts in Indonesia being associated with exposures to haze from the biomass burning.

Annual average data for heavy metals and B[*a*]P can be compared to cancer and noncancer dose-response assessments available in the integrated risk information system (IRIS) (27) or the health effects assessment summary tables (HEAST) (28) to obtain estimates of the long-term risks posed by exposure to these substances. Needless to say, the data reported here cannot be used for defining long-term average concentrations. However, the data can be used to place potential attendant health risks in perspective, if frequently repeated extended exposures to the levels measured in SE Asia were to occur annually over an individual's lifetime.

SUMMARY AND RECOMMENDATIONS

Summary of findings in SE Asia

Based on MDOE air monitoring results during the last half of September, 1997, daily PM_{10} concentrations in Kuala Lumpur (KL) dramatically increased to levels well in excess of US and Malaysian PM_{10} air standards, on some days approaching levels judged to be "Hazardous" in terms of US PSI or Malaysian API values, largely as the result of haze transported from Indonesian biomass fires. Although data are not readily available from

affected areas in Kalimantan and Sumatra, it may be surmised that similar or worse conditions were found in these areas.

USEPA air monitoring results, obtained during the first two weeks of November, 1997 (after the peak period of biomass fire haze over Malaysia had passed), indicated good agreement with MDOE results (within 15 per cent) obtained from collocated PM_{10} monitoring at Petaling Jaya (a KL suburb). Approximately 80 per cent of the PM_{10} mass at Petaling Jaya was attributable to $PM_{2.5}$ concentrations monitored there. Based on current knowledge of the sizes of particles produced by biomass burning and the results in Sumatra (which indicate that over 80 per cent was present as $PM_{2.5}$), most of PM_{10} monitored at Kuala Lumpur during the haze episodes was probably made up of $PM_{2.5}$.

Recent USEPA and WHO evaluations of available PM epidemiological studies indicate that such incremental acute exposures to daily (24-h) PM concentrations as found during the haze episode in Malaysia and Indonesia were likely associated with increased risk of adverse health effects (e.g., increased mortality or respiratory symptoms and hospital admissions of the elderly, those with preexisting chronic cardiorespiratory disease, and asthmatic persons) among the general local population, especially in Indonesian areas affected by the biomass fire haze.

The concentrations of specific chemical components monitored by EPA in the KL area or in Sumatra (e.g. trace metals, PAH compounds, etc.) were not found to be particularly remarkable, individually, in being likely to pose much, if any, health threat, unless repeated prolonged exposures over several weeks or months occurred virtually every year. Such repeated exposures could result in cumulative doses associated with some increased risk of adverse cancer or non-cancer health effects. However, even though the concentrations reported here were observed after peak exposures to haze components had passed, cancer risks projected to be possibly associated with much higher air pollution levels experienced earlier during the 1997 haze episode would still be much smaller than mortality or morbidity rates estimated to be associated with exposures to measured PM_{10} or $PM_{2.5}$ levels.

Recommendations

1. In addition to strong measures to control the setting and spread of biomass fires, public education programmes should be conducted to

better inform the populations in affected regions about the detrimental health and environmental impacts of uncontrolled biomass burning.

2. Air quality monitoring should be conducted on a regular basis in major urban areas and in areas likely to be impacted by biomass burning emissions. Monitoring the so-called criteria air pollutants (PM_{10}, $PM_{2.5}$, O_3, CO, SO_2, NO_x, and Pb) should be given priority, with measurements of PM_{10} and $PM_{2.5}$ given highest priority.

3. Prior to the establishment of a ground-based monitoring network, the location of sampling sites should be determined in accordance with existing guidelines (8, 29) to minimize artifacts in sample collection and measurement. An ongoing quality assurance programme should also be established according to international guidelines.

4. Efforts should be made to separate contributions to total aerosol mass and toxic components (e.g., sulfate, B[*a*]P, metals, etc.) from biomass burning and other sources.

5. An effective air quality index system analogous to the USEPA PSI system should be implemented to better inform local civil authorities and citizens about unhealthy air quality conditions and to assist in taking appropriate actions to avert or lessen public health impacts.

6. Possibilities for conducting health effects measurement studies to evaluate health impacts of recurring biomass fires should be explored. As an example, retrospective epidemiological analyses relating health statistics (e.g. hospital admissions, mortality rates, etc.) in Kuala Lumpur to PM_{10} levels measured by the MDOE from August to November, 1997 could be done to evaluate quantitatively the potential health impacts of the biomass burning haze on the general population.

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Table 1
US national ambient air quality standards

Pollutant	Standard value		Standard type
Carbon monoxide (CO)			
8-hour average	9 ppm	(10 mg/m^3)**	Primary
1-hour average	35 ppm	(40 mg/m^3)**	Primary
Nitrogen dioxide (NO_2)			
Annual arithmetic mean	0.053 ppm	(100 µg/m^3)**	Primary & secondary
Ozone (O_3)			
1-hour average*	0.12 ppm	(235 µg/m^3)**	Primary & secondary
8-hour average	0.08 ppm	(157 µg/m^3)**	Primary & secondary
Lead (Pb)			
Quarterly average		1.5 µg/m^3	Primary & secondary
Particulate matter < 10 micrometres			
(PM_{10})		50 µg/m^3	Primary & secondary
Annual arithmetic mean		150 µg/m^3	Primary & secondary
24-hour average			
Particulate matter < 2.5 micrometres			
($PM_{2.5}$)			
Annual arithmetic mean		15 µg/m^3	Primary & secondary
24-hour average		65 µg/m^3	Primary & secondary
Sulfur dioxide (SO_2)			
Annual arithmetic mean	0.03 ppm	(80 µg/m^3)**	Primary
24-hour average	0.14 ppm	(365 µg/m^3)**	Primary
3-hour average	0.50 ppm	(1300 µg/m^3)**	Secondary

* The ozone 1-hour standard applies only to areas that were designated nonattainment when the ozone 8-hour standard was adopted in July 1997. This provision allows a smooth, legal, and practical transition to the 8-hour standard.

** Parenthetical value is an approximately equivalent concentration.

Source: EPA Website: *www.epa.gov/criteria.html*.

Table 2
Comparison of PSI values with pollutant concentrations, descriptor words, generalized health effects, and cautionary statements

Index value	Air quality level	Pollutant levels					Health effect descriptor	General health effects	Cautionary statements
		PM_{10} (24-h) µg/m^3	SO_2 (24-h) µg/m^3	CO (8-h) ppm	O_3 (1-h) ppm	NO_2 (1-h) ppm			
								Acutely incapacitating symptoms experienced by significant portion of the population especially by persons undergoing light exercise; health status of particular vulnerable cardiopulmonary subjects may be compromised.	Same recommendations as for Emergency level
500	SIGNIFICANT HARM	600	2,620	50	0.6	2.0	HAZARDOUS	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity	All persons should remain indoors, keep windows and doors closed, minimize physical exertion, and avoid traffic.
400	EMERGENCY	500	2,100	40	0.5	1.6	HAZARDOUS	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General population should avoid outdoor activity.
300	WARNING	420	1,600	30	0.4	1.2	VERY UNHEALTHFUL	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Elderly and persons with existing diseases should stay indoors and reduce physical activity.
200	ALERT	350	800	15	0.2	0.6	UNHEALTHFUL	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with heart or respiratory ailments should stay indoors and reduce physical activity.
100	NAAQS	150	365	9	0.12	a	MODERATE		
50	50% OF NAAQS	75	80[b]	4.5	0.06	a	GOOD		
0	-	0	0	0	0	a			

a No index values reported at concentrations level below those specified by "Alert level" criteria
b Annual primary NAAQS

Source*:* *www.epa.gov/oar/oaqps/psi.html*

Table 3
US Environmental protection agency-designated reference and equivalent methods for PM_{10} (6)

Method No.	Identification	Description	Type	Date
RFPS-1087-062	Wedding & Associates PM_{10} Critical Flow High-Volume Sampler.	High-volume (1.13 m^3/min) sampler with cyclone-type PM_{10} inlet; 203 x 254 cm (8 x 10 in) filter.	Manual reference method	10/06/87
RFPS-1287-063	Sierra-Andersen or General Metal Works Model 1200 PM_{10} High-Volume Air Sampler System	High-volume (1.13 m^3/min) sampler with impaction-type PM_{10} inlet; 203 x 254 cm (8 x 10 in) filter.	Manual reference method	12/01/87
RFPS-1287-064	Sierra-Andersen or General Metal Works Model 321-B PM_{10} High-Volume Air Sampler System	High-volume (1.13 m^3/min) sampler with impaction-type PM_{10} inlet; 203 x 254 cm (8 x 10 in) filter. (No longer available.)	Manual reference method	12/01/87
RFPS-1287-065	Sierra-Andersen or General Metal Works Model 321-C PM_{10} High-Volume Air Sampler System	High-volume (1.13 m^3/min) sampler with impaction-type PM_{10} inlet; 203 x 254 cm (8 x 10 in) filter. (No longer available.)	Manual reference method	12/01/87
RFPS-0389-071	Oregon DEQ Medium Volume PM_{10} Sampler	Non-commercial medium-volume (110 L/min) sampler with impaction-type inlet and automatic filter change; two 47-mm diameter filters.	Manual reference method	3/24/89
RFPS-0789-073	Sierra-Andersen Models SA241 or SA241M or General Metal Works Models G241 and G241M PM_{10} Dichotomous Samplers	Low-volume (16.7 L/min) sampler with impaction-type PM_{10} inlet; additional particle size separation at 2.5 micron, collected on two 37-mm diameter filters.	Manual reference method	7/27/89
EQPM-0990-076	Andersen Instruments Model FH62I-N PM_{10} Beta Attenuation Monitor	Low-volume (16.7 L/min) PM_{10} analyzers using impaction-type PM_{10} inlet, 40 mm filter tape, and beta attenuation analysis.	Automated equivalent method	9/18/90
EQPM-1090-079	Rupprecht & Patashnick TEOM Series 1400 and Series 1400a PM_{10} Monitors	Low-volume (16.7 L/min) PM_{10} analyzers using impaction-type PM_{10} inlet, 12.7 mm diameter filter, and tapered element oscillating microbalance analysis.	Automated equivalent method	10/29/90
EQPM-0391-081	Wedding & Associates PM_{10} Beta Gauge Automated Particle Sampler	Low-volume (16.7 L/min) PM_{10} analyzer using cyclone-type PM_{10} inlet, 32 mm filter tape, and beta attenuation analysis.	Automated equivalent method	3/5/91
RFPS-0694-098	Rupprecht & Patashnick Partisol Model 2000 Air Sampler	Low-volume (16.7 L/min) PM_{10} sampler with impaction-type inlet and 47 mm diameter filter.	Manual reference method	7/11/94

Table 4
Sampling and analysis methods for data collected in Malaysia and Indonesia.

Sample collected	**Method**
$PM_{2.5}$, PM_{10}	Modified virtual impactor containing 47mm Teflon filters.
Organic carbon, elemental carbon	Samples collected on 47mm quartz filters mounted in same virtual impactor.
PAHs	Samples collected on 47mm Quartz filter for particulate bound PAHs followed by polyurethane foam (PUF) trap for gas phase PAHs.
Trace elements (Na-Pb)	Samples collected on 47mm Teflon filters.
Sample Analysis	**Method**
$PM_{2.5}$, PM_{10}	Gravimetric analysis of deposit on Teflon filters.
Organic carbon, elemental carbon	Thermo-optical analysis of deposit on quartz filters.
PAHs	Gas chromatography using FID/MS detection for analysis of extracts from quartz filters and polyurethane foam traps.
Trace elements (Na-Pb)	X-ray fluorescence analysis of particles collected on Teflon filters.

Table 5
Mean aerosol composition measured in Petaling Jaya, Malaysia; Palembang, Sumatra, Indonesia; and the campus of Sriwijaya University, Sumatra, Indonesia in November 1997.

Species	Petaling Jaya		Palembang		Sriwijaya University
Particulate matter (µg/m^3)					
	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)	Fine ($PM_{2.5}$)
No. of samples	9	9	5	5	5
Total mass	62.1	11.9	341	61	264
Organic carbon	26.1	no	282	no[1]	200
Elemental carbon	1.9	no	5.4	no[1]	3.2
Metal oxides	10.0	1.0	15	—	13
Sulfate	10.0	1.0	44	4.4	29
Trace elements (ng/m^3)					
Al	Bd[2]	630	bd[2]	1300	bd[1]
Si	160	1270	200	3700	115
S	2400	235	11000	1100	6900
Cl	70	83	4500	1200	4600
K	280	160	1400	420	1500
Ca	98	580	79	1400	47
Ti	27	55	11	100	6.5
V	9.3	1.5	bd[2]	3.0	bd[2]
Cr	0.2	2.4	bd[2]	1.3	bd[2]
Mn	4.5	3.9	1.7	17	bd[2]

[1]no = not obtained.
[2]bd = beneath detection limit.

Table 5 (Cont'd)
Mean aerosol composition measured in Petaling Jaya, Malaysia; Palembang, Sumatra, Indonesia; and the campus of Sriwijaya University, Sumatra, Indonesia in November 1997.

Species	Petaling Jaya		Palembang		Sriwijaya University
Particulate matter (μg/m³)					
Fe	120	310	83	1000	71
Ni	2.2	1.0	3.8	0.4	<0.1
Cu	9.3	10.2	2.1	2.1	3.9
Zn	34.3	13	13	20	6.4
As	2.3	0.5	1.2	0.5	1.3
Se	0.7	bd[2]	3.9	<0.1	1.4
Br	9.8	1.0	95	11	72
Pb	39	19	64	15	7.7

Table 6
Mean aerosol composition measured in Los Angeles, CA; Philadelphia, PA; Roanoke, VA; and Teplice Czech Republic.

	Los Angeles,[20] CA (1987)	Philadelphia,[21] PA (1994)		Roanoke,[22] VA (1988)	Teplice,[13] CR (1993)	
Particulate matter (μg/m³)						
	Fine ($PM_{2.5}$)	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)	Fine ($PM_{2.5}$)	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)
No. of samples	11	21	21	—	66	62
Total mass	41	32	8	20	122	18.5
Organic carbon	8.3	4.5	no[1]	7.3	33.8	no[1]
Elemental carbon	2.4	0.8	no[1]	1.5	2.3	no[1]
Metal oxides					6.5	14.0
Sulfate	11.8	13.8	bd[2]	4.9	41.3	1.5[3]
Trace elements (ng/m³)						
Al	35	114	325	18	510	1900
Si	52	165	933	77	930	3100
S	2830	3300	bd[2]	1180	10000	370[3]
Cl	93	26	47	53	410	100
K	41	60	100	177	300	210
Ca	22	58	421	47	140	600
Ti	5	<42	30	bd[2]	51	140
V	6	<13	bd[2]	1.7	7.7	-0.2[3]

[1]no = not obtained
[2]bd = beneath detection limit
[3]Detected at the analytical uncertainty in fewer than half the samples.
[4]Detected at 3 times the analytical uncertainty in fewer than half the samples.

Table 6 (Cont'd)
Mean aerosol composition measured in Los Angeles, CA; Philadelphia, PA; Roanoke, VA; and Teplice Czech Republic.

	Los Angeles,[20] CA (1987)	Philadelphia,[21] PA (1994)		Roanoke,[22] VA (1988)	Teplice,[13] CR (1993)	
Particulate matter (µg/m^3)						
Cr	22	bd[2]	bd[2]	1	4.7	-0.3[3]
Mn	16	3	6	12	17	12
Fe	99	127	352	114	390	840
Ni	5	7	2	bd[2]	3.6[4]	0.8[3]
Cu	63	7	bd[2]	7	12	7.8
Zn	90	41	5	83	160	20
As	22	bd[2]	bd[2]	2	34	3.6[3]
Se	13	<2	bd[2]	2	6.7	0.3[3]
Br	13	9	3	5	18	3.5
Pb	38	19	13	27	110	6.5

Table 7
Concentrations of benzo[*a*]pyrene (BAP) in selected areas of the world

Location	BaP concentration (ng/m^3)	Source
Los Angeles, CA		(23)
- summer	0.2	
- winter	0.6	
Teplice, Czech Republic		(13)
- summer	0.5	
- winter	8.0	
Prachatice, Czech Republic		(13)
- summer	0.1	
- winter	0.5	
Kuala Lumpur, Malaysia		(24)
- Sept. 1997	0.6	
Palembang, Indonesia		(1)
- Nov. 1997	7.1	

Figure 1
Daily PM10 concentrations and API values in July-November 1997 in Kuala Lumpur

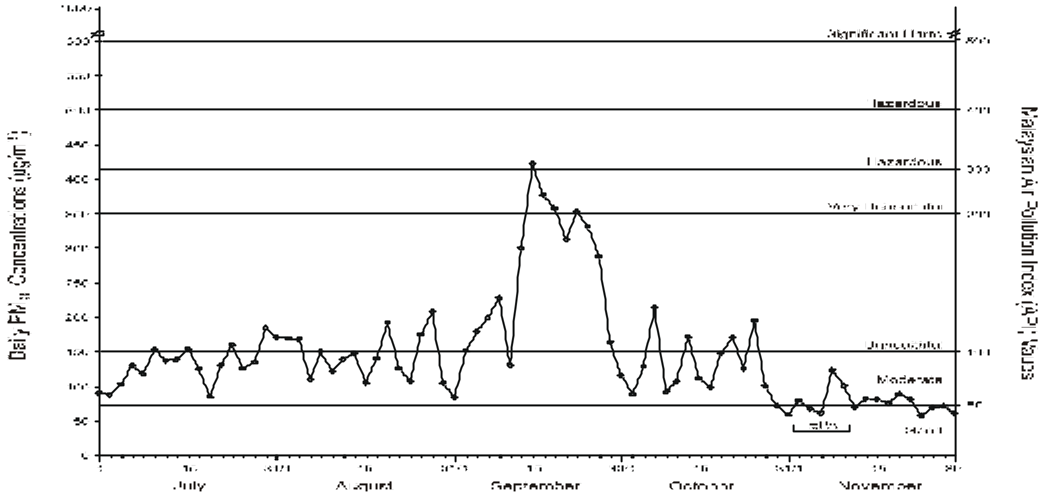


Figure 2
Location of sampling sites and general meteorological and haze conditions during sampling period

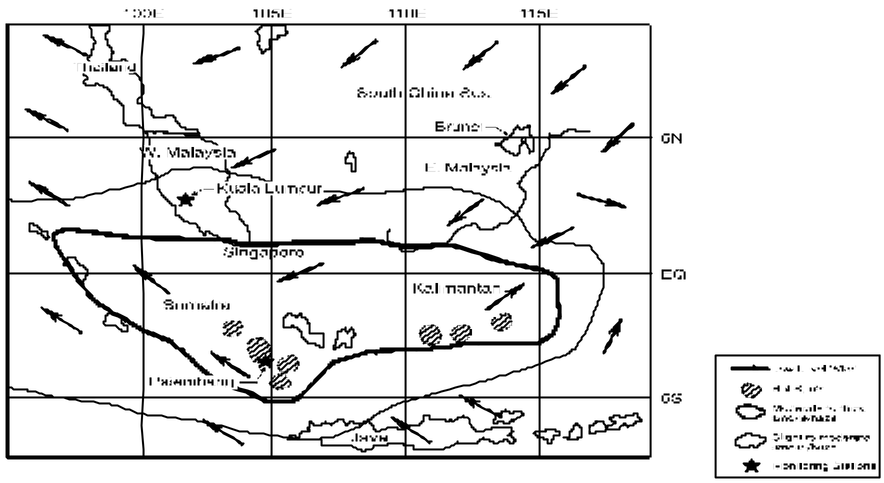


Figure 3
PM_{10} concentrations monitored by US EPA and ASMA, 3-11 November 1997

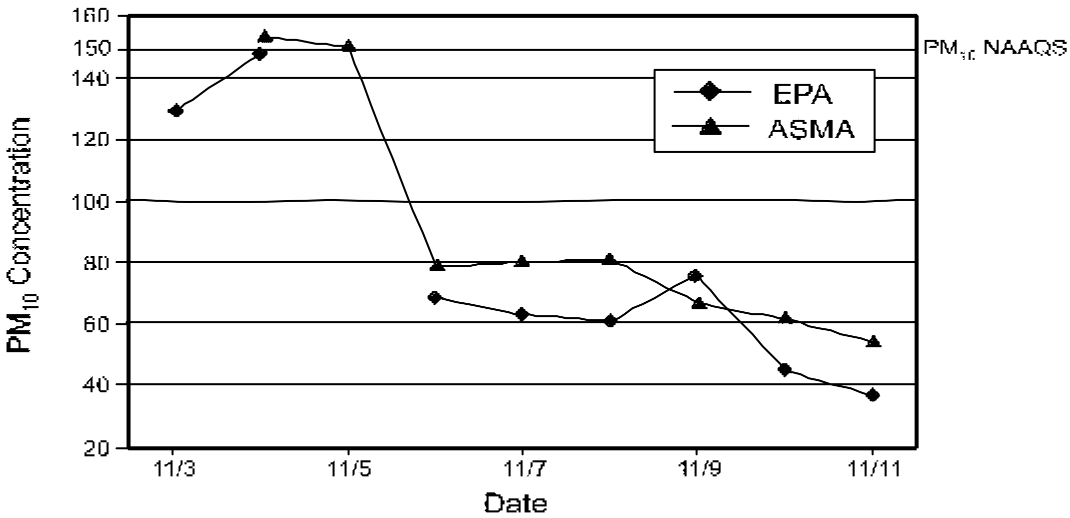
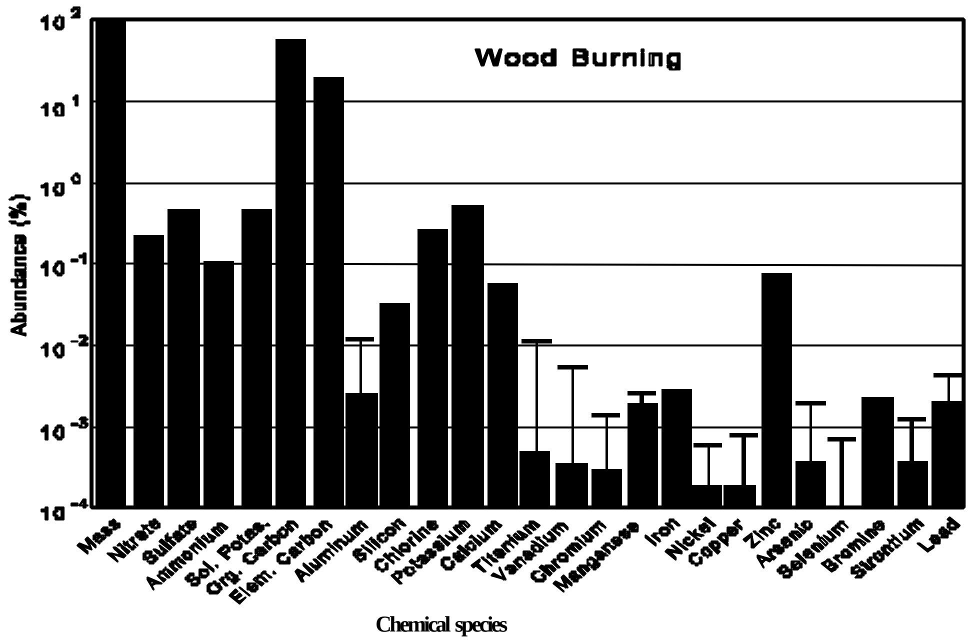


Figure 4
Typical profile of trace elemental composition of emissions from wood burning



Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

HEALTH IMPACTS OF BIOMASS AIR POLLUTION

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SUMMARY

In 1997, uncontrolled forest fires burning in Indonesia resulted in a regional air pollution episode of smoke which impacted several Southeast Asian nations. Beginning in late July 1997, elevated levels of particulate matter air pollution were observed for a period of approximately 2 months in many areas, with a severe episode occurring during most of the month of September. During this episode, particle levels in some areas were up to 15 times higher than normal levels. Exposures to "haze"-type air pollution can be substantial and are of public health concern due to the large numbers of individuals who may be exposed.

Smoke from biomass burning (in the following referred to as "biomass smoke") contains a large and diverse number of chemicals, many of which have been associated with adverse health impacts. These include both particulate matter and gaseous compounds such as carbon monoxide, formaldehyde, acrolein, benzene, nitrogen dioxide and ozone. Exposures to high concentrations of carbon monoxide and other pollutants are highly variable and only occasionally observed in individuals such as wildland firefighters and people who cook with biomass fuels. Particulate matter is itself a complex mixture which is associated with a wide range of health impacts. Review of the literature on exposure and health impacts, as well as initial evaluation of the available air monitoring data from the 1997 episode, indicate that the pollutant variable most consistently elevated in association with biomass smoke is particulate matter. Accordingly, the emphasis throughout this paper and of recommended future studies will be focused on particulate matter.

Non-cancer health effects

Studies of wildland firefighters, an occupational group exposed to high levels of biomass smoke clearly indicate an association between exposure and acute effects on respiratory health. Longer term effects, lasting for a 3-6 month firefighting season, have also been observed in most studies although these effects appear to be relatively small and may be reversible. Firefighters are an extremely fit and healthy group and cannot be considered representative of the general population. Accordingly, the demonstration of health effects in this occupational group indicates the plausibility, but not the magnitude, of an association between biomass smoke exposure and adverse effects in the general population.

The health effects of biomass smoke inhalation have also been documented in developing countries where women, and in some cases, children spend many hours cooking over unvented indoor stoves. Approximately 50 per cent of the world's population uses biomass fuels for cooking and/or heating. In particular, exposure to smoke from cooking fires has been identified as a risk factor for acute respiratory illness. Women and children are also at risk for chronic respiratory diseases. As these exposures last for 20 or more years, they are much higher than those associated with "haze" episodes. However, the studies conducted in developing countries indicate the serious consequences of exposure to high levels of biomass smoke. Increased acute respiratory illness in children is likely a major cause of infant mortality and the development of chronic lung disease in adults is associated with premature death and increased illness.

Many recent studies have also indicated that levels of air pollution currently measured in most urban areas in the world are associated with a range of adverse health outcomes. The most startling finding of these studies, is the association of particulate air pollution, with increased daily mortality. These studies have been conducted by different investigators in a variety of locations, using a variety of study designs. In nearly all cases, the studies indicate an association between particle air pollution and increased risk of death, primarily in the elderly and in individuals with pre-existing respiratory and/or cardiac illness. Recent studies have also suggested an association between particulate matter and infant mortality. Increased risk of hospital admissions and increased emergency room visits have also been associated with short-term increases in the levels of particle air pollution. These data strongly suggest that any combustion-source particulate air

pollution, including that produced during forest fires, is associated with a whole range of adverse health outcomes.

Specific studies of exposure to biomass smoke indicate a consistent relationship between exposure and increased respiratory symptoms, increased risk of respiratory illness and decreased lung function. These studies have mainly been focused on children, although the few studies which evaluated adults also showed similar results. A limited number of studies also indicate an association between biomass smoke exposure and visits to hospital emergency rooms. There are also indications from several studies that asthmatics are a particularly sensitive group. By analogy to the findings of numerous studies associating increased mortality with urban particulate air pollution mixtures, there is no evidence that particles from different combustion sources have different impacts on health, while particles generated by natural processes such as volcanic eruptions and windblown soil do appear to have less of an impact on health. Therefore, there is little reason to expect that biomass smoke particles would be any less harmful than other combustion-source particles and it is prudent to consider that “haze” exposure will also be related to increased mortality. The studies also do not show evidence for a threshold concentration at which effects are not observed.

Nearly all of the studies of biomass smoke health effects conducted in North America evaluated impacts of concentrations which were much lower than those associated with the 1997 Southeast Asian haze episode. Similarly, these studies involved exposure duration which were of comparable length to those experienced in Southeast Asia. Based on these studies, it is reasonable to expect that the Southeast Asian haze episode resulted in the entire spectrum of acute impacts, including increased mortality, as well as seasonal effects on lung function, respiratory illness and symptoms. It is not possible at this time to determine the long-term effect, if any, from a single air pollution episode, although repeated yearly occurrences of haze should be cause for serious concern. Long-term (several years) exposure to particulate air pollution in urban areas, at levels much lower than those experienced in Southeast Asia in 1997, has been associated with decreased life expectancy and with the development of new cases of chronic lung disease.

Cancer

The available, although limited, data on biomass smoke and cancer do not indicate an increased risk even at very high levels of exposure. This

evidence includes studies of long-term exposure to high levels of biomass smoke from domestic cooking in developing countries. Evidence for a relationship between urban particulate air pollution and lung cancer is also limited, but is suggestive of a small, but measurable, increased risk. There have not been enough studies conducted to evaluate the consistency of any increased risk for different particle sources. However, while biomass smoke clearly is potentially carcinogenic, it is much less so than motor vehicle exhaust.

Research questions

Given the uncertainty regarding the potential for long-term effects associated with "haze" type air pollution, it would seem reasonable to initially evaluate the acute health impacts, especially since these are likely to include severe impacts such as increased mortality. To help understand the potential for adverse health effects and to evaluate the effectiveness of various mitigation measures, there is also a need to investigate several exposure issues. Several major research questions are summarized below. However, before these questions can be addressed, it will be necessary to identify the availability of data, specifically air monitoring data and valid data on health indicators such as daily mortality, hospital visits, clinic/emergency room visits, etc.

1. What were the short-term human impacts associated with exposure to biomass air pollution in Southeast Asia?

   For the range of identified impacts, were the effects reversible or permanent?

2. What were the long-term human health impacts (if any) associated with exposure to biomass air pollution in Southeast Asia?

3. Which (if any) population groups were especially susceptible to adverse health effects of biomass air pollution in Southeast Asia?

4. What was the size of the exposed population?

   Using study results and available air monitoring data (possibly including satellite data), can the region-wide health impacts be estimated?

5. What was the relationship between differences in exposure and health impacts across the affected region?

   Were there exposed areas in which health impacts were larger/smaller than others?

   Can an exposure-response relationship be demonstrated throughout the region?

6. What was the effectiveness of the following health protection measures?

   a) The use of dust masks

   b) Advising the population to remain indoors

7. What was the composition of the biomass air pollution which affected Southeast Asia?

   Can specific biomass marker compounds be identified?

   To what extent is it possible to distinguish biomass air pollution from the "background" urban air pollution?

Recommended studies

With regard to the general research questions identified above, several possible study designs are proposed:

a. Formal study of the acute impacts of forest fire-related air pollution episodes should be conducted. Ideally, these studies should be directed towards the most severe health outcomes, while considering that impacts of air pollution will be small relative to all other causes of morbidity and mortality. To the extent possible, specific study protocols should be standardized and conducted in several regions where ambient air concentrations differed.

b. Formal study of the long-term impacts of forest fire-related air pollution may be attempted although it must be acknowledged that these studies are extremely difficult to conduct, and even the best studies are unlikely to provide firm results.

c. A region-wide composite database of ambient air concentrations should be developed. Estimated air pollution contour plots can be developed using available air monitoring data, and, if feasible, supplemented with airport visibility and remote sensing data. With this type of a database, the regional health impact of biomass air pollution episodes can be estimated.

d. The effectiveness of masks for use by the general public should be evaluated. An additional aim should be an adequate understanding of the variables which determine mask effectiveness, including technical factors such as filtration efficiency and leakage, as well as non-technical issues such as population compliance and comfort. Identification of the most important variables determining mask effectiveness will enable the design of new masks that are specifically applicable for general public use.

e. The effectiveness of remaining indoors during haze episodes should be investigated. Specifically, the effectiveness of air cleaners, air conditioners, open/closed windows within various building types as they relate to indoor penetration of fine particles should be assessed.

f. Detailed chemical analysis of particle samples should be conducted to identify the proportion of various functional groups within the haze particulate matter. While this analysis may be useful in future risk assessment

and in comparing the toxicity of these particulate samples to those collected in other locations, the current emphasis should be on identifying marker compounds which may be used to distinguish air pollution originating from biomass burning from other sources.

Recommended health protection measures

Due to the limited effectiveness of other health protection measures during regional haze episodes, priority emphasis must be given to elimination of the source of the air pollution, which in this case is extinguishing fires or preventing their occurrence. Close interaction between health, environment and meteorological agencies could result in effective forecasting of future air pollution episodes, be they related to forest fires or local sources of air pollution. However, despite efforts to prevent and control fires it is acknowledged that other measures may be necessary to help mitigate public health impacts. If the control or prevention of fires is not feasible, this should be followed by exposure avoidance activities such as reduced physical activity and remaining indoors. To enhance the protection offered by remaining indoors, individuals/building managers should take actions to reduce the infiltration of outdoor air. There is evidence that air conditioners, especially those with efficient filters, will substantially reduce indoor particle levels. To the extent possible, effective filters should be installed in existing air conditioning systems and individuals should seek environments protected by such systems. There is strong evidence that portable air cleaners are effective at reducing indoor particle levels, provided the specific cleaner is adequately matched to the indoor environment in which it is placed. Unfortunately, economics will limit the distribution of such devices throughout the population. As with air conditioners, the increased use of such devices by a large segment of the population may have a significant impact on energy consumption. The least desirable measure of health protection is the use of dust masks. While these are relatively inexpensive and may be distributed to a large segment of the population, at present, their effectiveness for general population use must be questioned. Despite this reservation, it is likely that the benefits (even partial) of wearing dust masks will outweigh the (physiological and economic) costs. Accordingly, in the absence of other mitigation techniques, the use of dust masks is warranted, Education of the population regarding specific mask types to purchase, how to wear masks and when to replace them will increase their effectiveness as will the development of new masks designed for general population use.

INTRODUCTION

In 1997, uncontrolled forest fires burning in the Indonesian states of Kalimantan and Sumatra, in combination with a severe regional drought, depressed mixing heights and prevailing winds resulted in a regional air pollution episode of biomass smoke which impacted Indonesia, Malaysia, Singapore, southern Thailand, Brunei, and the southern Philippines. In particular, several large urban areas such as Singapore, Kuala Lumpur and Kuching were affected. Emissions from biomass burning resulted in elevated levels of particulate air pollution for a period of approximately 2 months in many areas (beginning in late July 1997), with a severe episode occurring during most of the month of September. During this episode, a state of emergency was declared in Sarawak, Malaysia, as 24-hour PM_{10} levels reached as high as 930 $\mu g/m^3$, more than 15 times higher than normal levels. Intermittent episodes occurred in Indonesia, Malaysia and Singapore until mid-November.

Several recent review papers have discussed the health impacts and pollutants associated with wood smoke air pollution (1-3). Although the emphasis of these reviews was on North American exposures, many of the conclusions are relevant to the broader understanding of biomass air pollution, which is the subject of this paper. This chapter will describe materials presented in these reviews as well as updated information. In addition, this paper will cover additional exposures to biomass air pollution encountered by forest firefighters and by individuals who use biomass for cooking and heating in developing countries. The available data on health impacts associated with community exposure to forest/bush fire related air pollution will also be presented. Emphasis will be placed on epidemiological studies on human health impacts and on peer-reviewed literature. The emission of pollutants from forest fires will also be addressed, with particular emphasis on tropical rain forests. As data regarding the specific concentration measurements and health impacts associated with the 1997 Southeast Asian biomass air pollution ("haze") episode are just becoming available, these will not be addressed directly in the review portion of this paper. The second part of this paper will specifically be directed to the situation experienced in Southeast Asia and will cover research needs, suggest several possible research designs and discuss measures which national governments may employ or recommend to mitigate public health impacts associated with biomass air pollution originating from forest fires.

AIR POLLUTION RESULTING FROM BIOMASS BURNING

Biomass smoke contains a large and diverse number of chemicals, many of which have been associated with adverse health impacts. These include both particulate matter and gaseous compounds such as carbon monoxide, formaldehyde, acrolein, benzene, nitrogen dioxide and ozone. Particulate matter is itself a complex mixture which is associated with a wide range of health impacts. Components of particulate matter such as polycyclic aromatic hydrocarbons (PAHs) are also found in biomass smoke. The transport of biomass burning emissions over hundreds of kilometres in Brazil has been extensively documented (4). Haze layers with elevated concentrations of carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), and nitric oxide (NO) have been observed. During transport, many of the gaseous species are converted to other gases, such as ozone, or into particles, such as nitrate and organic nitrogen species. Table 1 summarises the major pollutants of biomass burning.

Pollutants

Gaseous

The main gaseous components in smoke which are potential health hazards are carbon monoxide and aldehydes. A number of studies have also reported elevated concentrations of ozone, as well as ozone precursors (nitrogen oxides and hydrocarbons), in plumes from forest fires. In particular, fires burning in the savanna regions of Central Africa and South America have been studied in detail. In Brazil, ozone concentrations reach equilibrium values of approximately 20 ppb above background levels throughout a 2 million km^2 region during fire seasons (5).

Comparisons have been made between three years of data collected at a coastal site in Brazil not significantly impacted by biomass burning and measurements collected in a savanna region directly downwind of an Amazon forest region with intense burning. During the dry season, elevated levels of CO and O_3 were measured at the savanna site, while during the wet season, levels at the two locations were nearly identical. Monthly average CO levels increased from 100 ppb to 700 ppb and monthly average (noontime) O_3 levels increase from 20 ppb to 80 ppb (6). At these O_3 levels, which are high

relative to those in rural areas, adverse health impacts have also been demonstrated.

Hydrocarbon and CO emissions were also measured in a study of savanna and forest regions in Brazil. The emission of hydrocarbons in forest regions were mainly alkanes (ethane and propane) and alkenes (ethylene and propylene) with smaller amounts (13 per cent) of aromatics (benzene and toluene). Some differences in the relative composition of hydrocarbons were observed between forest fire and savanna emissions. CO levels were only slightly (500 ppb) increased in the atmospheric boundary layer. A recent study documented the impact of biomass pollutants transported 300 km from a fire in Alberta, Canada, to the urban area of Edmonton (7). Air trajectory analysis combined with monitoring of O_3, nitrogen oxides and hydrocarbons, indicated that the forest fire had a significant impact on concentrations of gaseous pollutants. O_3 and nitrogen dioxide (NO_2) concentrations were 50-150 per cent higher than seasonal median levels.

Particulate composition and size distribution

The size distribution of wood smoke has been measured by several investigators and indicates that nearly all particles are smaller than 1 µm, with a peak in the distribution between 0.15 µm and 0.4 µm. One assessment of particle size distributions of forest residue indicated that 82 per cent of the particle mass was smaller than 1µm and 69 per cent smaller than 0.3 µm (8). These size ranges are consistent with particle formation via condensation (3). Particles of this size range are not easily removed by gravitational settling and therefore can be transported over long distances. Constituents of biomass smoke may also undergo atmospheric transformations, although these have not been studied in detail. Hueglin and colleagues (9) reported on a detailed analysis of wood smoke particle size. Particle sizes distributions were sensitive to specific combustion conditions, but generally were bimodal with a peak at approximately 0.1 - 0.2 µm, corresponding to incomplete combustion and larger (approximately 5 µm) particles consisting of unburned material. Only the smaller particles are expected to remain suspended in wood smoke (9). Measurements of particle size distribution inside forest fire plumes in the Amazonian forest indicate that two particle generation mechanisms operate in forest fires: gas to particle conversion resulting in particles smaller than 2.0 µm, and convective dispersion of ash and semi-burned material. Due to high settling velocities of large particles, only the smaller particles (smaller than 2 µm) can be transported over long distances (10).

Biomass smoke contains organic and inorganic particulate matter, including PAHs and a number of trace metals. Larson and Koenig (3) recently reviewed the available information on particle composition. While approximately 5-20 per cent of wood smoke particulate mass is elemental carbon, the composition of the organic carbon fraction varies dramatically with the specific biomass fuel being burned and with the combustion conditions. Accordingly, profiles of specific PAHs, which are of concern for their potential carcinogenicity, are likely to be variable. For this reason, many measurements have focused on a single PAH with probable human carcinogenic properties; benzo[a]pyrene (BaP), as a representative of the PAH group. Detailed analysis of organic wood smoke aerosol were conducted by Rogge et al (11). Nearly 200 distinct organic compounds were measured in wood smoke, many of them derivatives of wood polymers and resins. Wood consists of cellulose (50-70 per cent), hemicellulose (20-30 per cent), lignin (30 per cent), plus small amounts of resins and inorganic salts. In wood, cellulose compounds form a supporting mesh that is reinforced by lignin polymers. Together, these compounds form the rigid wood structure. When burned, lignin polymers produce methoxyphenols, methoxy benzenes, phenols, catechols and benzene. Non-wood biomass does not contain lignin and, therefore, the methoxy phenols and methoxy benzenes are unique tracers of wood smoke combustion. Conifers (softwoods) produce large amounts of resin acids while deciduous (hardwoods) trees do not. Combustion of hardwoods produces more ash and therefore more trace elements that softwoods (3). Potassium is the trace element found at highest concentrations in wood smoke and has often been used as a wood smoke tracer.

Daisey et al (12) compared concentrations of respirable particulate matter (RSP), extractable organic matter (EOM) and PAHs inside seven Wisconsin homes when the home's woodstove was operated and when it was not. No statistically significant difference was observed between the two periods for RSP concentrations. Concentrations of EOM, however, were approximately two times higher, and concentrations of PAH were 2 to 46 times higher during the periods when the wood stoves were in operation. Total PAH levels were below 10 ng/m^3. This study indicates that wood burning can increase indoor concentrations of particulate organic matter and PAH, due to direct indoor emissions and/or infiltration from outdoors (12). The atmospheric concentrations of total suspended particulate (TSP) matter and BaP were measured in a mountain community highly dependent on wood for residential space heating. BaP levels ranged from 0.6 to 14.8 ng/m^3.

These levels were significantly higher than BaP levels observed in metropolitan US cities which are in the range of 2-7 ng/m^3 (13).

Inorganic particle composition was studied inside biomass fire plumes from Amazonian forest and African and Brazilian savannas. Particles from savanna fires were enriched in K, P, Cl, Zn and Br, while tropical forest fire emissions were enriched in Si and Ca. The authors suggest that K may therefore be useful as a tracer for flaming and not smoldering fires (10). These measurements also indicated that smoldering fires contributed more than flaming fire to fine particle emissions (14). Mass concentrations ranged from 30 µg/m^3 in areas not affected by biomass burning to 300 µg/m^3 in large areas (2 million km^2) with intense burning. Additional studies of fine particle (<2 µm) composition associated with biomass burning in the Amazon Basin was reported by Artaxo et al (14). Biomass burning particulate is dominated by elemental (soot) and organic carbon, K and Cl, along with S, Ca, Mn and Zn. 24 hour average inhalable (PM_{10}) and fine ($PM_{2.5}$) mass concentrations as high as 700 µg/m^3 and 400 µg/m^3, respectively, were observed. The fine particle mass is composed of naturally released particle - organic carbon, soil dust particles and particles emitted during biomass burning. Dry season particulate levels were increased as a result of soil dust release during the entire dry season and biomass burning at the end of the dry season.

The issue of particulate matter air pollution and the components responsible for the observed associations between particulates and adverse health impacts is still quite controversial and currently unresolved. However, it may not be an important issue for health impacts, if one agrees with the assumption that even though $PM_{2.5}$ (or PM_{10}) itself may not be the agent responsible for health impacts, it is a good (the best known) surrogate for whatever components of air pollution are responsible. There is however, evidence to support a conclusion that $PM_{2.5}$ particulate is a better measure than PM_{10} (15, 16). Further, there is even reason to believe that combustion-source $PM_{2.5}$ itself is a responsible agent. This is based on the observation that numerous studies which demonstrate a relationship between particulate matter and health outcomes have been performed in different locations, where both the major particulate sources and the particulate composition itself are quite different. The only known common feature in these studies is the presence of combustion-source particulate air pollution.

Exposures

Exposure to biomass air pollution occurs in many settings. The highest concentrations of particles have been measured in forest fires themselves and in indoor air in developing countries where wood and other biomass is used as a cooking and heating fuel. In terms of exposure, domestic cooking and heating with biomass clearly presents the highest exposures since individuals are exposed to high levels of smoke on a daily basis for many years. Perez-Padilla and colleagues (17) developed an index of hour-years, analogous to pack-years for smoking history. In a study of rural Mexican women who cooked with biomass, the mean exposure was 102 hour-years. Pollutant levels measured in these settings have been described in several investigations, some of which are discussed in more detail in the following sections. Daytime respirable particulate matter measurements (approximately corresponding to $PM_{3.5}$) in China were 1600 $\mu g/m^3$ (18). In Kenya (19) and the Gambia (20), 24-hour respirable particulate measurements were 1400 and 2100 $\mu g/m^3$, respectively, while in Guatemala, 24-hour PM_{10} measurements were 850 $\mu g/m^3$ (21). Brauer and colleagues (22) measured particulate levels in rural Mexican homes. Mean PM_{10} levels were 768 $\mu g/m^3$. During cooking periods, the mean $PM_{2.5}$ level was 887 $\mu g/m^3$, while peak (5 minutes) $PM_{2.5}$ concentrations reached 2000 $\mu g/m^3$ or higher in most of the homes cooking with biomass (22). During cooking periods, measurements in Brazil and Zimbabwe reported respirable concentrations of 1100 and 1300 $\mu g/m^3$, respectively (18). Even higher levels have been reported in Nepal and India, accompanied by extremely high exposures to BaP. These exposures have recently been reviewed by Smith (18, 21).

Wildland (forest) firefighters comprise an occupational group with high exposure to biomass smoke. Exposures of wildland firefighter were recently reviewed by Reinhardt and Ottmar (23), and will be discussed further in the health effects section. The information regarding smoke exposures and health effects in firefighters is presented here to provide information on the plausibility of a relationship between smoke exposure and health impacts, as well as to indicate the levels of exposure encountered in this setting. It must be noted that firefighters are normally among the most physically fit in the entire population and do not normally suffer from any pre-existing health conditions. Accordingly, the absence of health impacts among this group does not indicate that health impacts will not be observed in the general population. In contrast, it is reasonable to argue that the demonstration of health impacts amongst firefighters provides strong evidence that similar effects will be observed within the general population at equivalent or lower levels of exposure. Exposures of the firefighter population are seasonal (4-5

months per year) and highly variable depending upon the number of fires per season, the intensity of the fires and specific job tasks.

In a large study of 221 firefighters at 39 prescribed fires, Reinhardt and Ottmar (23) measured mean CO and $PM_{3.5}$ levels of 4.1 ppm (maximum=38) and 0.63 (maximum=6.9) µg/m^3, respectively. Mean formaldehyde, acrolein and benzene levels were 0.047 ppm, 0.009 ppm and 0.016 ppm, respectively. Griggs and colleagues (24) measured CO exposures of firefighters at a peat and ground fire in North Carolina. Downwind of the fire, CO concentrations averaged 75 ppm and peak values of 500 ppm were measured. Carbon monoxide exposure of bush firefighters were measured by Brotherhood et al (25). Non-smoking individuals experienced mean exposures of 17 ppm and peak levels of 40-50 ppm. Smoking crew members were exposed to as much CO from their cigarettes as from the fires. Measurements of carboxyhemoglobin in these firefighters indicated that health impacts of CO exposure were unlikely to occur. In a study of 22 firefighters, personal sampling was conducted for carbon monoxide, sulphur dioxide, nitrogen dioxide, aldehydes, volatile organic compounds, total particulates, and PAHs. CO levels ranged between 4 and 8 ppm, while nitrogen dioxide concentrations were below the 0.2 ppm limit of detection. SO_2 concentrations ranged from non-detectable to 1.2 ppm. Aldehyde, PAH and volatile organic compound levels were also low or below detection limits. Most total particulate concentrations were below 1.2 mg/m^3, although two 4 hour samples were above 15 mg/m^3. It is not known what percentage of this was respirable. Across-shift symptom surveys indicated slight increases in eye, nose and throat irritation (26). Materna and colleagues (27) measured exposures of firefighters during several measurement campaigns over a three year period. Mean CO, respirable particulate and formaldehyde exposures were 14 ppm, 1.4 mg/m^3 and 0.13 ppm, respectively. Of the 12 specific PAHs detected, all were found at low levels (mean exposures <100 ng/m^3 except for phenanthrene at 380 ng/m^3). Although these data are limited, they are the most extensive available for PAH exposures.

Reh and colleagues (28) conducted extensive exposure assessment in combination with a medical evaluation. Respirable particulate levels were 0.6 - 1.7 mg/m^3 and sampling for acid gases detected low levels. Lung function decreased (<3 per cent change) and symptoms reports increased across workshifts. Electron microscopic examination of bandanas worn by the firefighters indicated that the bandanas had pore sizes of more than 100 µm, and therefore were not protective against respirable particulates or gaseous

pollutants (28). Another extensive series of exposure measurements was conducted by Reinhardt and colleagues. Personal sampling was conducted on 37 firefighters. Peak (15 minute) exposures averaged 14 ppm, 2.08 mg/m^3, 0.018 ppm, 0.177 ppm and 0.035 ppm, for carbon monoxide, respirable particulates, acrolein, formaldehyde and benzene, respectively (29). In summary, the exposure measurements of firefighters, while variable, indicate the potential for exposure to carbon monoxide and respirable particulates at levels (above 40 ppm for CO and above 5 mg/m^3 for respirable particulate) which have been associated with adverse health impacts. These health effects will be discussed in more detail in the health effects section.

In one of the few measurements of rural community air pollution associated with large tropical forest fires, Reinhardt (29) measured formaldehyde, acrolein, benzene, CO and respirable particulates ($PM_{3.5}$) in a rural area of Rondonia, Brazil, during the peak of the biomass burning season in 1996. Of the species measured, respirable particulate matter levels were significantly elevated, with mean levels of 190 µg/m^3, and with levels as high as 250 µg/m^3 measured during several of the 12-hour sampling periods. The author estimated that background levels of particulates in non-burning periods were 10-20 per cent of the levels measured during their study period. Particulate matter levels were also highly correlated with carbon monoxide concentrations, suggesting that carbon monoxide could be used as surrogate measurement of smoke exposure. Similar correlations have been observed in studies of North American wildland firefighters (23). The mean CO level was 4 ppm, which is similar to levels measured in moderately polluted urban areas and below the level expected to be associated with acute health impacts. The authors also reported increased levels of formaldehyde (average ambient levels of 16 µg/m^3) and benzene. Benzene levels (11 µg/m^3 average) were found to be higher than those measured in rural areas in other parts of the world and were comparable to those measured in many urban areas.

Another population with biomass pollution exposure are residents of North American communities where wood burning is prevalent. Elevated levels of ambient air pollution are seasonal (3-8 months depending upon the climate) and variable as they are strongly influenced by local meteorology. PM_{10} concentrations as high as 800 µg/m^3 have been measured in these communities, although peak levels (24-hour averages) of 200-400 µg/m^3 are more common (3, 30). PM_{10} measurements in British Columbia communities where wood smoke is the primary source of particulates indicate 24-hour averages of 2-420 µg/m^3 (2). Larson and Koenig (3) summarised several studies of PM measurements in communities with wood

smoke as a major particulate source. In the reported studies, PM_{10} concentrations as high as 150 µg/m^3 and $PM_{2.5}$ levels of 86 µg/m^3 were measured in cases where wood smoke contributed more than 80 per cent of the particulate mass. As wood smoke is generally emitted outdoors and since people spend most of their time indoors, indoor penetration is an important variable for exposure assessment and will be discussed in more detail in following sections. It is estimated that approximately 70 per cent of wood smoke particulate penetrates indoors (3), although this estimate is based upon a limited number of measurements in North American winter conditions.

Summary of biomass smoke exposures

Elevated concentrations of particulate matter are consistently observed in situations where exposure to biomass combustion occurs. Due to the size distribution of biomass particulates, essentially all will be contained in the $PM_{2.5}$ fraction, while the PM_{10} fraction will include additional particulates from resuspension of soil and ash. The highest concentrations are associated with indoor biomass combustion in developing countries and with exposures of wildland firefighters. These levels are 10-70 times above those observed in urban areas. Lower concentrations have been observed in ambient air within communities where wood burning is common and in plumes associated with large-scale tropical forest fires. These levels are 2-15 times those observed in urban areas. Domestic biomass burning in developing countries has also been associated with extremely high BaP levels (4000 times levels in urban air), while ten-fold lower exposures have been measured in wildland firefighters and even lower concentrations measured in community wood smoke (100 times urban air levels). Exposures to high concentrations of carbon monoxide are highly variable and only occasionally observed in wildland firefighters and in those exposed to domestic biomass smoke. Concentrations associated with tropical forest fires and community wood smoke are similar or slightly higher than those associated with motor vehicle emissions in urban areas. Large-scale tropical biomass fires are also associated with the production of ozone. Concentrations similar to those often measured in urban smog episodes have been measured in remote rural areas. Review of the literature on exposure and health impacts, as well as initial evaluation of the available air monitoring data from the 1997 “haze” episode, indicates that the pollutant variable most consistently elevated in association with biomass smoke is particulate matter. Accordingly, the emphasis throughout this paper and of recommended future studies will be focused on this compound.

ACUTE AND CHRONIC HEALTH IMPACTS

Experimental and animal toxicology studies

Many of the constituents present in wood smoke have been studied for their abilities to irritate mucous membranes and aggravate respiratory disease. Relatively few studies have evaluated the effects of whole wood smoke. Several studies have found an overall depression of macrophage activity as well as increases in albumin and lactose dehydrogenase levels, indicating damage to cellular membranes. Epithelial cell injury has also been demonstrated. A study in dogs indicated an increase in angiotensin-1-converting enzyme, a possible indication of an initial step towards pulmonary hypertension (3).

Two preliminary reports suggest that wood smoke exposure may lead to increased susceptibility to lung infection (31). These observations lend support to epidemiological associations between wood smoke exposure and respiratory illnesses in young children, as discussed below. In one study, Mary Jane Selgrade of the US EPA compared infectivity of Streptococcus zooepidemicus aerosol exposure in mice exposed previously to clean air, oil furnace emissions and wood smoke. The Streptococcus zooepidemicus causes severe respiratory infections. Two weeks post-exposure, 5 per cent of the mice in the control and oil furnace groups died, compared to 26 per cent of the wood smoke exposed group. Judith Zelikoff and colleagues at New York University exposed rats nasally to 800 $\mu g/m^3$ red oak smoke for one hour. The rats were then exposed to Staphylococcus aureus, a respiratory pathogen. These bacteria were more virulent in rats exposed to the smoke relative to controls, although the rats' lungs did not show any signs of inflammation. The researchers suggested that the wood smoke suppressed marcrophage activity.

These studies are best viewed as indications of plausibility for observed epidemiological associations and to help understand the mechanisms by which biomass smoke exposure may lead to adverse health outcomes. To demonstrate that adverse impacts of biomass smoke exposure in humans do occur, we will first evaluate population groups which are exposed to high levels; i.e. forest firefighters and those exposed to indoor air pollution in developing countries where biomass is used for cooking and/or heating.

Epidemiological studies of non-cancer health risks

Although the composition and concentrations of specific contaminants in smoke may vary by specific sources, associations between adverse health effects, particularly amongst children and the elderly, have been documented in numerous studies. Little is known about the toxicology of biomass smoke as a complex mixture, although the epidemiological findings are most consistent with those found for particulate matter.

Wildland firefighters

Several studies have evaluated impacts of biomass smoke exposure on wildland (forest) firefighters. These studies are summarised in Table 2, and several of them are discussed in more detail in the following section.

A study of 76 firefighters in the US Pacific Northwest evaluated cross-shift and cross-season respiratory effects. No significant increase or decrease in respiratory symptoms was observed across the firefighting season. The cross-shift and cross-season analysis identified significant mean individual declines in lung function. Although annual lung function changes for a small subset (n=10) indicated reversibility of effect, this study suggests a concern for potential adverse respiratory effects in forest firefighters. These firefighters worked an average of 15 fires during the season (31). Sutton et al (33) measured CO levels of 4-200 ppm and 24-hour TSP levels of approximately 0.5 mg/m^3 at a firefighter camp in California. Health assessment of the firefighters indicated a high prevalence of headaches (50 per cent), cough (66 per cent), shortness of breath (38 per cent), lightheadedness (32 per cent) and wheezing (31 per cent).

Letts and colleagues (34) evaluated cross-season changes in lung function and respiratory symptoms in 78 Southern California firefighters. Overall, the mean cross-season changes for lung function were -0.5 per cent FEV_1 (forced expiratory volume), 0.2 per cent FVC (forced vital capacity) and -0.5 per cent in the FEV_1/FVC ratio. No significant increase in the prevalence of respiratory symptoms was noted cross seasonally and those, which did occur, were not associated with exposure. The authors concluded that there was limited evidence that forest fire fighting results in cross-season changes in lung function, although the firefighters themselves indicated that the season of measurements contained fewer fires than was typical (34).

Rothman and colleagues (35) studied cross-seasonal changes in pulmonary function and respiratory symptoms in 52 wildland firefigthers in Northern California. The mean cross-seasonal change in FEV_1 was –1.2 per cent, with a corresponding mean change in FVC of -0.3 per cent. Decreases in FEV_1 and FVC were most strongly associated with hours of recent fire-fighting activity. When the study group was divided into three categories based on recent fire-fighting activity, firefighters in the high activity category (mean +/- SE, 73+/- hours of fire fighting in previous week) had a -2.9 per cent change in FEV_1 and a -1.9 per cent change in FVC. There was a significant cross-seasonal increase in most respiratory symptoms evaluated. Several symptoms (eye irritation, nose irritation, and wheezing) were associated with recent fire fighting. These findings suggest that wildland firefighters experience a small cross-seasonal decline in pulmonary function and an increase in several respiratory symptoms (35).

Liu and colleagues (36) studied cross-season lung function and airways responsiveness in 63 wildland fire fighters during a 5-month season of active fire fighting. There were significant mean individual declines in post-season lung function, compared with pre-season values. There was also a statistically significant increase in airway responsiveness when comparing pre-season methacholine dose-response slopes with post-season dose-response slopes. The increase in airway responsiveness appeared to be greatest in fire fighters with a history of lower respiratory symptoms or asthma, but it was not related to smoking history. These data suggest that wildland firefighting is associated with decreases in lung function and increases in airway responsiveness independent of a history of cigarette smoking (36).

A recent study compared lung function of wildland firefighters in Sardinia with a control group of policemen, in an attempt to evaluate chronic impacts of firefigthing exposure. On average, the firefighters worked during the 4-month fire seasons for 16 years. The firefighters had significantly lower levels of lung function (after controlling for age, height and smoking). Lung function measurements were conducted 10-11 months after the conclusion of the previous fire season. No relationship was observed between years of firefighting and lung function leading the authors to suggest that the adverse effect was due to repeated episodes of acute intoxication (37).

Summary of wildland firefighter studies

In summary, these studies clearly indicate an association between exposure and acute effects on respiratory health. Cross-seasonal effects have also been observed in most studies although these effects appear to be relatively small and may be reversible. As stated earlier, firefighters are an extremely fit and healthy group and cannot be considered representative of the general population. Accordingly, the demonstration of acute and sub-chronic effects in this occupational group indicates the plausibility, but not the magnitude of an association between biomass smoke exposure and adverse effects in the general population.

Indoor air pollution in developing countries

The health effects of biomass smoke inhalation have been documented in developing countries where women and children spend many hours cooking over unvented indoor stoves. On a global basis, it is the rural population in developing countries who are most highly exposed to fine particulates (22). Approximately 50 per cent of the world's population uses biomass fuel for cooking and/or heating.

The potential health effects associated with exposure to biomass combustion products in developing countries are widespread and have recently been reviewed (21). In particular, exposure to biomass combustion products has been identified as a risk factor for acute respiratory infections (ARI). ARI are the leading cause of infant mortality in developing countries. In addition to the risks of infants, the women who are cooking are also at risk for chronic respiratory diseases as well as adverse pregnancy outcomes.

A number of studies have reported associations of health impacts with use of biomass fuels, although few have directly measured exposure. These studies have been reviewed in detail by (21, 38) and are summarised in Table 3. Several of the more recent studies, including some in which exposures were measured will be discussed further. A case control study conducted in Zimbabwe found a significant association between lower respiratory disease and exposure to atmospheric wood smoke pollution in young children. Air sampling within the kitchens of 40 children indicated very high concentrations (546-1998 µg/m^3) of respirable particulates. Blood carboxyhaemoglobin (COHb) was determined for 170 out of 244 children confirming that they did experience smoke inhalation (39).

The association between exposure to air pollution from cooking fuels and health aspects was studied in Maputo, Mozambique (40). Personal air samples for particulate matter (roughly equivalent to PM_{10}) were collected when four types of fuels [wood, charcoal, electricity and liquified petroleum gas (LPG)) were used for cooking]. Wood users were exposed to significantly higher levels of particulate pollution during cooking time (1200 µg/m^3) than charcoal users (540 µg/m^3) and users of modern fuels (LPG and electricity)(200-380 µg/m^3). Wood users were found to have significantly more cough symptoms than other groups. This association remained significant when controlling for a large number of environmental variables. There was no difference in cough symptoms between charcoal users and users of modern fuels. Other respiratory symptoms such as dyspnea, wheezing, and inhalation and exhalation difficulties were not associated with wood use (40). Lifetime exposure from cooking fuels was estimated by multiplying the exposure level (1200 µg/m^3 for wood) by years of exposure (23 for wood), duration of daily exposure (3 hours) and use intensity factor (proportion of respondents using wood on the day of the measurement). The mean lifetime exposure variable was 2800 exposure-years for those currently using wood as the principal fuel. For comparison to other studies, the group using wood for burning had 69 hour-years of exposure.

A recent case-control study of Mexican women reported an increased risk of chronic bronchitis and obstructive airways disease associated with cooking with wood (41). The risk of chronic bronchitis was linearly associated with hour-years of cooking with biomass. Crude odds ratio for chronic bronchitis and chronic bronchitis/obstructive airways disease with wood smoke exposure were 3.9 and 9.7, respectively. Adjusted odds ratios ranged from 1.6-8.3, and 1.1-2.0 for chronic bronchitis and obstructive airways disease, respectively, depending upon the specific control group used

for comparison. The median duration of wood smoke exposure were 25 and 28 years for the chronic bronchitis and obstructive airways disease groups, respectively. The median hours per day of wood smoke exposure was 3 in the groups. Interestingly, the same research group who conducted a cross-sectional study of Mexican women currently exposed to varying levels of biomass smoke, indicated an association between biomass exposure and increased phlegm production and reduced lung function. Although these adverse effects were observed, they were smaller than expected based on the results of the case-control study. Possible explanations include different study design, bias in the case-control study and the development of resistance in women repeatedly exposed (41).

A case-control study conducted in Colombia identified a similar risk of obstructive airways disease (OAD) in women who cooked with biomass. Univariate analysis showed that tobacco use (OR=2.22; $p<0.01$), wood use for cooking (OR=3.43;$p<0.001$) and passive smoking (OR=2.05;$p<0.01$) were associated with OAD. The adjusted odds ratio for OAD and wood use (adjusted for smoking, gasoline and passive smoke exposure, age and hospital) was 3.92. The mean number of years of wood smoke exposure was 33 in the cases. The authors suggested that wood smoke exposure in these elderly women was associated with the development of OAD and may help explain around 50 per cent of all OAD cases (42).

A recent clinical report described a group of 30 non-smoking patients with lung disease thought to be associated with biomass smoke exposure during cooking. The patients had abnormal chest x-rays and evidence of pulmonary arterial hypertension. Their pulmonary function was consistent with mixed obstructive-restrictive disease (43).

Cassano and colleagues (44) reported on a cross-sectional study of approximately 8000 individuals in rural areas of China with 58 per cent wood use as domestic cooking fuel and 77 per cent use of vented stoves. Vented stoves were associated with increased lung function and time spent cooking was related to decreased lung function. Countywide chronic obstructive pulmonary disease (COPD) mortality data were inversely related to lung function data. These findings were similar for all fuel types and suggest a link between wood use as a cooking fuel and COPD.

Summary of studies of indoor air pollution in developing countries

Studies in developing countries indicate that biomass smoke exposure is associated with both acute respiratory illness in children and the development of chronic lung disease in adults. As these exposures are much higher than would occur as a result of short-term exposure to biomass air pollution associated with forest fires, direct comparisons are difficult to make. More so than with studies of wildland firefighters, the studies conducted in developing countries indicate the serious consequences of exposure to high levels of biomass air pollution. Increased acute respiratory illness in children associated with biomass smoke exposure is a likely cause of infant mortality while the development of chronic lung disease in adults is associated with premature mortality and substantial morbidity.

Community/cohort indoor and ambient air pollution studies

Particulates - overview

This paper will not discuss the voluminous particulate epidemiology literature in detail as a book (45) and several review articles have recently been published (16,46,47). Instead, an overview of the findings, and examples of the major study types and their findings, will be discussed with emphasis on the time series studies of acute health impacts and the recent prospective cohort studies of chronic exposure impacts. The available evidence associating biomass air pollution with adverse health outcomes will then be discussed in detail.

Early air pollution disasters, such as the London fog of 1952, were dramatic examples of the impact of air pollution on mortality and other health effects (48,49). These air pollution episodes were the motivation for regulations and consequent air quality improvements in the past 30-40 years. However, recent studies have indicated that current levels of air pollution are associated with adverse health outcomes. The most startling finding of these studies is the association of particulate matter air pollution, with increased daily mortality (50-58). Different investigators have conducted these studies in a variety of locations, using a variety of study designs. In nearly all cases, the studies indicate an association between particle air pollution and increased risk of death, primarily in the elderly and in individuals with pre-existing respiratory and/or cardiac illness (59,60). Recent studies have also suggested an association between particulates and infant mortality (61,62) as well as with low birth weight (63). Increased risk of hospital admissions and increased emergency room visits have also been associated with short-term

increases in the levels of particle air pollution (46, 59, 64-68). Table 4 summarizes the results of these studies for the various health outcomes assessed. One common feature of the study locales is that ambient particulate matter is produced in combustion processes. Studies of naturally-produced particles (such as those generated from windblown soil or volcanic eruptions) show a much smaller impact on health outcomes for an equivalent particle concentration (46, 69, 70). These data support the hypothesis that any combustion-source particulate air pollution is associated with adverse health outcomes. The implications of this hypothesis are far-reaching, as they suggest that particulates are associated with adverse health effects in essentially all urban areas.

The majority of the particulate epidemiology studies have evaluated the acute impacts of particulate air pollution with time-series study designs. Only a limited number of studies have investigated long-term effects. Of these, the most significant are the prospective cohort studies in which the analyses can control for individual differences in risk factors such as smoking. Dockery et al (50) studied over 8,000 adults in six US cities with different levels of air pollution over a period of 16 years. The adjusted mortality risk was 26 per cent higher in the most polluted city relative to the least polluted city. Survival decreased with increasing particulate levels. In a study of more than 500,000 adults with 8-year follow-up, Pope and colleagues found a significant association between fine particles and particle sulfate with cardiopulmonary mortality after controlling for smoking, education and other potential confounding factors (58). The adjusted mortality risk was 15-25 per cent higher in cities with the highest particulate levels relative to the cities with the lowest levels. Together these studies indicate that long-term exposure to particulate air pollution has a significant impact on reduction of life expectancy. The results of the cohort studies of Dockery and Pope (46) were used to estimate the reduction in life expectancy associated with long-term particulate exposure. For a 10 $\mu g/m^3$ difference in long-term exposure to $PM_{2.5}$, the relative risk of mortality is 1.1. When applied to a 1992 life expectancy for Dutch men, the estimated effects is a 1.1 years reduction for each 10 $\mu g/m^3$ difference in long-term exposure to $PM_{2.5.}$

In the only cohort study of morbidity associated with long-term particulate exposure, Abbey and colleagues (71, 72) studied a cohort of nearly 4000 non-smoking Seventh Day Adventists in California. The relative risks of developing new cases of chronic respiratory disease were significantly associated with particulate levels. For TSP levels above 100

μg/m^3 (in this case similar risks were observed for PM_{10} levels above 80 μg/m^3), significantly elevated risks were observed for as few as 500 hours (21 days) of exposure per year, for 4 years (71,72). Increased risks were observed for longer duration and higher levels of exposure. A significant risk for the development of asthma was associated with long-term exposure to TSP above 150 μg/m^3. Similar analyses were also conducted for estimated and measured concentrations of PM_{10} and $PM_{2.5}$. While the risk of asthma development was not evident in these analyses, significant risks for the development of new cases of chronic bronchitis and obstructive airways disease were found at annual average PM_{10} and $PM_{2.5}$ levels of 20-100 μg/m^3 (73). Increased symptoms severity was associated with annual average concentration of 20-40 μg/m^3 and 40-50 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively.

While the vast majority of studies have measured PM_{10}, there is evidence to support regulating $PM_{2.5}$ levels. Schwartz et al (74) compared $PM_{2.5}$ and the coarse fraction of PM_{10} (PM_{10}-$PM_{2.5}$) as indicators of mortality. A significant relationship between $PM_{2.5}$ and mortality, but not with coarse particles, was found. These results are also consistent with our understanding of particle deposition since coarse particles are efficiently removed in the upper respiratory tract, while fine particle penetrate deep into the lung. A recent analysis of insoluble particles in autopsy lungs found that 96 per cent of the particles were smaller than 2.5 μg/m (75). The $PM_{2.5}$ fraction also contains primarily particles produced in combustion processes, while the coarse fraction contains solid and crustal material that is not as toxicologically reactive.

Currently inhalable particulate matter is regulated in many countries. Since 1987, the US EPA standard for PM_{10} has been 150 µg/m^3 and 50 µg/m^3 for 24-hours and one year, respectively. California has set a standard of 50 and 30 µg/m^3 for 24 hour and annual averages, respectively. The WHO Air Quality Guidelines for Europe declined to recommend specific guidelines for particulate matter as the available studies do not indicate an obvious exposure concentration and duration that could be judged a threshold. The document argues that the available data suggest a continuum of effects with increasing exposure. Recently the US EPA set the first standard for $PM_{2.5}$ as 65 µg/m^3 and 15 µg/m^3 for 24 hour and annual averages, respectively.

Wood and other biomass smoke

Epidemiological studies of wood smoke in North America have focused on symptoms and/or lung function as the main outcome measures. The majority of studies have focused on children, due to the assumption that children are susceptible due to small lung volumes and incompletely developed immune systems. Children are also somewhat simpler to study, as cigarette smoking or occupation does not confound their exposures.

Several early studies focused on the presence of a wood burning stove in the home as a risk factor. These studies indicate that wood stoves, especially older varieties can emit smoke directly into the home (3). Newer airtight stoves emit less smoke into the homes, but indoor exposure still occurs due to infiltration of smoke emitted outdoors into the home. Therefore, while these earlier studies strongly suggest that there are adverse impacts associated with wood smoke exposure, their crude exposure assessment precludes more specific conclusions. The Harvard University Six Cities Study reported that wood stove use was associated with an increased risk of respiratory illness in children (76). Honicky and colleagues (77, 78) studied 34 children living in homes with wood stoves compared to 34 with other heating sources, mainly gas. Occurrence of wheeze and cough was much greater in the group of children living in homes with wood stoves, although no measurements were made of wood smoke (77). The study of Honicky and Osborne (78) was motivated by a case report of a 7 month old infant hospitalised with serious respiratory disease, which was associated with the family's purchase of a wood burning stove. Another clinical case report strongly argues for the biological relationship between wood smoke exposure and lung disease, in this case, interstitial disease, and not the obstructive lung disease commonly associated with biomass smoke exposure in developing countries (79). Ramage et al (80) reported on the case of 61-

year-old women with interstitial lung disease. Bronchioalveolar lavage revealed numerous particulates and fibres, as well as cellular and immunoglobulin abnormalities. The particles were shown to be carboneceous by energy dispersive X-ray analysis (EDXA). Inflammation and fibrosis were found surrounding them on open biopsy. The particle source was traced to a malfunctioning wood-burning heater in the patient's home (80).

Tuthill (81) measured respiratory symptoms and disease prevalence in 258 children living in homes with wood stoves compared to 141 children in homes without wood stoves. A slight, but not statistically significant elevated risk of symptoms was found in this study. No exposures were measured. Butterfield et al (82) monitored 10 respiratory disease symptoms in 59 one to 5½ year old children, again comparing those living in homes with and without wood stoves. Wheeze and cough symptoms were associated with living in a home with a wood stove. Although no measurements were made of wood smoke exposure, a study conducted during the following winter indicated monthly mean outdoor PM levels of approximately 50-65 $\mu g/m^3$ while source apportionment studies indicated that approximately 70 per cent of the winter particulate was from wood burning (83). A case-control study of 59 matched pairs of native American children less than 2 years old indicated increased risk of lower respiratory tract infection for children living in homes with wood stove (84).

A similar case-control study conducted among Navajo children evaluated the association between wood smoke exposure and acute lower respiratory illness (ALRI). In a significant improvement from earlier studies, indoor particulate levels were measured in this investigation. Forty-five 1-24 month old children hospitalised with an ALRI were compared with age and gender matched controls who had a health record at the same hospital and had never been hospitalised for ALRI. Home interviews of parents of subjects elicited information on heating and cooking fuels and other household characteristics. Indoor PM_{10} sampling was conducted in the homes of all cases and controls. Matched pair analysis revealed an increased risk of ALRI for children living in households that cooked with any wood or had indoor particle concentrations greater than or equal to 65 $\mu g/m^3$. The indoor particle concentration was positively correlated with cooking and heating with wood (geometric mean levels of approximately 60 $\mu g/m^3$) but not with other sources of combustion emissions (85). In the only study to date to evaluate impacts of wood burning on adult asthma, Ostro et al (86) measured symptoms in a panel of 164 asthmatics. Exposure to indoor combustion

sources, including wood stoves was associated with increased asthma exacerbation. The studies of low-level indoor exposure are summarized in Table 5.

Several other studies, summarised in Table 6, have evaluated health outcomes in communities where wood smoke is a major, although not the only, source of ambient particulate. Heumann et al (30) studied lung function in 410 school children in Klamath Falls, Oregon, during a winter season. Children from schools in high and low exposure areas were studied. In Klamath Falls, it has been estimated that wood smoke accounts for as much as 80 per cent of winter period PM_{10}. Winter period PM_{10} levels in the high exposure area ranged from approximately 50-250 µg/m^3 while levels in the low exposure area ranged from 20-75 µg/m^3. Lung function decreased during the wood burning season for the children in the high exposure area, but not in the low exposure area (30). Two studies were conducted in Montana to evaluate acute changes in lung function in children within a single community at different levels of air pollution and also to evaluate cross-sectional differences in lung function between communities with different air quality levels, as an indication of chronic impacts (87). Acute lung function decrements measured in 375 children were associated with increased levels of particulates. 24-hour averages ranged from 43-80 µg/m^3 and 14-38 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. The chronic impact study also associated small decrements in lung function with residence in communities with higher levels of air pollution. Although particle composition was not measured directly in this study, measurements conducted in the acute study community during the same period, attributed 68 per cent of the $PM_{3.5}$ to wood smoke (3).

A questionnaire study of respiratory symptoms compared residents of 600 homes in a high wood smoke pollution area of Seattle with 600 homes (questionnaires completed for one parent and two children in each residence) of a low wood smoke pollution area. PM_{10} concentration averaged 55 and 33 µg/m^3 in the high and low exposure areas, respectively. When all age groups were combined, no significant differences were observed between the high and low exposure areas. However, there were statistically significant higher levels of congestion and wheezing in 1-5 year olds between the two areas for all three questionnaires (1 baseline questionnaire and two follow-up questionnaires which asked about acute symptoms). This study supports the other investigations suggesting that young children are particularly susceptible to adverse effects of wood smoke (88).

A more comprehensive study in the same high exposure Seattle area was initiated in 1988. In these residential areas in Seattle, 80 per cent of particulate matter are from wood smoke (3). Lung function was measured in 326 elementary school children (including 24 asthmatics) before, during and after two wood burning seasons. Fine particulate matters was measured continuously with an integrating nephelometer. Significant lung function decrements were observed in the asthmatic subjects, in association with increased wood smoke exposure. The highest (night time 12-hour average) $PM_{2.5}$ level measured during the study period was approximately 195 µg/m^3 and PM_{10} levels were below the US National Ambient Air Quality Standard of 150 µg/m^3 during the entire study period (89). For the asthmatic children FEV_1/FVC decreased by 17 and 18.5 ml for each 10 µg/m^3 increase in $PM_{2.5}$, while no significant decreases in lung function were observed in the non-asthmatic children. A companion study evaluated the impact of particulate matter on emergency room visits for asthma in Seattle (66). In this study a significant association was observed between PM_{10} particle levels and emergency room visits for asthma. The mean PM_{10} level during the 1-year study period was 30 µg/m^3. At this concentration, PM_{10} appeared to be responsible for 125 of the asthma emergency room visits. An exposure response relationship was also observed down to very low levels of PM_{10}, with no evidence for a threshold at concentrations as low as 15 µg/m^3. The authors indicate that on an annual basis 60 per cent of the fine particle mass in Seattle residential neighbourhood is from wood burning.

Two time series studies (90, 91) have been conducted in Santa Clara County, California, an area in which wood smoke is the single largest contributor to winter PM_{10}, accounting for approximately 45 per cent of winter PM_{10}. Particulate matter levels are highest during the winter in this area. The first study was one of the initial mortality time series studies which indicated an association between relatively low PM_{10} levels and increased daily mortality (90). A recent study of asthma emergency room visits in Santa Clara County and winter PM_{10} found a consistent relationship. Specifically, a 10 µg/m^3 increase in PM_{10} was associated with a 2-6 per cent increase in asthma emergency room visits (91). These results demonstrate an association between ambient winter time PM_{10} and increased daily mortality and exacerbation of asthma in an area where one of the principal sources of PM_{10} is residential wood smoke.

Two other studies (92, 93) conducted in North America focused on other sources of biomass burning besides wood burning stoves or fireplaces. In a small study of 7 medicated asthmatics, subjects were walked 0.5 mile

with and without exposure to burning leaves on the same day, under very similar environmental conditions. Significant decreases in lung function were observed in the asthmatics within 30 min of exposure to leaf burning, while lung function of non-asthmatics was not affected (92). In a recent study, 428 subjects with moderate to severe airways obstruction were surveyed for their respiratory symptoms during a 2-week period of exposure to combustion products of agricultural burning (straw and stubble). During the exposure period, 24-hour average PM_{10} levels increased from 15-40 $\mu g/m^3$ to 80-110 $\mu g/m^3$. 1-hour level of carbon monoxide and nitrogen dioxide reached 11 ppm and 110 ppb, respectively. Total volatile organic compound levels increased from 30-100 $\mu g/m^3$ before the episode to 100-460 $\mu g/m^3$ during the episode. While 37 per cent of subjects were not bothered by smoke at all, 42 per cent reported that symptoms (cough, wheezing, chest tightness, and shortness of breath) developed or became worse due to the air pollution episode and 20 per cent reported that they had breathing trouble. Those with symptoms were more likely to be female than male and ex-smokers than smokers. Subject with asthma and chronic bronchitis were also more likely affected (93). The results of these studies indicate that other forms of biomass air pollution, in addition to wood smoke, are associated with some degree of impairment, and suggest that individuals with pre-existing respiratory disease are particularly susceptible.

Perhaps the study with the most relevance to the issue of biomass air pollution in Southeast Asia is an analysis of emergency room visits for asthma in Singapore during the 1994 "haze" episode (94). The study, described briefly in a letter to Lancet, indicates an association between PM_{10} and emergency room visits for childhood asthma. During the "haze" period, mean PM_{10} levels were 20 per cent higher than the annual average. Although a time series analysis was not conducted, the authors suggest that the association remained significant for all concentrations above 158 µg/m^3.

Two studies (95, 96) have been conducted regarding asthma emergency room visits and PM_{10} levels associated with smoke from bushfires in Sydney Australia. During 1994, PM_{10} levels were elevated (maximum hourly values of approximately 250 µg/m^3) for a 7-day period. Ozone levels were not elevated during the period in which smoke impacted Sydney. Neither study detected any increase in asthma emergency room visits during the bushfire smoke episode. Both studies used relatively simple analyses. One study had little power to detect small changes in emergency room visits as they related to air pollution and the other only used relatively short periods for comparison; neither detected any association. The results appear to conflict with those of studies conducted in North America. Possible reasons are differences in study design and sample size as well as differences in chemical composition of the particulates and differences in the relative toxicity of the specific particle mixture.

In a similar analysis to the studies of Australian bushfires, Duclos et al (97) evaluated the impact of a number of large forest fires in California on emergency room visits. During the approximately 2½ week period of the fires, asthma and chronic obstructive pulmonary disease visits increased by 40 and 30 per cent, respectively. PM_{10} concentrations as high as 237 µg/m^3 were measured. Based on TSP concentration, PM_{10} levels were significantly higher in other regions without PM_{10} monitoring.

Summary of wood and biomass community/cohort studies

The epidemiological studies of indoor and community exposure to biomass smoke indicates a consistent relationship between exposure and increased respiratory symptoms, increased risk of respiratory illness and decreased lung function. These studies have mainly been focused on children. The few studies which evaluated adults also showed similar results. A limited number of studies also indicate an association between biomass smoke exposure and visits to hospital emergency rooms. A notable

exception is the analysis of populations exposed to large bushfires in Australia, which did not show any association between PM_{10} and asthma emergency room visits. There are also indications from several studies that asthmatics are a particularly sensitive group. No studies have explicitly evaluated the effect of community exposure to biomass air pollution on hospitalisation or mortality, although one study indicated a relationship between PM_{10} and mortality in an area where wood smoke is a major contributor to ambient PM_{10}. By analogy to the findings of numerous studies associating increased mortality with urban particulate air pollution mixtures, it is reasonable to conclude that similar findings would also be observed in locations exposed to biomass smoke. From the vast number of particulate studies, there is no evidence that airborne particles from different combustion sources have different impacts on health. Particles generated by natural processes such as volcanic eruptions and windblown soil do appear to have less of an impact on health. Therefore, there is little reason to expect that biomass smoke particulate would be any less harmful than other combustion-source particles and it is prudent to consider that biomass smoke exposure is also related to increased mortality. The particulate mortality studies also do not show evidence for a threshold concentration at which effects are not observed. If such a threshold level does exist it is likely to be a very low level, below those levels measured in most urban areas to the world.

Nearly all the low-level indoor and community biomass smoke studies mentioned above evaluated impacts of concentrations which were much lower than those associated with the 1997 Southeast Asian haze episode. Similarly, the studies of seasonal exposure to wood smoke involved exposure duration, which were of comparable length to those experienced in Southeast Asia. Based on these studies it is reasonable to expect that the Southeast Asian haze episode resulted in the entire spectrum of acute impacts, including increased mortality, as well as subchronic (seasonal) effects on lung function, respiratory illness and symptoms. It is not possible at this time to determine the long-term effect, if any, from a single air pollution episode, although repeated yearly occurrences of high biomass smoke exposure should be cause for serious concern. Chronic (several years) exposure to particulate air pollution in urban areas, at much lower levels than experienced in Southeast Asia in 1997, has been associated with decreased life expectancy and with the development of new cases of chronic lung disease.

Cancer

Cohen and Pope (98) recently reviewed the evidence associating air pollution with lung cancer. Studies suggest rather consistently that ambient air pollution resulting from fossil fuel combustion is associated with increased rates of lung cancer. Two recent prospective cohort studies observed 30-50 per cent increases in lung cancer rates associated with exposure to respirable particulates, best viewed as a complex mixture originating from diesel exhaust, coal, gasoline and wood. One of these studies suggested that sulfate particles (likely originating from coal and diesel combustion) appeared to be more strongly associated with lung cancer than fine particles. The results of these cohort studies are generally consistent with other types of exposure to combustion-source pollution such as occupational exposure and environmental tobacco smoke. While biomass smoke may be similar in some respects to cigarette smoke, the excess lung cancer risk associated with ambient air pollution (relative risks of 1.0-1.6) is small compared with that from cigarette smoking (relative risks of 7-22) but comparable to the risk associated with long-term environmental tobacco smoke exposure (relative risk of 1.0-1.5).

There is little direct information regarding the human cancer risks associated with biomass air pollution. The US EPA studied the contribution of wood smoke and motor vehicle emissions to the mutagenicity of ambient aerosols in Albuquerque, NM. This study found that, despite wood smoke being the major contributor to the mutagenicity of ambient particulate matter, it was 3 times less potent as a mutagen than extractable organic associated with vehicle emissions (99). The mutagenic potency of air samples decreased linearly with increased fraction of samples originating from wood smoke.

In an application of this and other work, the estimated lifetime cancer risk associated with 70 years of exposure to air pollution dominated by wood smoke (80 per cent) was calculated to be approximately 1 in 2,000. This calculation assumes lifetime exposure to PM_{10} levels of 25-60 $\mu g/m^3$ of which wood smoke is a major component for approximately 3 months every year. Extrapolating these estimates to an environment of 100 per cent wood smoke estimates an individual lifetime cancer risk of approximately one in 10,000 (83). It must be emphasized that these risk estimates do not mean that out of every 10,000 exposed people, one will develop cancer, but rather serve as estimates upon which different exposure scenarios and pollutants can be compared and to evaluate whether certain exposures can be considered as significant risks. For environmental exposure, regulatory agencies often

consider lifetime cancer risk greater than one in one million to be significant.

BaP is a human carcinogen as defined by the International Agency for Research on Cancer (IARC) and is present in biomass smoke at high levels. Smith and Liu (18) reviewed studies of BaP levels in biomass smoke and discussed studies which have evaluated lung cancer risks. Despite high exposures to a known human carcinogen, there is relatively little evidence for a relationship between lung cancer and biomass smoke exposure. If any effect does exist it is thought to be small, relative to other risk factors such as diet or exposure to air pollution from coal burning. Lung cancer is itself relatively rare in areas of biomass fuel use, even if age-adjusted cancer rates are analysed (18). A similar argument is presented for nasopharyngeal cancers, which are also rare in areas of biomass smoke use (100).

The findings of relatively low mutagenicity for wood smoke, have, to some extent, been validated in an ongoing study (101) of indoor environmental exposure risks and lung cancer in China. Cross-sectional comparisons of population subgroups in Xuan Wei, China, an area noted for high mortality from respiratory disease and lung cancer, suggested that the high lung cancer rates cannot be attributed to smoking or occupational exposure. Since residents of Xuan Wei, especially women, are exposed to high concentration of coal and wood combustion products indoors, a study was undertaken to evaluate the lung cancer risks of these exposures. On average women and men in Xuan Wei spend 7 and 4 hours per day, respectively, near a household fire. A 1983 survey indicated that the lung cancer rate in Xuan Wei was strongly associated with the proportion of homes using smoky coal in 1958 (101). No relationship was observed between lung cancer and the percentage of homes using wood.

A follow-up study (102) compared exposures in two otherwise similar Xuan Wei communities, one with high lung cancer mortality (152/100,000) where smoky coal was the major fuel and another with low lung cancer mortality (2/100,000) where wood (67 per cent) and smokeless coal (33 per cent) were used. Lung cancer mortality was strongly associated with indoor burning of smoky coal and not with wood burning. This association was especially strong in women who seldom smoked and were more highly exposed to cooking fuel emissions than men. Indoor PM_{10} concentrations measured during cooking were extremely high (24, 22 and 1.8 mg/m^3 for smoky coal, wood and smokeless coal, respectively). In contrast to other studies of wood smoke particle size distribution, measurements in Xuan Wei

indicated that only 6 per cent of the particles emitted during wood combustion were smaller than 1 µm in size, whereas 51 per cent of the smoky coal particles were submicron. Mutagenicity tests of particulates collected from the various combustion processes indicated that smoky coal was approximately 5 times more mutagenic than wood (103). This study suggests that there was little association between open-fire wood smoke exposure and lung cancer, despite very high exposure with long duration (women generally start cooking at age 12). One possible explanation is the relatively low biological activity of wood smoke particulate matter combined with less efficient deposition of the larger particles.

The available, although limited, data on biomass smoke and cancer do not indicate an increased risk even at very high levels of exposure. This evidence includes studies of long-term exposure to high levels of biomass smoke from domestic cooking in developing countries. Evidence for a relationship between urban particulate air pollution and lung cancer is also limited but is suggestive of a small, but measurable, increased risk. There have not been enough studies conducted to evaluate the consistency of any increased risk for different particle sources. However, while biomass smoke is clearly mutagenic, it is much less so than motor vehicle exhaust, on a comparable mass basis.

RESEARCH NEEDS

The studies discussed above indicate that biomass air pollution is clearly associated with some degree of adverse health outcome. By analogy to the general particulate epidemiology, it is likely that the exposures encountered during biomass air pollution episodes in Southeast Asia will result in acute health impacts spanning the entire range of severity, from sub-clinical impacts on lung function to increased daily mortality. Shorter duration episodes at lower air pollution concentrations have been linked with adverse impacts, while chronic exposure to higher levels of biomass air pollution and to lower levels of urban air pollution have been associated with development of chronic lung disease and decreased life expectancy. Therefore, the Southeast Asian biomass air pollution scenario falls into a relatively unique exposure category in which acute effects are highly probable but at exposure levels much lower (especially in terms of duration) than those experienced in studies which have demonstrated chronic impacts. Given the uncertainty regarding the potential for chronic effects, it would seem reasonable to initially evaluate the acute health impacts, especially since these are likely to include severe impacts such as increased mortality. Further, acute impacts are expected to be much easier to detect with a high degree of confidence than chronic health endpoints. To help understand the potential for adverse health effects and to evaluate the effectiveness of various mitigation measures, there is also a need to investigate several exposures issues. Several major research questions are summarised below. However, before these questions can be addressed, it will be necessary to identify the availability of data, specifically air monitoring data and valid data on health indicators such as daily mortality, hospital visits, clinic/emergency room visits, etc.

1. What were the short-term human health impacts associated with exposure to biomass air pollution in Southeast Asia?

   For the range of identified impacts, were the effects reversible or permanent?

2. What were the long-term human health impacts (if any) associated with exposure to biomass air pollution in Southeast Asia?

3. Which (if any) population groups were especially susceptible to adverse health effects of biomass air pollution in Southeast Asia?

4. What was the size of the exposed population?

   Using study results and available air monitoring data (possibly including satellite data) can the region-wide health impacts be estimated?

5. What was the relationship between differences in exposure and health impacts across the affected region?

   Were there exposed areas in which health impacts were larger/smaller than others?

   Can an exposure-response relationship be demonstrated throughout the region?

6. What was the effectiveness of the following health protection measures ?

   a) The use of dust masks

   b) Advising the population to remain indoors

7. What was the composition of the biomass air pollution, which affected Southeast Asia?

   a) Can specific biomass markers compounds be identified?

   b) To what extent is it possible to distinguish biomass air pollution from the "background" urban air pollution?

POSSIBLE RESEARCH DESIGNS

In developing study designs for epidemiological investigations, it is important to note that, in general, the more serious the outcome measure, the smaller the affected population will be. In turn, the more serious the outcome measure, the greater the availability of data. The pyramid (Figure 1) illustrates these tradeoffs, with the size of each level representative of the number of people affected. Severe outcomes such as mortality will only be seen in a relatively small group of people, and will therefore require a large sample size to detect an effect. However, such information is often easily

available from administrative databases (death registries, for example). Less severe outcomes such as reduced lung function will generally be evident in a larger segment of the population, therefore requiring a smaller sample population to detect an effect. To obtain this information, however, requires individual assessment.

A similar set of trade-off occurs when selecting exposure measurements. At one extreme, regional data on air quality can be obtained from remote sensing data relatively inexpensively and efficiently. These data are imprecise and only provide a crude, but still quantitative, estimate of exposure. It is possible to estimate concentrations for several gases and for particulates by this technique. No detailed information on particle composition can be obtained and the measurements are "snapshots" of selected time intervals. This approach may be most useful for evaluating impacts in rural areas without ambient monitoring stations. Ground-based ambient air monitoring can either provide a continuous or time-integrated assessment of particulate and gaseous pollutants. Integrated particulate measurements have the advantage that post-sampling of chemical analysis of particles is possible. The usefulness of these data is determined by the extent of regional coverage of a monitoring network. In the absence of these measurements, airport visibility data has been used as a surrogate measure of particulate concentrations (73). For particular study populations, specific ambient monitoring stations that more closely reflect the populations' exposure may be required - such as placing specific monitors in selected neighbourhoods.

Since individuals spend the majority of time indoors, more precise exposure estimates are obtained from indoor monitoring. The cost of this enhancement is that an individual monitor must be placed in each residence/workplace of the study population. Often indoor and outdoor measurements can be combined with information about an individual's activity patterns (how much time they spend in particular locations) to estimate their exposure. Large scale models have been developed to estimate population exposure based on census data, time-activity surveys of the population, and information on indoor and outdoor relationships for various pollutants within the various "microenvironments" where individuals spend time throughout their lives (home, work, school, etc.). The US EPA has developed models for CO and O_3. Currently, researchers at the US EPA, Harvard University and The University of British Columbia are working together to develop models for PM_{10} and $PM_{2.5}$ exposure. The most precise exposure measure is obtained by actually monitoring personal exposure -

having an individual wear a monitor as they move from microenvironment to microenvironment throughout the day. While it is possible with this approach to accurately measure exposure of a representative population sample, the extent of such monitoring limited by financial and logistical constraints. Further, such monitoring is often inconvenient for subjects and the measurement technology may be constrained to the extent that precision is affected.

With regard to the general research questions identified above, several possible study designs are proposed:

Acute health impacts

Comprehensive studies of the acute impacts of forest fire-related air pollution episodes should be conducted. Ideally, these studies should be directed towards the most severe health outcomes. Accordingly, the use of adequately large sample sizes is critical, as is the selection of appropriately sensitive statistical modelling techniques. Examples of studies are:

(a) A time-series study of hospital visits in one or more major metropolitan areas with air monitoring and complete hospital visit data. In such studies, daily counts of deaths/hospital admission are compared to daily air pollution concentrations.

(b) A time-series study of acute mortality in one or more major metropolitan areas.

(c) Where feasible, additional time series studies on emergency visits, clinic visits, respiratory symptoms, work or school absenteeism can be conducted.

To the extent possible, individual factors such as age, health status, socioeconomic factors, etc. should be evaluated in the analysis, both to control for potential confounding as well as to evaluate the existence of susceptible population sub-groups.

Further, to the extent possible, specific study protocols should be standardised and conducted in several regions where ambient air concentrations differ.

Chronic health impacts

Comprehensive study of the long-term impacts of forest fire-related air pollution may be attempted although it must be acknowledged that such studies are extremely difficult to conduct, and even the best studies will provide equivocal results due to issues of confounding variables and misclassified exposure. Such issues are particularly complicated in the study of impacts of episodic air pollution events. Furthermore, the cross-sectional and semi-individual study designs depend on the identification of measurable variability in exposure, and in this case, that the impact of the specific haze episode(s) resulted in variability in exposure. Possible study designs might include:

(a) continuation of any ongoing cohort studies of health status (in which individual-level data are available) in locations where air monitoring data are available or where concentrations can be reliably estimated. Studies of large populations with varying exposure to biomass air pollution would be particularly useful. If available, such databases can be linked retrospectively with air pollution data.

(b) cross-sectional comparisons of respiratory/cardiovascular disease incidence and mortality in areas with differing exposure to biomass air pollution.

(c) semi-individual studies in which members of a demographically homogeneous population can be individually evaluated for health outcomes (lung function measurements, for example) and in which potential confounding variables (smoking status, for example) can be measured. The measured health outcome is then compared to individual exposure profiles which are determined retrospectively by combining subject interviews with ambient air monitoring data. Examples of populations studied by this method are military recruits and students entering university.

(d) Case-control studies have also been used in the past to estimate the risk of chronic health impacts. In such studies, individuals with some well-defined health outcomes are identified and the exposure of these "cases" is compared to a suitable control group which is similar to the case group, except for the presence of the health outcome. It is quite difficult to conduct such studies, primarily

since the selection of a suitable control group is critical. If an inappropriate control group is used, biased results can be obtained. To estimate the impact of biomass-related air pollution using this study type would require the identification of a control group which was similar (in terms of age, socioeconomic status, smoking status, etc.) to a group treated for some respiratory illness after the haze episode.

Exposure issues

Regional exposure

A region-wide composite database of ambient air concentration should be developed. Estimated air pollution contour plots can be developed using available air monitoring data, and if feasible, supplemented with airport visibility and remote sensing data. Using such a database combined with region-specific demographic data and with exposure-response relationship determined from epidemiological studies, the regional impact of the biomass air pollution episode can be estimated.

Mask effectiveness

The effectiveness of masks for use by the general public should be evaluated. An additional aim should be an adequate understanding of the variables determining mask effectiveness, including technical factors such as filtration efficiency and leakage, as well as non-technical issues such as population compliance and comfort. Identification of the most important variables determining mask effectiveness will enable the design of new masks that are specifically applicable for general public use.

Indoor penetration

The effectiveness of air cleaners, air conditioners, open/closed windows within various building types (residential or office) as they relate to indoor penetration of fine particles should be assessed. Perhaps the simplest investigation would be to measure air exchange rates in representative building types under different scenarios. As discussed in the Mitigation Measures section, once air exchange rate information is known the infiltration of outdoor particles can be calculated. Verification of these calculated values could then be undertaken on a smaller set of buildings.

Biomass smoke composition

Detailed chemical analysis of particulate samples should be conducted to identify the proportion of various functional groups (PAHs, elemental carbon, trace metals, etc.) within the haze particulate matter. While this analysis may be useful in future risk assessment and in comparing the toxicity of these particulate samples to those collected in other locations, the current emphasis should be on identifying marker compounds which may be used to distinguish air pollution originating from biomass burning from other sources. If identified, tracer compound(s) may be used to refine exposure assessment in epidemiological studies and to specifically evaluate indoor penetration of biomass particulate. Additional efforts should be directed to the determination of the size distribution of the biomass particulate and to an analysis of impacts of the haze episode on other routinely monitored ambient air pollutants, in particular, carbon monoxide and ozone.

MITIGATION MEASURES

Due to the limited effectiveness of exposure avoidance activities during regional haze episodes, priority emphasis must be given to elimination of the source of the air pollution, which in this case is extinguishing fires or preventing their occurrence. Close interaction between health, environment and meterological agencies could result in effective forecasting of future air pollution episodes, be they related to forest fires or local sources of air pollution. However, despite efforts to prevent and control fires it is acknowledged that other measures may be necessary to help mitigate public health impacts. Following from basic principles of exposure control, if source control is not feasible then administrative or engineering controls receive priority, followed by personal protective equipment such as dust masks. In this exposure situation, administrative controls might include recommendations to the population to reduce their level of physical activity, while engineering controls include the use and/or enhancement of air conditioning or indoor air cleaning. Reduction of physical activity will certainly reduce the dose of inhaled air pollutants and will likely reduce the risk of health impacts, although no formal studies have been conducted for particulate matter. Other mitigation measures are discussed in more detail in the following sections.

Dust masks

During the 1997 haze episode, one of the major government and commercial efforts to mitigate public health impacts was the distribution of facial masks. Many different types of masks with variable filtration effectiveness were used. Several of the most effective masks have been tested to meet older United States of America National Institute of Occupational Safety and Health (NIOSH) standards for dust respirators. These masks passed a test procedure which uses 0.5 µm silica particles and have been demonstrated to filter more than 99 per cent of challenge particles. However, in order for these masks to reduce human exposure by the same degree, the masks must provide an airtight seal around the face. As all masks are designed for use by adult workers, the effectiveness of even the highest quality masks for use by the general public (including children) has not been evaluated. It is likely that they will provide more than partial protection. Lower quality masks will offer even less protection. Further, while it is expected that such masks would also filter a high percentage of the smaller (<0.1um) particles present in biomass smoke, no performance data are available.

Wake and Brown (104) evaluated nuisance dust masks, which are generally not approved by health and safety authorities, for their filtration efficiency. These masks are designed for coarse dusts and not for the fine particles present in biomass smoke. Handkerchiefs and tissues were also tested. Although the smallest particle size used in testing was 1.5 µg/m, they found no difference between wet and dry handkerchiefs and in general found the penetration of 1.5 µm particles to be quite high (60-90 per cent) for all dust masks tested. Penetration for handkerchiefs and tissues was 70-90 per cent. In all case, higher airflow was associated with increased filtration (104).

Qian et al (105) evaluated dust/mist respirators which met older NIOSH regulations and surgical masks, and compared these to new N95 respirators which, by definition, meet newer NIOSH regulations. In 1995 NIOSH issued new regulations for non-powered particulate respirators. The regulations indicate 9 classes of filters (3 efficiency levels - 95, 97 and 99 per cent and 3 series of filter degradation resistance). Criteria are met by testing with aerosols of the most penetrating size (0.1-0.3 µm) at an 85 l/min flow rate. N95 respirators from different companies were found to have different particle penetration for the most penetrating sizes (0.1 -0.3µm), but all were more than 95 per cent efficient. For particles larger than 0.3 µm, the filtration increased with increasing size such than 99.5 per cent of 0.75 µm

particles are removed. For welding fumes with sizes smaller than 1 µm, approximately 1.8 per cent of the mass penetrated the respirator, indicating excellent protection if a good face seal exists. Minimum efficiencies at the most penetrating particle sizes were 96, 82 and 71 per cent for the N95, dust mask and surgical mask, respectively.

The devices were also tested at a lower flow rate, which may be more representative of general population use. Under these conditions, efficiencies increased due to the increased time available for particle removal by the electrostatic material in the masks. Efficiencies were 98.8, 86 and 80 per cent for the N95, dust masks and surgical masks, respectively. It should be noted that these efficiencies do not consider face seal leakage. As filter material is loaded the pressure drop across it increases, encouraging air to bypass the filter material through any leaks that are present. Dust masks meeting the older NIOSH certification were used in Malaysia during the 1997 haze. It is unclear whether any N95 respirators were used. Although the N95 respirators have higher collection efficiencies, the dust masks, and even surgical masks will provide a high degree of protection, provided there is an adequate seal around the face and provided that they are changed once loaded.

Chen et al (106) evaluated dust masks and surgical masks for their filtration efficiency of 0.8 µm polystrene latex spheres at a flow rate of 46 l/min. As with the other studies, the effect of facial fit was not addressed. NIOSH has estimated that at least 10-20 per cent leakage occurs in masks not fitted to the wearers' face and measurements have confirmed this problem for dust masks (106). One of the masks tested by Chen et al was used in Malaysia during the 1997 haze. This mask had a mean efficiency of 96 per cent while the surgical mask had an efficiency of 96 per cent (106). The same mask was tested by Hinds and Kraske at a number of flow rates and particle sizes (108). Efficiency decreased with decreasing particle size and increasing flow rate. At normal resting or moderately active respiratory rates and for the particle sizes present in biomass smoke, this mask type would be expected to be 80-90 per cent efficient. However, despite these relatively high filtration efficiencies, the magnitude of the face seal leakage (up to 100 per cent for sub-micron particles) indicates that fit testing and selection of tight-fitting masks is essential for protection. Surgical masks, in contrast to approved dust masks, are not designed for fit testing or for an adequate face seal.

Adverse effects of wearing a disposable respirator (the same type used in Malaysia as described above) were evaluated by doing treadmill exercise. Physiological stress indicators such as heart rate, breath rate, and blood pressure were monitored as well as breath assistance and heat stress imposed by wearing a respirator. Although resistance to breathing through a disposable respirator is not great, a disposable respirator imposes significant physiological stress including increased heart and respiratory rates, especially at moderate and heavy work load (109).

The Ministry of the Environment of Singapore (110) developed recommendations for mask use during biomass air pollution episodes. These recommendations suggest that surgical and other similar masks are not useful in preventing the inhalation of fine particles as they are not efficient in the filtration of particles of less than 10 µm, such as those present in biomass smoke. Accordingly, the use of these masks may provide a false feeling of protection to the users. The recommendations also suggest that respirators (which include some types of dust masks) are able to filter 80 per cent to 99 per cent of particles between 0.2 and 0.4 µm. The recommendations indicate that respirators may be useful, but are uncomfortable and increase the effort of breathing. According to some assessments, over an eight-hour period of use, a respirator of 95 per cent efficiency can offer satisfactory filtration without undue breathing resistance to an average healthy adult. At higher efficiencies, breathing resistance increased and the user will experience more discomfort. Respirators may have a role for those with chronic cardio-respiratory illness, but should be used on the recommendation of their attending physicians. The recommendations also suggest that during periods of intense air pollution, it would be better for the public to avoid outdoor activity than to put on a mask and stay outdoor for prolonged periods. However, for those who cannot avoid going outdoors, the use of respirators would provide some relief.

Indoor penetration

Another major recommendation for the population was to stay indoors. Unfortunately, this recommendation is likely to provide only partial protection, and in some cases, no protection at all. Data from studies conducted in the US for combustion-source particulates indicate that in non air-conditioned homes, approximately 88 per cent of outdoor particles penetrate indoor during summer (111). Limited measurements conducted in Singapore in 1994 indicate that during biomass episode periods, the increase in particle concentrations was due to particles smaller than 2 µm and on

average 60 per cent penetrated indoors (112). In a sample of 11 homes with air conditioning, an average infiltration factor of 44 per cent was measured. Simultaneous indoor and outdoor measurements with continuous particle monitors were performed in Seattle areas impacted by residential wood burning. These measurements demonstrated a strong correlation between indoor and outdoor levels and an indoor:outdoor ratio of 0.98, presumably due to the high air exchange rates in these homes (113). Brauer et al (114) measured indoor:outdoor ratios in 6 non air-conditioned homes in Boston during summer. Using sulfate as a tracer of outdoor source fine particles, indoor:outdoor ratios of 0.96 was measured. Other studies in homes have measured indoor:outdoor sulfate ratios of approximately 0.7, while a similar value was observed in office buildings with mechanical ventilation systems. The variation between these measurements are likely due to differences in air exchange rates (114), as discussed below. The PTEAM study of nearly 300 homes in Riverside, California indicated that nearly 100 per cent of indoor particle sulfur was of outdoor origin (115).

Since the majority of time is spend indoors, exposure indoors is an important variable to consider, even for pollutants generated outdoors. The impact of outdoor particles on indoor levels was discussed in detail by Wallace (116). Recent research has indicated that the impact of outdoor particle on indoor levels is a function of the particle penetration through the building envelope, the air exchange rate and the particle decay rate. Several studies indicate that penetration is complete for PM_{10} and $PM_{2.5}$. This means that the impact of outdoor particle on indoor levels is determined by the decay of particles indoor and by the rate of ventilation. Particle decay rates for PM_{10} and $PM_{2.5}$ are also known. Therefore, the impact of outdoor particles can easily be calculated for any air exchange rate. In typical North American homes, outdoor air accounts for 75 per cent and 65 per cent of fine and coarse particles, respectively. In North American homes, the geometric mean air exchange rates are 0.45-0.55/hr, but vary by season and specific geographic location. In general, air-conditioned homes typically have lower air exchange rates than homes that use open windows for ventilation. In one study, air conditioned homes had air exchange rates of 0.8/hr, while non air-conditioned homes had rates of 1.2/hr, implying indoor fractions of outdoor $PM_{2.5}$ of 67 and 75 per cent, respectively. Wallace comments that one method of reducing particle exposure would be to decrease home air exchange rates, by weatherizing in cold seasons and by installing air conditioners for hot seasons to reduce the use of open windows (116).

Commercial building studies were also reviewed by Wallace, although little information is available as most studies have been directed toward the impact of smoking and not outdoor air pollution (116). In a study of 40 non-smoking buildings, the mean indoor:outdoor respirable particulate ratio was 0.9, although it is not possible to determine the relative importance of particles originating outdoors or indoors. The infiltration of outdoor particles into commercial buildings is likely to be highly variable as it is dependent upon the air exchange rate and specific characteristics of the ventilation system, including the efficiency of air filters.

Air cleaners

Offermann et al (117) conducted chamber tests to evaluate portable air cleaners for their effectiveness in controlling indoor levels of respirable particles. Mixing fans, ion generators and small panel-filter devices were ineffective for particle removal. In contrast, electrostatic precipitators, extended surface filters and HEPA filter units worked well, with effective cleaning rates (for removal of 98 per cent of particles in a room) of 100-300 m^3/hr.

The Ministry of the Environment (ENV) of Singapore conducted an assessment of the use of portable air cleaners for homes, during period of biomass air pollution (118). The ENV found that several models of portable air cleaners were able to reduce the level of fine particles in a typical living room or bedroom to an acceptable level when there is an intense biomass episode. The ENV also suggest that households can add a special filter to window or split-unit air-conditioners to achieve similar results for particle removal. For central air conditioning systems, electrostatic precipitators, high-efficiency media filters and medium-efficiency media filters can be added so that the particle level in the indoor air can be kept within acceptable levels during a prolonged biomass smoke period.

Portable air cleaners were also discussed in a US EPA report (119). Studies have been performed on portable air cleaners, assessing particle removal from the air in room-size test chambers or extensively weatherized or unventilated rooms. All of the tests addressed removal of particles from cigarette smoke, which is similar in size to biomass smoke. The studies show varying degrees of effectiveness of portable air cleaners in removing particles from indoor air. In general, units containing either electrostatic precipitators, negative ion generators, or pleated filters, and hybrid units containing combinations of these mechanisms, are more effective than flat

filter units in removing cigarette smoke particles. However, effectiveness within these classes varies widely. The use of a single portable unit would not be expected to be effective in large buildings with central heating, ventilating, and air-conditioning (HVAC) systems. Portable units are designed to filter the air in a limited area only.

The effectiveness of air cleaners in removing pollutants from the air is a function of both the efficiency of pollutant removal as it goes through the device and the amount of air handled. A product of these two factors (for a given pollutant) is expressed as the unit's clean air delivery rate (CADR). The Association of Home Appliance Manufacturers (AHAM) has developed an American National Standards Institute (ANSI)-approved standard for portable air cleaners (ANSI/AHAM Standard AC-1-1988)25. This standard may be useful in estimating the effectiveness of portable air cleaners. Under this standard, room air cleaner effectiveness is rated by a CADR for each of three particle types: tobacco smoke, dust, and pollen. For induct systems, the atmospheric dust spot test of ASHRAE Standard 52-76 and the DOP method in Military Standard 282 may be used, respectively, to estimate the performance of medium and high efficiency air cleaners (119).

Table 7 shows the percentage of particles removed from indoor air in rooms of various size by rated CADR, as estimated by AHAM. The table provides estimates of the percent of particles removed by the air cleaner and the total removal by both the air cleaner and by natural settling. If the source is continuous, the devices would not be expected to be as effective as suggested by Table 7. In addition, the values represent a performance that can be expected during the first 72 hours of use. Subsequent performance may vary depending on conditions of use.

RECOMMENDATIONS OF HEALTH PROTECTION MEASURES

As discussed above, the hierarchy for health protection is control or prevention of fires followed by administrative controls such as reduced physical activity and remaining indoors. To enhance the protection offered by remaining indoors, individuals/building managers should take action to reduce the air exchange rate. Clearly there are comfort and economic costs associated with reduced air exchange, as well as potential health effects due to increased impact of indoor pollution sources. It is not possible at this time to recommend more specific measures which would be feasible to employ on a population-wide basis. There is evidence that air conditioners,

especially those with efficient filters, will substantially reduce indoor particle levels. To the extent possible, effective filters should be installed in existing air conditioning systems and individuals should seek environments protected by such systems. There is strong evidence that portable air cleaners are effective at reducing indoor particle levels, provided the specific cleaner is adequately matched to the indoor environment in which it is placed. Fortunately most air cleaners have been evaluated by manufacturers and their effectiveness in known. Unfortunately, economics will limit the distribution of such devices throughout the population. As with air conditioners the increased use of such devices by a large segment of the population will have a significant impact on energy consumption, and may in turn have negative impacts on ambient air quality. The least desirable measure is the use of personal protective equipment, such a dust masks. While these are relatively inexpensive and may be distributed to a large segment of the population, at present their effectiveness for general population use must be questioned. Education of the population regarding specific mask types to purchase, how to wear masks and when to replace them will increase their effectiveness as well as the development of new masks designed for general population use.

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Table 1
Summary of major biomass pollutants

Compound	Examples	Source	Notes
Inorganic Gases	Carbon monoxide (CO)	Incomplete combustion of organic material	Transported over distances
	Ozone (O_3)	Secondary product of nitrogen oxides and hydrocarbons	Only present downwind of fire, transported over distances
	Nitrogen dioxide (NO_2)	High temperature oxidation of nitrogen in air	Reactive-concentrations decrease with distance from fire
Hydrocarbons	Benzene	Incomplete combustion of organic material	Some transport - also react to form organic aerosols
Aldehydes	Acrolein	Incomplete combustion of organic material	
	Formaldehyde (HCHO)	Incomplete combustion of organic material	
Particles	Inhalable particles (PM_{10})	Condensation of combustion gases; incomplete combustion of organic material; entertainment of vegetation and ash fragments	Coarse and fine particles. Coarse particles are not transported and contain mostly soil and ash
	Respirable particulate matter	Condensation of combustion gases; incomplete combustion of organic material	For biomass smoke, approximately equal to fine particles
	Fine particles (PM2.5)	Condensation of combustion gases; incomplete combustion of organic material	Transported over long distances; primary and secondary production
Polycyclic aromatic hydrocarbons (PAHs)	Benzo[a]pyrene (BaP)	Condensation of combustion gases; incomplete combustion or organic material	Specific species varies with composition of biomass

Table 2
Summary of epidemiological studies on occupational exposure of wildland firefighters

Study design	**Endpoints measured**	**Results**	Reference
Longitudinal	Symptoms, lung function	Decreased cross-shift and cross-season lung function	32
Prevalence	**Symptoms**	High prevalence of headaches, lightheadedness, cough, shortness of breath, wheeze	33
Longitudinal	Symptoms, lung function	Slightly decreased cross-season lung function. No increase in symptoms	34
Longitudinal	Symptoms, lung function	Increase in cross-season symptoms. Slight decrease in cross-season lung function. Increased symptoms associated with increased recent firefighting.	35
Longitudinal	Lung function, airways responsiveness	Cross-season increase in airways responsiveness and decreased lung function	36
Cross-sectional	Lung function	Decreased lung function in firefighters measured 11 months post-exposure relative to unexposed control group. No association between years of firefighting and lung function.	37

Table 3
Summary of epidemiological studies on indoor exposure (high level)

Population	Study design	Endpoints measured	Results	Reference
Children in Papua New Guinea	Cross-sectional	Symptoms	Increased cough and rhinitis in high exposure group. Increased wheeze in low exposure group.	122
Children in Papua New Guinea	Prospective	Symptoms	No difference in symptoms between the two exposure groups	122
Adult women in Papua New Guinea	Cross-sectional	Lung function	10 per cent of women >45 years had FEV_1/FVC <60 per cent. No control group	123
Children in South Africa	Cross-sectional	Respiratory illness	Increased serious lower respiratory illness in exposed group	124
Adults in Nepal	Cross-sectional	Respiratory illness	Increased chronic bronchitis prevalence with increasing hours of exposure	79
Children in Nepal	Cross-sectional	Respiratory illness	Increased severe respiratory illness with increased hours of exposure	125
Children in Malaysia	Cross-sectional	Lung function	Decreased lung function with home wood stove	126
Children in Malaysia	Cross-sectional	Symptoms	Slight increase in cough and phlegm prevalence in exposed group	127
Children in Kenya	Cross-sectional	Respiratory illness	No increase in illness rates for exposed children	19
Children in Gambia	Cross-sectional	Respiratory illness	Increased acute respiratory infection risk in girls exposed while carried on mothers' back. No effect in boys.	20
Children in Zimbabwe	Cross-sectional	Respiratory illness	Increased lower respiratory illness with wood smoke exposure (blood COHb)	39
Adult, non-smoking women in India	Cross-sectional	Lung function	Reduced FEVI/FVC with increased exposure (expired CO)	128

Table 3 (continued)
Summary of epidemiological studies on indoor exposure (high level)

Population	Study design	Endpoints measured	Results	Referenc e
Adult women in Mexico	Case series	COPD	COPD in non-smoking women	43
Adults in China	Cross-sectional	Lung function	Increased lung function in adults with vented stoves. Decreased lung function with time spent cooking. County-wide COPD mortality highest in countries with lowest lung function	44
Adult women in Mexico	Case-control	COPD	COPD in non-smoking women	17
Adult women in Mexico	Cross-sectional	Symptoms, lung function	Slightly reduced lung function and increased cough and phlegm in women with highest PM_{10} exposure	41
Adult women in Mozambique	Cross-sectional	Symptoms	Increased cough symptoms in wood smoke exposed group (relative to charcoal, gas, electric). No increase in other respiratory symptoms (wheeze, difficulty breathing, etc.)	40
Adult women in Colombia	Case-control	COPD	COPD in non-smoking women	42

Table 4
Combined effect estimates of daily mean PM_{10} (46)

	per cent change per each 10 µg/m³ increase in PM_{10}
INCREASE IN DAILY MORTALITY	
Total deaths	1.0
Respiratory deaths	3.4
Cardiovascular deaths	1.4
INCREASE IN HOSPITAL USAGE **(all respiratory)**	
Admissions	.8
Emergency department visits	1.0
EXACERBATION OF ASTHMA	
Asthmatic attacks	3.0
Bronchodilator	2.9
Emergency department visits	3.4
Hospital admissions	1.9
INCREASE IN RESPIRATORY **Symptoms reports**	
Lower respiratory	3.0
Upper respiratory	0.7
Cough	1.2
DECREASE IN LUNG FUNCTION	
Forced expiratory volume	0.15
Peak expiratory flow	0.08

Source: Dockery and Pope (46).

Table 5
Summary of epidemiological studies on indoor exposure (low level)

Population	Study design	Endpoints measured	Results	Reference
Children	Cross-sectional	Symptoms	No association between respiratory illness and home wood burning	81
Children	Cross-sectional	Symptoms	Increased cough, wheeze, allergic symptoms with home wood burning	77
Children	Cross-sectional	Symptoms, respiratory illness	Increased history of chest illness in past year with home wood burning; no effect on symptoms	76
Children	Longitudinal	Symptoms	Increased frequency of wheeze and cough with increased hours of wood stove use	82
Children <2 years	Longitudinal	Respiratory illness	Increased risk of lower respiratory illness with wood burning	84
Children	Cross-sectional	Symptoms, respiratory illness, lung function	No increased symptoms or illness and no decreased lung function with home wood burning	2
Children	Case-control	Hospitalisation for respiratory illness	Increased hospitalisation with home wood burning - results dependent upon control group	2
Adult asthmatics	Longitudinal	Symptoms	Increased cough, shortness of breath on days with home wood burning	86
Children <2 years	Case-control	Respiratory illness	Increased acute respiratory illness in wood burning homes with PM_{10} >65 µg/m^3	85

Table 6
Summary of epidemiological studies on ambient exposure

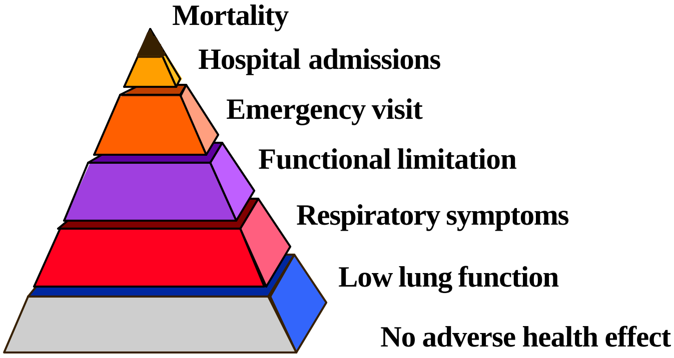
Population	Study design	Endpoints measured	Results	Reference
All ages >1	Cross-sectional	Symptoms, respiratory illness	No significant effects. Trend for children 1-5	88
Children	Longitudinal	Lung function	Decreased lung function during and after wood burning season is exposed community but not in control community.	30
Children	Longitudinal	Lung function	Decreased winter lung function in exposed community but not in control community	87
Children	Longitudinal	Spirometry	Decreased lung function and fine particles in asthmatics	89
All ages	Longitudinal	Emergency room visits	Increased asthma visits with fine particles in areas where wood smoke accounts for 80 per cent of $PM_{2.5}$	66
All ages	Longitudinal	Emergency room visits	Increased asthma visits with PM_{10} in area where wood smoke accounts for 45 per cent of winter PM_{10}	91
All ages	Longitudinal	Mortality	Increased daily mortality with PM_{10} in areas where wood smoke accounts for 45 per cent of winter PM_{10}	90
All ages	Longitudinal	Emergency room visits	Increased respiratory visits in community exposed to fire smoke	97
Adult asthmatics	Experimental	Lung function	Decreased lung function following exposure to burning leaves in asthmatics, but not in non-asthmatics	92
Adults with airways obstruction	Prevalence	**Symptoms**	42 per cent of population reported increased or worsened symptoms during episode of exposure to agricultural burning emissions. 20 per cent reported breathing trouble	93
All ages	Longitudinal	Emergency room visits	Increased asthma visits with PM_{10} during episode of exposure to biomass burning emissions in Singapore	94
All ages	Longitudinal	Emergency room visits	No increase in asthma visits with PM_{10} during episode of exposure to bushfire emissions in Australia	95
All ages	Longitudinal	Emergency room visits	No increase in asthma visits with PM_{10} during episode of exposure to bushfire emissions in Australia	96

Table 7
Estimated Percentage of Particle Removal for Portable Units by CADR and by Room Size

		Percentage of Particles Removed					
Room Size	CADR	Smoke (20 min.)		Dust (20 min.)		Pollen (10 min.)	
		AC	T	AC	T	AC	T
5 x 6	10	49%	68%	49%	70%	-	-
	40	89%	97%	88%	98%	57%	93%
	80	95%	100%	95%	100%	75%	99%
9 x 12	40	53%	71%	52%	72%	24%	78%
	80	76%	89%	75%	89%	40%	86%
	150	89%	98%	89%	98%	58%	94%
12 x 18	80	53%	71%	52%	72%	24%	78%
	150	74%	87%	73%	88%	38%	85%
	300	89%	97%	-	-	-	-
	350	-	-	91%	99%	-	-
	450	-	-	-	-	69%	97%
18 x 24	150	51%	70%	50%	71%	23%	78%
	300	73%	87%	-	-	-	-
	350	-	-	77%	91%	-	-
	450	-	-	-	-	50%	91%
20 x 30	300	63%	79%	-	-	-	-
	350	-	-	67%	84%	-	-
	450	-	-	-	-	40%	86%

AC=Removal by the air-cleaning device
T= Removal by the air-cleaning device plus natural settling
Note: Estimates ignore the effect of incoming air. For smoke and, to a lesser extent, dust, the more drafty the room, the smaller the CADR required. For pollen, which enters from outdoors, a higher CADR is needed in a drafty room.
Source: Reference 26.

Figure 1
Adverse health effects associated with air pollution. The size of each level of the pyramid represents the proportion of the population affected.



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Background papers

A REVIEW OF FACTORS AFFECTING THE HUMAN HEALTH IMPACTS OF AIR POLLUTANTS FROM FOREST FIRES

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SUMMARY

Although total emissions and adverse health effects have been documented in past studies, the overall toxicity of exposure to smoke or haze from forest fires has yet to be fully evaluated. A review of the literature identifies potential factors that influence forest fire emissions and allows for extrapolation of possible health effects. Fire dynamics involves fire, fuel, and climatological factors. The ecosystem's chemical and physical features combined with environmental parameters (humidity, temperature, and wind speed) and the type of ignition, affect the combustion factor and efficiency and, therefore, the amount of biomass consumed, the composition of smoke emissions, and the rate of release of emissions. Characteristics of fuel (e.g., arrangement, size distribution, moisture, and chemical composition) affect the phases of combustion, for which the quantities and rates of releases vary. Exposure to combustion products can have potentially detrimental short and long term effects on human health. These products, their known health effects, and the factors influencing their effects are described for (1) particulate matter; (2) polycyclic aromatic hydrocarbons; (3) carbon monoxide; (4) aldehydes; (5) organic acids; (6) semivolatile and volatile organic compounds; (7) free radicals; (8) ozone; (9) inorganic fraction of particles; (10) trace gases and other releases; and (11) radionuclides. The biological aspects of severe aerosol loading require further investigation.

INTRODUCTION

Given the objective of protecting public health, a complete understanding of the spectrum of health effects from biomass fires requires knowledge of the full range and potential of factors that might affect health outcomes and related impacts. Although total emissions and adverse health effects have been documented in public health and medical literature, the overall toxicity of exposure to smoke or haze has yet to be fully evaluated. A review of the current literature, primarily from atmospheric chemistry, identifies several factors that potentially influence the impact of air pollutants from forest fires on the susceptibility of individuals and vulnerable groups. Knowledge of adverse effects on public health from direct and indirect linkages is lacking, and efforts to elucidate the biological mechanisms by which exposures to biomass smoke affect human health have yet to be described. However, an extrapolation of potential factors on health effects can be attempted, taking into consideration biological plausibility, linkage between cause and effect, and coherence of past and current studies.

FIRE DYNAMICS AND THE COMBUSTION PROCESS

Fire dynamics is a complex process involving fire, fuel and climatological factors including altitude and meteorology. Under ideal conditions (i.e., complete combustion), the burning of organic material is an oxidation process that primarily produces water vapor and carbon dioxide (CO_2) (1). In natural and anthropogenic fires, combustion is incomplete due to an insufficient supply of oxygen (O_2). As a result, incompletely oxidized compounds (e.g., carbon monoxide) or reduced compounds (e.g., methane, nonmethane hydrocarbons, ammonia) are formed (1). These compounds are found in smoke, which often consists of irritant respirable particles and gases, and in some cases may be carcinogenic. Smoke itself is a complex mixture with components that depend on fuel type, moisture content, fuel additives such as pesticides sprayed on foliages or trees, and combustion temperature (2).

The combustion process involves two key parameters: the amount of biomass material burned and the proportion of a compound released during combustion, or emission factor, which is measured by grams (g) of pollutant

per kilogram (kg) of fuel consumed. Combustion efficiency, defined as the ratio of carbon released by the fire as CO_2, is a fundamental parameter that integrates many of the variables affecting biomass volatilization and oxidation (3). The ecosystem's chemical and physical features combined with environmental parameters (humidity, temperature, wind speed) and the type of ignition, affect the combustion factor and combustion efficiency and, therefore, the amount of biomass consumed, the composition of smoke emissions, and the rate of release of emissions (4).

Combustion can consist of several phases relative to the time after ignition: (i) flaming phase, 0-20 minutes; (ii) initial smoldering phase, 20-80 minutes; and (iii) smouldering phase, 80-200 minutes. These processes are different phenomena involving different chemical reactions that result in diverse products (3). Characteristics of fuel (e.g., arrangement, size distribution, moisture, and chemical composition) affect the duration of each phase (3). The relative amount of biomass consumed through flaming and smoldering combustion can also vary due to these factors (4).

Exposure to combustion products can have potentially detrimental short and long term effects on human health. Although some of these products have been observed to occur in varying amounts after biomass fires (5, 6), little or no information exists about the intensity of human exposure and resulting health effects. The products, their known health effects, and the factors influencing their effects have been described for particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), aldehydes, organic acids, semivolatile and volatile organic compounds (VOCs), free radicals, ozone, inorganic fraction of particles, trace gases and other releases, and radionuclides.

COMBUSTION PRODUCTS OF BIOMASS FUELS

Particulate matter (PM)

Health effects

The solid component of smoke is PM, which at respirable size presents risks to human health. The PM mass is categorized into two modes: fine particle, with a mean-mass diameter of 0.3 micrometers (µm), and a coarse particle, with a mean-mass diameter greater than 10 µm. Even at low concentrations, fine particles have been observed to cause changes in lung function, leading to increases in respiratory and cardiovascular mortality and morbidity including asthma. Fine particles may reach the alveoli, and if not sufficiently cleared in the lungs and in great concentrations, may enter the bloodstream or remain in the lung, resulting in chronic lung disease such as emphysema. Airborne particulates may also contain toxic recondensed organic vapors, such as PAHs, which are indicated to be carcinogenic in animals (7).

Factors affecting health effects

The size of the fire event may influence resulting health effects. Particulate matter is produced abundantly, at least 0.6 tons per second after large fires, during forest fire combustion (8). 40 to 70 per cent of fine PM consists of organic carbon material, containing known carcinogens (9). 2-5 per cent is graphitic carbon; the remainder inorganic ash. Particulate matter may carry absorbed and condensed toxicants, and possibly, free radicals.

Polycyclic aromatic hydrocarbons (PAHs)

Health effects

PAHs comprise a group of organic compounds with two or more benzene rings, such as methyl anthracene, pyrene, chrysene, benzo(a)anthracene, fluroranthene, and methylchrysene. Benzo(a)pyrene is considered the most carcinogenic. Exposure to PAHs has been linked to lung cancer in railway workers exposed to diesel exhaust fumes and occupational lung cancer in coke oven and coal gas workers (7).

Factors affecting health effects

Factors related to combustion may affect the production and quantity of PAHs released into the atmosphere. Although little is known about which combustion conditions yield highest amounts of PAHs, some combustion conditions produce PAHs more abundantly than others. Low intensity backing fires (i.e., a line of fire moving into new fuel in an upwind direction) are found to produce larger amounts of benzo(a)pyrene than heading fires, which move into new fuel in the same direction as the wind movement (10). In one study, the amount of benzo(a)pyrene ranged from 98 µg/g to 274 µg/g of PM for low intensity backing fires and 2 µg/g to 3µg/g for heading fires (11).

Fuel characteristics also affect the production of PAHs during combustion. Emission of benzo(a)pyrene increased as the density of live vegetation covering the prescribed fire units thickened (5). Under natural conditions of a tropical medium such as savanna fires, PAHs were observed to be abundantly produced, mainly in gaseous form. The total flux of PAH emitted in tropical Africa during the biomass burning season is estimated to be 605±275 tons per year for gaseous PAHs and 17±8 tons per year for particulate PAHs. Although savanna fires occur during only a few months of the year, their contribution to the global burden of atmospheric PAH is significant compared to anthropogenic sources (12).

In wind tunnel simulations of open burning, emission factors for 19 PAHs were measured for agricultural and forest biomass fuels, including cereal grasses, agricultural tree prunings, and fir and pine wood. Yields of total PAH varied from 5 milligrams (mg)/kg to 685 mg/kg depending on burning conditions and fuel type; barley straw and wheat straw emitted PAHs including benzo(a)pyrene at much higher levels than other cereals and wood fuel types. Total PAH emission rates increased with increasing particulate matter emission rates and with declining combustion efficiency (13).

Studies from wood stoves indicate that higher burn rates lead to fewer total organic emissions but the proportion of PAHs increases (5). Emission rates for PAHs were observed to be highest for temperatures in the range 500-800^{o}C (14), and were consistent with results from a study of PAHs released in low intensity backing fires (9,11). The emission and mutagenic activity of PAHs from small wood stoves were observed to be greatly influenced by the quality of wood, with high levels (10-30 mg PAH) detected per kilogram of virgin wood (15).

Carbon monoxide (CO)

Health effects

Carbon monoxide gas causes tissue hypoxia by preventing the blood from carrying sufficient oxygen (16). At low to moderate concentrations, health effects include impaired thinking and perception, headaches, slow reflexes, reduced manual dexterity, decreased exercise capacity, and drowsiness. At higher concentrations, death may result. Persons at higher risk include those with preexisting cardiovascular and respiratory disease, infants, the elderly, and pregnant women. Unborn children are particularly susceptible because CO has a longer duration for clearance in the foetal circulatory system and foetuses cannot compensate for a reduction in oxyhemoglobin without a sustained increase in cardiac output (7).

Factors affecting health effects

Together with CO_2, CO accounts for 90 per cent to 95 per cent of the carbon produced during the combustion of biomass (17). CO release correlates highly with the release of other compounds in smoke, including PM and formaldehyde. CO emission factors range from 60 g/kg to more than 300 g/kg of fuel consumed. Studies indicate that CO emission factors in Brazil ranged from 167 g/kg to 209 g/kg, which is generally higher than similar measurements for logging slash fires in the western United States where the average emission factor is 171 g/kg. The differences are thought to result from variations in vegetation or moisture content.

Although one study indicates a significant increase in blood carboxyhemoglobin levels in non-smoking people who used biomass fuels for cooking (18), the factors that affect health effects have yet to be fully evaluated. According to the United States Occupational Safety and Health Administration (OSHA) regulations, the time-weighted average exposure limit is 50 parts per million (ppm) CO for an 8-hour work shift; the National Institute for Occupational Safety and Health limit is 35 ppm for 8 hours of exposure and 200 ppm for no defined time (5). Systematic studies of the effects of CO on human health should be performed, with carboxyhaemoglobin levels checked soon after exposure.

Aldehydes

Health effects

Aldehydes are primarily mucous membrane irritants. Some, such as formaldehyde, may be carcinogenic and in combination with other irritants may lead to an increase in the carcinogenicity of other compounds, such as PAHs (9). Formaldehyde and acrolein are the main aldehydes released during biomass burning. Formaldehyde, which is probably the most abundantly produced compound of this class, causes eye, nose, and throat irritation during smoke exposure (5). Low molecular weight aldehydes such as acrolein are thought to cause pulmonary lesions in rabbits (5).

Factors affecting health effects

These compounds have been poorly quantified as byproducts of the forest fuel combustion in the open environment. Sharkey (9) states that it is highly likely that acrolein is an irritant in smoke near firelines, with concentrations as high as 0.1 ppm to 10 ppm near fires.

Organic acids

Health effects

Organic acids, such as formic acid produced by the oxidation of formaldehyde, are known to form during the combustion of biomass fuels. Anticipated health effects include irritation of mucous membranes.

Factors affecting health effects

Organic acid production rates and combustion conditions, and the synergistic effects of some or all of these compounds, are unknown (9). It has been observed, however, that under equilibrium, high humidity could drive reactions to the production of organic acids. Aldehydes, for example, can produce acidic groups (e.g., formic acid, acetic acid) under conditions of high moisture.

Semivolatile and volatile organic compounds (VOCs)

Health effects

Some VOCs may cause skin and eye irritation, drowsiness, coughing and wheezing, while others (e.g., benzene and 1,3-butadiene) may be carcinogenic. Benzene and benzo(a)pyrene may be genetoxic carcinogens (7).

Factors affecting health effects

VOCs may have significant vapor pressures at ambient temperatures. Some compounds, such as benzene, naphthalene, and toluene, are partitioned between gaseous, liquid, or solid phases at ambient temperatures. Little work has been done to characterize VOCs in forest fires. To date, methane and CO gases are produced in proportion to semivolatile and VOCs and serve as indicators of their abundance (9).

Free radicals

Health effects

Free radicals are abundantly produced during the combustion of forest fuels. Free radicals may react with human tissues. They have been observed to persist up to 20 minutes following formation and pose a problem for firefighters exposed to fresh aerosols. Additional research is needed to determine the types and quantities of free radicals emitted during the combustion of biomass fuels, their persistence in the atmosphere, and subsequent health effects (9).

Factors affecting health effects

None noted at this time.

Ozone (O_3)

Health effects

O_3 is an extremely reactive oxidant. At high concentrations, it may impair lung function and reduce respiratory resistance to infectious diseases. People at risk include those with chronic respiratory illness. At low levels, human health may be affected when physical exercise is combined with several hours of exposure, i.e., tissue dose is enhanced by increased respiratory rate (7). At low concentrations, O_3 can cause symptoms such as coughing, choking, shortness of breath, excess sputum, throat tickle, raspy throat, nausea, and impaired lung function when exercising. Long-term health effects include decreased lung function and chronic obstructive pulmonary disease (7).

Factors affecting health effects

Concentrations of concern are not expected in areas close to fires. O_3 is formed photochemically near the top of smoke plumes under high sunlight. It is also formed when smoke is trapped in valleys or where there is a temperature inversion. Additionally, increased levels of O_3 may be encountered at high elevations.

OSHA has established standards for occupational exposure to O_3; however, these regulations have yet to be evaluated, along with other chemicals for biomass burning.

Inorganic fraction of particles

Health effects

Toxicologic effects of inorganic fractions from biomass fires have not been quantified. Health effects are dependent on the substance in question, such as lead, asbestos, and sulphur.

Factors affecting health effects

Inorganic materials, which are generally present in trace levels in smoke particles, are dependent on the chemistry of the fuels burned and the intensity at which the fire burns. Often, variability in the mineral content of fuels is enough to affect combustion. For example, in the United States,

particles in the Los Angeles Basin were found to have a higher lead content than particles from fires in the Pacific Northwest due to deposition of lead deposits in those areas (5). Similarly, asbestos fibers were carried with smoke from areas that naturally contained high deposits of asbestos (5). Also, organic soils of the southeast and fuels in the Yellowstone geyser basins would have emissions with sulphur-containing gases because they contain naturally occurring areas of high sulphur deposition (5).

Savannah fire aerosols are characterized by enrichments in elements such as potassium (K), chlorine (Cl), zinc (Zn), and bromine (Br), whereas forest fire emissions are enriched in silicon (Si) and calcium (Ca). Of the trace elements, K is found in relatively high concentrations in wood smoke. The combustion of hardwoods produces more ash and therefore higher concentrations of trace elements than does the combustion of softwoods (19).

Trace gases and other releases

Health effects

Trace gases, particularly polychlorinated dibenzo-p-dioxins (PCDDs), are extremely persistent and widely distributed in the environment. Very little human toxicity data related to PCDD are available. Data of health effects in occupational settings are based on exposure to chemicals contaminated with 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), which has a half-life of 7 to 11 years in humans. Dioxin exposures are associated with an increased risk of severe skin lesions (e.g., chloracne), and hyperpigmentation, altered liver function and lipid metabolism, general weakness associated with weight loss, changes in activities of various liver enzymes, immune system depression, and endocrine and nervous system abnormalities. TCDD also causes cancer of the liver and other organs in animals. Exposure to dioxin-contaminated chemicals has resulted in increased incidences of soft-tissue sarcoma and non-Hodgkin's lymphoma (20).

Methyl bromide and methyl chloride, which are sources of Br and Cl that destroy stratospheric ozone (21), may be carcinogenic (22). Health effects resulting from the emission of these compounds from biomass fires have yet to be determined.

Factors affecting health effects

Smoke emitted during the global annual combustion of about 2 to 3 billion metric tons of plant materials contains numerous toxic materials, some of which are dioxins. Forest and brush fires are major sources of PCDDs (23, 24). If flame temperatures exceed 1000 ^{o}C, essentially no dioxins are produced; however, this is rarely the case. In a study that involved burning various wood specimens in different stoves, total dioxins released were as much as 160 µg dioxin/kg wood. Soot collected and analyzed by well-designed and documented procedures indicated the presence of tetrachlorinated, hexachlorinated, heptachlorinated, and octachlorinated dioxins (23, 24).

Wood combustion products are spread around the world by winds. Consequently, PCDDs are found in soils in remote areas and tend to be bioconcentrated in the food chain (23).

Biomass fires emit a complex mixture of particulates and gases into the atmosphere. Globally, the diversity of combustion products results from wide ranges in fuel types and fire behaviour, which are induced by large variations in ecological types and weather phenomena. For instance, forest fires have lower combustion efficiency than grass fires, and therefore a larger fraction of smouldering compounds. During less efficient smouldering combustion, a large number of organic compounds are formed (5).

Radionuclides and herbicides

Health effects

Radionuclides, such as iodine-129 (^{129}I), cesium-137 (^{137}Cs), and chlorine-36 (^{36}Cl), can be released into the atmosphere, soil, and water, with immediate and long term consequences on health (25). They can cause cancer, depending on where in the body they are localized. For example, iodine is concentrated in the thyroid gland and the radioactive isotopes can cause thyroid cancer.

Fire occurring immediately after the application of herbicides may lead to adverse health effects in forest workers; however, in one study, no herbicide residues from an application containing the active ingredients imazapyr, triclopyr, hexazinone, and pioloram were detected in 140 smoke samples and 14 fires (26).

Factors affecting health effects

Fires can mobilize radionuclides from contaminated biomass through suspension of gases and particles in the atmosphere or solubilization and enrichment of the ash. Loss to the atmosphere increased with fire temperature, and during a typical field fire, 80 per cent to 90 per cent of the I and Cl, and up to 40 per cent to 70 per cent of the Cs was lost to the atmosphere (25).

In assessing exposure, factors such as fire conditions (high density smoke versus low density smoke) and personnel location should be taken into consideration when assessing exposure to airborne herbicide residues in smoke from prescribed fires (26).

RADIATIVE EFFECTS THROUGH GLOBAL COOLING

Smoke particles affect the global radiation balance by reflecting solar radiation directly, acting as cloud condensation nuclei, and increasing cloud reflectivity. The radiative effects of aerosols generated from biomass burning, dust storms, and forest fires could increase global cooling (i.e., or reduce the rate of global warming). Anthropogenic increases of smoke emissions may help weaken the net greenhouse warming from anthropogenic trace gases (27).

The effect is measured by Direct Radiative Forcing (DRF), the perturbation in the energy balance of the earth-atmosphere system; positive and negative values indicate warming and cooling, respectively, of the troposphere. For comparison, the net incoming solar radiation at the top of the atmosphere is 342 watts per square meter (W/m^2). Radiative forcing due to aerosols is comparable in magnitude to current anthropogenic greenhouse gas forcing but opposite in sign. The DRF due to long-lived greenhouse gases is 2.45 ± 0.37 W/m^2; the global average of DRF due to anthropogenic aerosols is -0.5 W/m^2, largely attributed to sulphate particles from fossil fuel combustion and smoke particles from biomass burning (28).

Severe aerosol loading results in immediate health effects, specifically respiratory disease from particle inhalation. It also may lead to a reduction in photosynthesis, which may affect the incidence of infectious and mosquito-borne diseases in the long-term. In regions of intensive biomass

burning, the photosynthetically active spectrum of sunlight (wavelengths of 400-700 nanometers (nm)) is reduced by 35 per cent to 40 per cent for two months (27). In one study, smoke from biomass burning caused significant aerosol optical thickness and up to an 81 per cent reduction in ultraviolet-B (UV-B) rays (29).

UV-B in natural sunlight kills airborne bacteria (27). The bactericidal effects of solar UV-B are well-known, and significantly reduced UV-B resulting from severe air pollution in regions where UV-B levels are ordinarily high might enhance the survivability of pathogenic organisms in air and water and on surfaces exposed to sunlight. In one study, exposing drinking water to normal intensities of UV-B has reduced diarrhea in children in Kenya by 33 per cent (30).

An increased incidence of respiratory, cardiopulmonary and other diseases are known to be associated with severe air pollution, but the biological mechanisms remain unknown.

The increased incidence of infectious and mosquito-transmitted disease has been raised as a possible consequence of severe aerosol loading. The larvae and pupae of some disease-transmitting mosquitoes are highly photophobic to ultraviolet-A (UV-A) rays and green wavelengths of sunlight. In 1995, in Brazil, smoke reduced sunlight in UV-A (340 nm range) as much as 45 per cent in an area peripheral to the region of maximum burning (29). Experiments with Culex pipiens, a vector for encephalitis, indicated that the females deposited eggs in the darkest nurseries and that their larvae avoided UV light (27).

The biological aspects of severe aerosol loading require further investigation. Estimates of emission factors of pollutants from forest fires and biological mechanisms leading to adverse health effects will improve global accounting of radiation-absorbing gases and particles that may be contributing to climate change and will provide strategic data for fire management.

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Background papers

GUIDANCE ON METHODOLOGY FOR ASSESSMENT OF FOREST FIRE INDUCED HEALTH EFFECTS

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INTRODUCTION

Air pollution has been linked to human morbidity and mortality in many parts of the world. The most famous air pollution episode occurred in London, England in December, 1952 and resulted in 3500 excess deaths. This watershed event in air pollution epidemiology was related to high levels of particulate and sulfur dioxide air pollution emanating from coal burning and exacerbated by an atmospheric inversion which trapped the pollutants in the city for almost one week. This episode, along with subsequent ones in other parts of the world, resulted in more research into the effects of air quality on human health and governmental intervention to monitor air quality with a view to decrease the levels of air pollutants.

Several factors are critical in ascertaining health effects of air pollution exposure. These factors include characteristics of the pollutants; population exposures; individual exposures; susceptibility of the exposed individual; potential confounding factors; and the range of health effects being studied. The availability of data on these factors greatly affects the type of study that one might be able to undertake.

This paper will focus on the assessment of forest fire related health effects (1). Forest fire related pollutants are similar, in many ways, to other combustion-generated fine particulate pollutants (2, 3). Thus, we will describe the methods used to ascertain the health effects of particulate pollution on human health (4). The types of study designs in air pollution epidemiology vary widely and include short-term controlled exposure studies (chamber studies); short-term exposure studies; and long-term exposure studies. This paper will focus on the latter two study designs, as they reflect a typical epidemiological approach to the problem of air pollutant exposure (5).

IMPORTANT COMPONENTS OF ALL STUDIES

Community level air pollution measurements

Having population-based monitors (as opposed to source-based monitors) is important to obtain better information on population exposures.

Particulate matter (PM_{10}, $PM_{2.5}$)

The current trend is to get more data on the finer particulate fraction. Coarser fractions, in some parts of the world, can contain dust from windblown earth or sand which can affect visibility but has only a small effect on human health. The fine particulate fraction is probably the best indicator of transported fire smoke.

Volatile organic compounds (VOCs)

Certain VOCs may serve as markers for fire-related pollutant exposure. Better characterization of the fire smoke and transported pollutants is needed to determine which VOCs are the best markers.

Other pollutants (ozone, carbon monoxide, etc.)

There is some evidence that ozone levels may increase in conjunction with forest fires.

Personal level pollutant exposure data

Such data are less likely to be available.

Personal or home-based air sampling

While this method gives the best data, it is impractical for large population studies. Some studies have used personal monitors to validate the use of population-based monitors.

Biomarkers of exposure

If an appropriate VOC was identified, one might be able to obtain blood and look for this compound as a marker of recent exposure.

Non-pollutant environmental factors associated with both air quality and health outcomes

Most of the health outcomes studied (respiratory disease exacerbation or hospitalization) are affected by changes in the weather. These weather changes can also affect air pollution due to factors such as inversions and wind speed. Important environmental factors include temperature, wind speed and direction, humidity, seasonality, and the presence of pollen and other allergens.

Personal factors affecting exposure to outdoor air pollutants

Time activity patterns

In the US, 90 per cent of the time is spent in indoor environments. This proportion may vary in other parts of the world.

Housing characteristics

This factor relates to the question of how much of the outdoor pollution comes indoors. Many tropical regions do not have a true “indoor” environment.

Interventions to reduce pollutant exposures

Although interventions such as masks or respirators or staying indoors have been recommended, their efficacy is still unclear.

Masks or respirators

Masks or respirators typically increase the work of breathing.

Personal factors affecting outcomes (and pollutant exposure)

Age, ethnicity, gender

Health effects tend to be more dramatic in the very young and the very old.

Existing diseases

People with preexisting respiratory disease (asthma and chronic obstructive pulmonary disease (COPD)) or heart disease are usually more susceptible to air pollutants.

Socioeconomic status

This factor can affect both exposure to pollutants (because of location or type of housing) and health outcomes (due to access to care and treatment)

Occupational exposures

Some occupational exposures are associated with chronic respiratory disease.

Tobacco smoking

Smoking is a confounding variable associated with respiratory and pulmonary disease.

Nutritional status

Nutritional status may influence health status and susceptibility to air pollution.

Health outcomes

The type of outcome used depends on what types of data are available and the type of analysis planned.

Mortality

Data on total mortality and cardio-pulmonary mortality are usually available, although the quality of cause-specific data may vary in different parts of the world.

Hospitalisation

Hospitalisation data are frequently obtained from available administrative or billing data. It can also be available from the hospital directly, but may require manual searches.

Emergency room/outpatient visits

Data are sometimes available using administrative information. Many studies have been done using emergency room log books to extract data.

Symptomatic exacerbation

Symptomatic exacerbation is a component of panel or cohort studies that can be linked to emergency room visits or hospitalizations. It can also be part of an exposed/unexposed study.

Changes in lung function

Such changes are part of a panel study which requires the use of peak flow or portable spirometry measurement. It can also be part of an exposed/unexposed study.

Cardiopulmonary symptoms

Such symptoms (cough, wheezing, shortness of breath, angina) are part of a panel study and can also be part of an exposed/unexposed study.

Upper respiratory illnesses

These illnesses are part of a panel study and can also be part of an exposed/unexposed study

Mucous membrane irritations

Mucous membrane irritations (conjunctivitis, ear, nose and throat irritation) are part of a panel study.

SHORT-TERM EXPOSURE-RELATED HEALTH EFFECTS

These effects can include death, hospitalisation, exacerbation of disease, worsening of preexisting disease, worsening of symptoms, and worsening of physiological parameters such as lung function.

Population-based studies

These study models typically focus on endpoints such as mortality or hospitalization for either specific diseases or all diseases. The prototype study in this category is the study of deaths in the London smog episode of 1952

Time series studies

In recent years, numerous time series studies have been published focusing on the effect of particulate air pollution on mortality due to cardiovascular and respiratory diseases and hospitalizations due to diseases such as asthma, pneumonia, COPD, coronary artery disease and congestive heart failure. These types of studies can be very complicated analytically.

Cohort or individual-based studies

These studies typically focus on endpoints such as symptoms or exacerbation of disease, or worsening of lung function.

Panel studies

This type of study involves the collection of data (peak flows, use of bronchodilators, asthma symptoms, possible personal monitoring) among a small group of people (people with asthma) over a relatively short period of time. Typically, it depends on self-reporting and may also be analytically challenging.

Case-control study

The study involves collecting data on individuals with a specific acute health endpoint (such as an exacerbation of or hospitalization for lung disease, or death from cardiopulmonary disease) and similar individuals without these endpoints and assessing previous exposures to pollutants and other risk factors. Limitations include problems of assessing retrospective exposures. The method might be a useful model to examine the effects of preventive interventions.

LONG-TERM EXPOSURE-RELATED HEALTH STUDIES

These health effects can include mortality (life-shortening as opposed to acute death), hospitalization rates, disease rates (specifically for diseases such as COPD, heart disease and lung cancer), and presence of symptoms or lower levels of lung function.

Population–based study

Ecological Studies

In these studies, we do not know the specific exposure to any individual, but we have information on what the community exposures were. The goal in this type of studies is to look at outcomes (long-term mortality rates or disease rates) in areas with large differences in air pollution levels. Limitations of these studies are large potentials for confounding and questions about the validity of the data.

Cohort or individual-based study

Cohort study

In this type of study, baseline data (sex, age, smoking status, occupation, presence of underlying disease, etc.) on groups of subjects are collected and the groups are followed over time to look for outcomes such as early mortality, development of cardiopulmonary disease, or declines in lung function. While these studies have the potential to yield very important data in a well-defined population with reasonably defined exposures, they are limited by being very costly and difficult to perform.

Case-control study

This type of study involves assessing individuals with a specific chronic health endpoint (such as development of COPD, lung cancer or congestive heart failure) and similar individuals without these endpoints on previous exposures to pollutants and other risk factors. Limitations of this type of study include problems in assessing retrospective exposures.

EVALUATION OF STUDY DATA

Data collected in any of these types of studies needs to be analysed very carefully, accounting for appropriate confounding factors and covariates. Analytic techniques vary with the type of study design used, and is well beyond the scope of this paper. New analytic computer programmes have been developed that allow us to better account for the important factors that determines health effects related to pollutant exposures.

CONCLUSION

Determining the health effects related to forest fires is a difficult task. There are a variety of different study models that can be used, depending on the resources and data available. Any model, though, requires careful planning and analysis.

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GASEOUS AND PARTICULATE EMISSIONS RELEASED TO THE ATMOSPHERE FROM VEGETATION FIRES

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SUMMARY

During 1997 and 1998, relatively small-scale, human-initiated fires for land clearing and land use change developed into uncontrolled large-scale and devastating fires. These fires occurred in Southeast Asia, South and Central America, Africa, Europe, China, and the United States. These uncontrolled and widespread vegetation fires were a consequence of extreme drought conditions apparently brought about by the 1997 El Niño, one of the most severe on record. On a daily basis, these fires were reported on the front pages of the world's newspapers and on radio and television throughout the world. Internet websites described the daily, and in some cases, the hourly progress of these wildfires. To assess the health and environmental impacts of these fires, knowledge of the gaseous and particulate emissions produced in vegetation fires and released into the atmosphere is critical. The calculation of gaseous and particulate emissions from vegetation fires is outlined. This paper considers the gaseous and particulate species produced during vegetation fires and the procedures to calculate their source strengths.

INTRODUCTION

Biomass burning, the burning of living and dead vegetation for land-clearing and land-use change, has been identified as a significant source of gases and particulates to the regional and global atmosphere (1-3). A variety of carbon and nitrogen species are released into the atmosphere during vegetation fires (Tables 1 and 2) (4). These tables give the amount of each compound expressed as the percentage of carbon (Table 1) and nitrogen (Table 2) in the vegetation.

The major gases produced during the biomass burning process listed in Tables 1 and 2 include many environmentally important gases, such as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), oxides of nitrogen (NO_x = nitric oxides (NO) + nitrogen dioxide (NO_2)), and ammonia (NH_3). Carbon dioxide and methane are greenhouse gases, which trap earth-emitted infrared radiation and lead to global warming. Carbon monoxide, methane, and the oxides of nitrogen lead to the photochemical production of ozone (O_3) in the troposphere. In the troposphere, ozone is an irritant and harmful pollutant, and in some cases, is toxic to living systems. Nitric oxide leads to the chemical production of nitric acid (HNO_3) in the troposphere. Nitric acid is the fastest growing component of acidic precipitation. Ammonia is the only basic gaseous species that neutralizes the acidic nature of the troposphere. Particulate matter, small (usually about 10 micrometres or smaller) solid particles, such as smoke or soot particles, are also produced during the burning process and released into the atmosphere. These solid particles absorb and scatter incoming sunlight and hence impact the local, regional, and global climate. In addition, these particles (specifically, particulates 2.5 micrometres or smaller) can lead to various human respiratory and general health problems when inhaled. The gases and particulates produced during biomass burning lead to the formation of "smog." The word "smog" was coined as a combination of smoke and fog and is now used to describe any smoky or hazy pollution in the atmosphere.

The bulk of the world's biomass burning occurs in the tropics - in the tropical forests of South America and Southeast Asia and in the savannas of Africa and South America. The majority of biomass burning (perhaps as much as 90 per cent) is believed to be human-initiated, with natural fires triggered by atmospheric lightning only accounting for about 10 per cent of all fires (5).

Over the last few years, a series of books have documented much of our current understanding of biomass burning, including the remote sensing of fires, fire ecology, fire measurements and modelling, fire combustion, gaseous and particulate emissions from fires, the atmospheric transport of these emissions and the chemical and climatic impacts of burning. These volumes include: Goldammer (6), Levine (7), Crutzen and Goldammer (8), Goldammer and Furyaev (9), Levine (10), Levine (11), and van Wilgen et al (12). The topic of health impacts of biomass burning gaseous and particulate emissions is noticeably lacking in these volumes.

To assess both the health and environmental impacts of forest burning, the gaseous and particulate matter emissions produced during the fire and released into the atmosphere must be known. The expression for calculating total mass burned and the various gases and particulates produced, makes use of the following information: area burned, biomass burned, biomass loading, fire efficiency, and the various species emission ratios.

The calculation of gaseous and particulate emissions from vegetation fires

The gaseous emissions from vegetation fires can be calculated using an expression from Seiler and Crutzen (2):

$M = A * B * E$ ……………………………………………………**I**

where M = total mass of vegetation consumed by burning (tons), A = area burned (km^2), B = biomass loading ($tons/km^2$), and E = burning efficiency (dimensionless). Typical values for B and E for tropical vegetation are summarized in Table 3 (13). A global estimate of the total annual amount of biomass consumed during burning is given in Table 4 (5).

The total mass of carbon [M(C)] released to the atmosphere during burning is related to M by the following expression

$M(C) = C * M$ (tons of carbon)………………………………**II**

C is the mass percentage of carbon in burning biomass. For tropical vegetation, C=0.45 (5). The mass of CO_2 [$M(CO_2)$] released during the fire is related to M(C) by the following expression

$M(CO_2) = CE * M(C)$…………………………………………**III**

The combustion efficiency (CE) is the fraction of carbon emitted as CO_2 relative to the total carbon compounds released during the fire. For tropical vegetation fires, CE = 0.90 (5).

Once the mass of CO_2 produced by burning is known, the mass of any other species, X_i [$M(X_i)$], produced by burning and released to the atmosphere can be calculated with knowledge of the CO_2-normalized species emission ratio [$ER(X_i)$]. The emission ratio is the ratio of the production of species X_i to the production of CO_2 in the fire. The mass of species X_i is related to the mass of CO_2 by the following expression

$M(X_i) = ER(X_i) * M(CO_2)$ (units of tons of element X_i)…**IV**

where X_i = CO, CH_4, NO_x, NH_3, O_3, etc. It is important to note that O_3 is not a direct product of biomass burning. However, O_3 is produced via photochemical reactions of CO, CH_4, and NO_x, all of which are produced directly by biomass burning. Hence, the mass of ozone resulting from biomass burning may be calculated by considering the ozone precursor gases produced by biomass burning. Values of CO_2 and CO_2-normalized gaseous species emission ratios for tropical forests are given in Table 5. The tropical forest fire emission ratios for gases in Table 5 are based on the measurements of Andreae (5), Andreae et al (14), and Blake et al (15). These emission measurements were obtained for burning tropical forests in South America. Emission ratios for tropical savanna fires are summarized in Table 6 (16). Sometimes, the emission of gases or particulates is represented by the "emission factor." The emission factor provides information on the quantity of gas or particulate produced as a function of the amount of biomass consumed by burning. The emission factor usually has units of grams of gas or particulate produced per kilogram of biomass consumed by fire.

To calculate the total particulate matter (TPM) released from vegetation fires, we use the following expression (17):

TPM = M * P…………………………………………………..**V**

where P is the emission factor, i.e., the conversion of biomass matter to particulate matter during burning. For tropical forest burning, C = 20 tons of TPM per kiloton of biomass consumed by fire (17).

Recent studies using forms of equations **I** to **V**, have estimated the gaseous and particulate emissions resulting from vegetation fires in various tropical regions, including Brazil (15), southern Africa (16,18), and Southeast Asia (19,20). An estimate of the annual production of gases and particulates resulting from burning in the African and global savannas is given in Table 7 (16) and an estimate for annual global production of gases and particulates is given in Table 8 (5). The values in this table are based on the amount of burned biomass given in Table 3 (13).

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Table 1
Carbon and gases produced during biomass burning (4)

Compound	Mean emission factor relative to the fuel C (%)
Carbon dioxide (CO_2)	82.58
Carbon monoxide (CO)	5.73
Methane (CH_4)	0.424
Ethane (CH_3CH_3)	0.061
Ethene (CH_2=CH_2)	0.123
Ethine (CH=CH)	0.056
Propane (C_3H_8)	0.019
Propene (C_3H_6)	0.066
n--butane (C_4H_{10})	0.005
2-butene (cis) (C_4H_8)	0.004
2-butene (trans) (C_4H_8)	0.005
i-butene, i-butene (C_4H_8 + C_4H_8)	0.033
1,3-butadiene(C_4H_6)	0.021
n-pentane (C_3H_{12})	0.007
Isoprene (C_5H_8)	0.008
Benzene (C_6H_6)	0.064
Toluene (C_7H_8)	0.037
m-, p-xylene (C_8H_{10})	0.011
o-xylene (C_8H_{10})	0.006
Methyl chloride (CH_3Cl)	0.010
NMHC (As C) (C_2 to C_8)	1.18
Ash (As C)	5.00
Total Sum C	94.92 (including ash)

Table 2
Nitrogen gases produced during biomass burning (4)

Compound	Mean emission factor relative to the fuel N (%)
Nitrogen oxides (NO_x)	13.55
Ammonia (NH_3)	4.15
Hydrogen cyanide (HCN)	2.64
Acetonitrile (CH_3CN)	1.00
Cyanogen (NCCN) (As N)	0.023
Acrylonitrile (CH_2CHCN)	0.135
Propionitrile (CH_3CH_2CN)	0.071
Nitrous oxide (N_2O)	0.072
Methylamine (CH_3NH_2)	0.047
Dimetylamine ($(CH_3)_2NH$)	0.030
Ethylamine ($CH_3CH_2NH_2$)	0.005
Trimethylamine ($(CH_3)N$)	0.02
2-methyl-1-butylamine ($C_5H_{11}NH_2$)	0.04
n-pentylamine (n-$C_5H_{11}NH_2$)	0.137
Nitrates (70% HNO_3)	1.10
Ash (As N)	9.94
Total sum N (As N)	33.66 (Including ash)
Molecular nitrogen (N_2)	21.60
Higher HC and particles	20

Table 3
Biomass load range and burning efficiency in tropical ecosystems (13)

Vegetation type	**Biomass load range (tons/km^2)**	**Burning efficiency**
Tropical rainforests(21)	5000-55000	0.20
Evergreen forests	5000-10000	0.30
Plantations	500-10000	0.40
Dry forests	3000-7000	0.40
Fynbos	2000-4500	0.50
Wetlands	340-1000	0.70
Fertile grasslands	150-500	0.96
Forest/savanna mosaic	150-500	0.45
Infertile savannas	150-500	0.95
Fertile savannas	150-500	0.95
Infertile grasslands	150-350	0.96
Shrublands	50-200	0.95

Table 4
Estimates of annual amounts of global biomass burning and the resulting release of carbon to the atmosphere (5)

Source	Biomass burned **(Tg dm/yr)**	**Carbon released (TgC/yr)**
Savanna	3690	1660
Agricultural waste	2020	910
Fuel wood	1430	640
Tropical forests	1260	570
Temperate/boreal forests	280	130
World total	8680	3910

Table 5
Typical emission ratios for tropical forest fires

Species	**Tropical forest fires**
CO_2	90.00%
CO	8.5%
CH_4	0.32%
NO_x	0.21%
NH_3	0.09%
O_3	0.48%
TPM[a]	20 ton/kiloton(20)

a - Total particulate matter emission ratios are in units of tons/kiloton (tons of total particulate matter/kiloton of biomass or peat material) consumed by fire.

Table 6
Typical emission ratios for tropical savanna fires (16)

Species	Tropical savanna fires
CO	6.2%
CH_4	0.4%
NMHC	0.6%
H_2	1.0%
NO_x	0.28%
N_2O	0.009%
NH_3	0.15
SO_2	0.025%
COS	0.001%
CH_3Cl	0.095%
CH_3Br	0.00083%
CH_3I	0.00026%
TPM	10 ton/kiloton

Table 7
Emissions from the African savanna and the global savanna (16)
(Units are Tg species/year; 1 Tg = 10^{12} grams = 10^6 metric tonnes)

Species	Global savanna	African savanna
CO_2	3280	6070
CO	130	240
CH_4	5	9
NMHC	6	11
H_2	1.5	2.8
NO_x	6	11
N_2O	0.30	0.56
NH_3	2	3.7
SO_2	1.2	2.2
COS	0.4	0.7
CH_3Cl	0.22	0.41
CH_3Br	0.004	0.007
CH_3I	0.002	0.004
TPM	20	37
PM2.5	10	19
CCN[1]	2.4×10^{27}	4.5×10^{27}

[1] cloud condensation nuclei (CCN) in units of CCN per kilogram of dry matter.

Table 8
Comparison of annual global emissions from biomass burning with emissions from all sources (including biomass burning) (5)

Species	Biomass burning (Tg element/yr)	All sources (Tg element/yr)	Biomass burning (%)
CO_2 (gross)[a]	3500	8700	40
CO_2 (net)[b]	1800	7000	26
CO	350	1100	32
CH_4	38	380	10
NMHC[c]	24	100	24
N_2O	0.8	13	6
NO_x	8.5	40	21
NH_3	5.3	44	12
Sulphur	2.8	150	2
COS	0.09	1.4	6
CH_3Cl	0.51	2.3	22
H_2	19	75	25
Tropospheric O_3	420	1100	38
TPM[d]	104	1530	7
POC[e]	69	180	39
EC[f]	19	<22	>86

a. Biomass burning plus fossil fuel burning.
b. Deforestation plus fossil fuel burning.
c. Nonmethane hydrocarbons (excluding isoprene and terpenes).
d. Total particulate matter (Tg/yr).
e. Particulate organic matter (including elemental carbon).
f. Elemental (black-soot) carbon.

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

BASIC FACTS - DETERMINING DOWNWIND EXPOSURES AND THEIR ASSOCIATED HEALTH EFFECTS, ASSESSMENT OF HEALTH EFFECTS IN PRACTICE: A CASE STUDY IN THE 1997 FOREST FIRES IN INDONESIA

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INTRODUCTION

The dry conditions in Southeast Asia resulting from the 1997 El Niño Southern Oscillation climate phenomenon together with land clearing practices caused the second largest forest fires in Indonesia in this century. Since June 1997, more than 1,500 fires had consumed over 300,000 hectares mainly in Kalimantan and Sumatra islands, and generated intense smoke, which had affected neighbouring countries for several months and triggered secondary disasters like airbus and tanker collisions.

By September 1997, 2 haze-related deaths, some 32,000 suffering from respiratory problems, 2 million affected by haze were reported in Indonesia. In addition, a drought, which was harshest in 50 years, and related epidemics of cholera or dysentery caused over 260 deaths in Irian Jaya. However, no detailed data and information was available to explain public health impacts of the haze and to consider further countermeasures for prevention and protection of general population from the haze.

For providing advice and finding further assistance needs, the Japanese government dispatched public health experts to Indonesia in September 1997. In this paper, I would like to illustrate the results of air quality measurements and an assessment of health effects in the 1997 forest fires of Indonesia, and

review downwind exposures and their associated health effects in previous forest fires in the world.

METHODS

Air quality

The size distribution of particulate matter, carbon monoxide (CO) and carbon dioxide (CO_2) were measured in 8 sites between Jakarta, which was little affected by haze, and Jambi in Sumatra, which was seriously affected. The size distribution of particulates was measured with light scattering particle analyzer (RION KM-07).

Sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), particulate matters less than 10 microns in diameter (PM_{10}), CO, CO_2 were measured in three sites of Jambi. SO_2, NO_2 and O_3 were measured by the methods of Parazosanilin, Saltzmann and KI. PM10 was measured with a low volume air sampler. Inorganic ions, such as chlorite (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{2-}) and ammonium (NH_4^+) were analyzed with ion chromatography using particulate samples collected with the high volume air sampler. From airborne particulate matter samples collected with the high air volume sampler, the polycyclic aromatic hydrocarbon (PAH) fractions, which are known carcinogens, were also analysed by the high performance liquid chromatography (HPLC)/spectrophotometric/ computer system.

Health effects and perception and behaviour

A total of 543 persons in six sites (an elementary school, a secondary high school, a high school, a nursing home, a local government office and a village) were interviewed. In the questionnaire, the following information was gathered: whether symptoms developed or worsened after the occurrence of haze, their severity, past history of respiratory or heart diseases, perception about the haze, shortage of drinking water/food, and preventive behaviours.

In addition, among the respondents, 88 persons with respiratory symptoms were physically examined which included auscultation for abnormal respiratory sounds and clinical signs of conjunctivitis. These subjects were also given a respiratory function test by spirometry.

RESULTS

Air pollution

The concentration of particulate matter 0.3-5.0 µm in size was observed to increase gradually as the measurement site became closer to the heavily affected area, while the concentration of particulate matter over 5.0 µm showed little increase (Figure 1). CO and CO_2 concentrations were also increased in the affected sites; with slight increase typical of urban air pollution in Jakarta (Figure 2).

The major air pollutant of the haze in Indonesia was particulate matter which far exceeded the 'hazardous' level and the maximum value of 500 in the Pollutant Standards Index (PSI) (Table 1). The concentration of 1864 $\mu g/m^3$ was over 10 times higher than that in Jakarta, and about 8 times higher than the maximum level of PM_{10} in the 1987 forest fire disaster in California, which consumed more than 2.4 million hectares (1). CO also showed considerably high concentrations at the 'very unhealthful' level of PSI, but SO_2, NO_2 and O_3 were in the 'good' or 'moderate' range.

Table 2 shows the concentration of inorganic ions in the suspended particulates. The concentration of SO_4^{2-} was 5-10 times higher than that in Tokyo, while Cl^- and NO_3^- were almost at the same level and NH_4^+ was slightly less. The concentrations of the 5-7 ring polycyclic aromatic hydrocarbons (PAHs) in the affected area were 6 to 14 times higher than those in the unaffected area, which showed almost proportional value to the particle concentration. The levels of 4-ring PAHs in Jambi were 40 – 60 times higher than those measured in Jakarta (Table 3).

Health effects

We collected data on the reported cases with pneumonia, bronchial asthma and conjunctivitis from central and local health authorities. Only statistics on outpatients with pneumonia were reported to the central government. In Central Kalimantan, which was one of the areas most heavily hit by the haze during the six-month period, the number of hospitalized cases with pneumonia in September was 33 times higher than that in the previous 12 months (Figure 3).

In Jambi, reported outpatient cases with pneumonia and asthma increased by 1.5 times in September. In a health centre of Jambi, serious cases which needed to be referred to higher level medical facilities increased by 20 per cent in September. In a district hospital of Jambi, cases admitted for bronchitis, acute laryngitis and bronchiectasis increased by 1.6, 8.0 and 3.9 times, respectively.

Out of 539 respondents, 532 (98.7 per cent) developed or became worse with some kinds of symptoms. Of these, 491 (91.1 per cent) had respiratory symptoms. The symptoms developed were considered mild, but all of the respondents had more than one symptom and 85.9 per cent had over 10 symptoms (Table 4). About 30 per cent developed fever which was suspected to be due to infection. For physical and economic reasons, some respondents with serious symptoms did not seek medical care. Respondents 16 to 59 years of age reported a significantly higher rate of symptoms than the other age groups. However, those over 60 years of age had a higher proportion of moderate and severe symptoms, and reported the worst health condition (Table 5). Those with a past history of asthma, bronchitis and heart disease also had a higher rate of symptom manifestations.

During physical examination, conjunctivitis was seen in 33.3 per cent of respondents, wheezing in 8.9 per cent, and other abnormal respiratory sounds in 2.9 per cent. Lung function tests showed that constrictive lung disorder, measured as vital capacity (VC) <80 per cent, and obstructive lung disorder, measured as forced expiratory volume in 1 second (FEV_1) <70 per cent, were seen in 67.4 per cent and 26.9 per cent, respectively (Figure 4).

Regarding perception of haze, 83.3 per cent felt threatened by the haze, and 60.5 per cent wanted to evacuate to safer places. Young respondents were more worried about their future and contemplating moving out of the area affected by the haze.

Of the respondents, 13.7 per cent always put on a protective mask when going out, while 10.9 per cent never and 13.0 per cent seldom did. Young respondents reported lower rate of using a mask.

DISCUSSIONS

The chemical composition of the smoke haze caused by forest fires is determined by the biota and material that are being burnt (2). Incomplete combustion of cellulosic materials in a forest fire produces air pollutants, such as particulate matter, CO_2, CO, NO_x, O_3, SO_2 and over 20 species of hydrocarbons (2, 3). Our study confirmed the findings of other investigations that particulate matter, especially inhalable or respirable particulate matter, is the major air pollutant. Carbon oxide and PAHs are also compounds of concern.

Typical urban air pollution also consists of particulate matter and gaseous compounds. Among them, PM_{10} or much finer $PM_{2.5}$ has been reported to be significantly associated with several indicators of acute health effect, such as mortality (4, 5), hospital admissions (4 - 6), emergency visits (7, 8), physical/functional limitation (9), symptom manifestations (10) and lung function (11, 12). A number of reports also illustrate the association between other typical urban air pollutants and adverse health effects (13 - 15). In contrast, epidemiological studies on the health effects of forest fire smoke are limited. An increase in emergency room visits of asthmatic patients was shown in two studies in California: one on an urban warehouse fire (16) and the other on bushfire (1). Studies of the 1991 urban wildfire in California (17) and the 1994 Sydney bushfires (18) demonstrated little or no increase in emergency room visits for asthma. Several studies on occupational exposures of firefighters to forest/wildland fire showed relatively mild and reversible respiratory health effects (19 - 21). Although we did not conduct an epidemiological study on emergency visits this time, there was evidence of increases in outpatient visits for pneumonia as well as asthma. Hospital admissions for respiratory symptoms were also increased in the affected area. However, due to unreliability of available data and lack of access of local people to medical facilities, outpatient visits and hospital admissions may not represent the real public health impact of the haze. Therefore, we conducted a survey on the health effects of the general population and found that almost all the people developed some kinds of symptoms after the haze, and over 90 per cent had respiratory problems. The

survey indicates an extremely strong association between biomass smoke exposure and acute adverse health effects.

There was no epidemiological study on mortality of air pollution from forest fires. In air pollution episodes from fossil fuel combustion, a number of studies indicated that PM_{10} or $PM_{2.5}$ is significantly associated with overall and disease-specific mortality (4, 5, 22 - 24). Several reviews of these studies suggest that there is a dose-response relationship between PM_{10} and mortality (22). Most of the studies indicate that a 10 µgm^3 change in PM_{10} is associated with a 1.0 - 1.6 percent change in mortality (23, 24). A meta-analysis suggests that a 10 µg/m^3 change in PM_{10} is associated with a 3.4 per cent and a 1.4 per cent change in respiratory and cardiovascular mortality, respectively (23). WHO presented a methodology for estimating the total number of expected cases of premature mortality resulting from acute exposure to PM_{10} (25). It is uncertain whether the calculation of the mortality effects derived from epidemiological data of typical urban air pollution can be applied to cases of biomass smoke. However, if we assume it can be applied, the expected death cases can be estimated using the following formula:

Expected death cases = r/(1+r) x (current mortality rate) x (exposed population) where r is the additional risk associated with the current level of particles relative to the standard; and r is calculated by:

r = (estimated percent effect of PM_{10} per µg/m^3) x (1/100) x (change in PM_{10})

Using 7.5 per 1000 (the crude mortality rate in Indonesia for the period 1990-1995) as the current mortality, 12 million as the exposed population (26), 422 µg/m^3 as the change in PM_{10} [based on the one-month average PM_{10} concentration of 565 µg/m^3 measured by Environmental

Management Center in Indonesia (27) minus the standard level of 143 µg/m^3], the number of expected death cases is 0.52/1.52 x (7.5/1000) x 12,000,000 = 30,789. [r = (0.123 x (1/100) x 422) = 0.52].

This figure might be overestimated since the calculation used the one-month average of PM_{10} in October-November during the haze episode instead of the annual average which is not available. Although 527 deaths were reported in eight haze-affected provinces of Indonesia from September to November 1997 (27), the precise number of the haze-related deaths was unknown because of poor documentation, misclassification or miscoding of the cause of death. Increased mortality from air pollution seems to be attributable to cardiovascular as well as respiratory causes (25, 28) and is dependent on the vulnerable population groups such as children, the elderly and those with respiratory/cardiovascular disease. However, it is not certain whether biomass smoke has the same mechanism of action and impact on the vulnerable groups and the general population as in the case of urban air pollution.

From a number of studies on particulate matter, there is no evidence that airborne particles from different combustion sources have different impacts on health. Therefore, it is not expected that biomass smoke particulate would be less harmful than that originated from fossil fuel combustion. However, the excess deaths may be different for particulate matter generated from fossil fuel combustion and biomass burning. There may be two reasons for this. One is that the chemistry of respirable particles produced by forest fires differs from that of typical urban particulate pollution. The other is that it might be difficult to attribute adverse health effects to a single pollutant in light of the complexity and variability of the mixture of air pollution to which people are exposed. The high intercorrelation between the pollutants makes it difficult to assess the health effect of one single pollutant. There are many reports that the concentration of other pollutants like ozone were more strongly related to mortality (29). The technical feasibility and scientific validity of implicating a single pollutant in such a complex mixture of air pollution to the health effects requires careful consideration and further research.

The forest fire episode of 1997 also resulted in high concentrations of sulfate (SO_4^{2-}). While sulfate, per se, is an unlikely causal factor for pollution-related mortality or morbidity, it is often closely correlated with variations in the strong acid component of ambient particulate matter (H^+) and concentrations of $PM_{2.5}$ which are more likely causal factors (30).

Sulfate has been demonstrated to be a useful surrogate for ambient $PM_{2.5}$ and H^+ in epidemiological studies and as an index of PM exposure in ambient air quality guidelines and standards. In addition, the haze contained considerably high concentrations of CO. Evidence from seven large cities in the USA showed that high concentrations of CO were associated with increased hospital admissions for congestive heart failure among elderly people (31). And high concentrations of CO were also associated with increased plasma viscosity, which may lead to a rise in such hospital admissions. Little is known about the biological mechanisms linking ambient air pollution with exacerbation of cardiovascular diseases, but Seaton et al (32) postulated that inflammation in the peripheral airways caused by air pollutants might increase the coagulability of the blood, and thereby lead to an increased number of deaths.

There is limited evidence on the long-term health effects of typical industrial air pollution as well as biomass generated air pollution. As large populations were exposed for a long duration to intense biomass air pollutants, especially inhalable/respirable particulate matter and carcinogen from the forest fire episode in Indonesia, further studies are needed to evaluate long-term health effects.

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Figure 1
Particle concentrations of sizes >0.3 μm and >5.0 μm measured in 8 sites in Indonesia

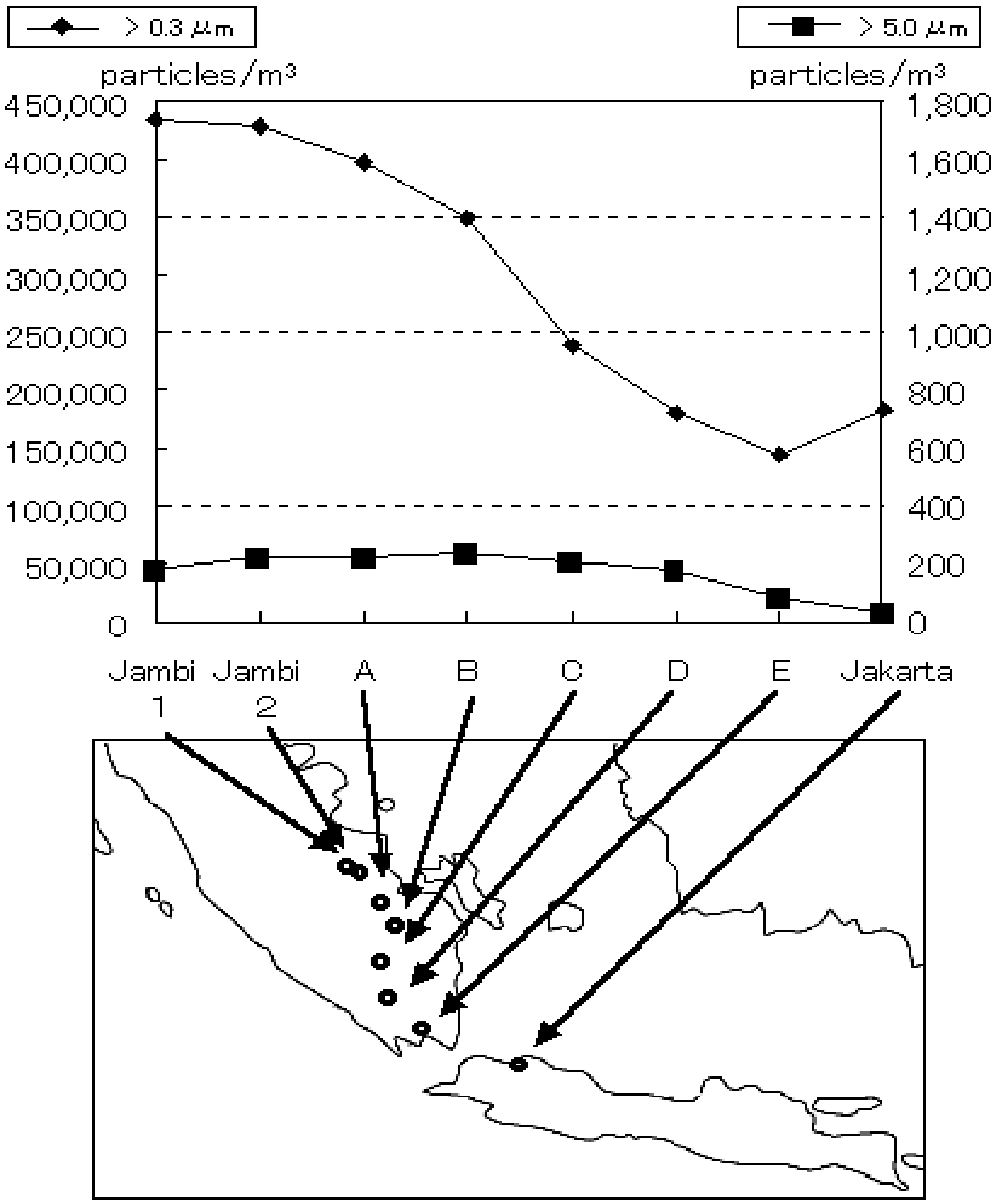

Figure 2
CO and CO_2 concentrations measured in 8 sites in Indonesia

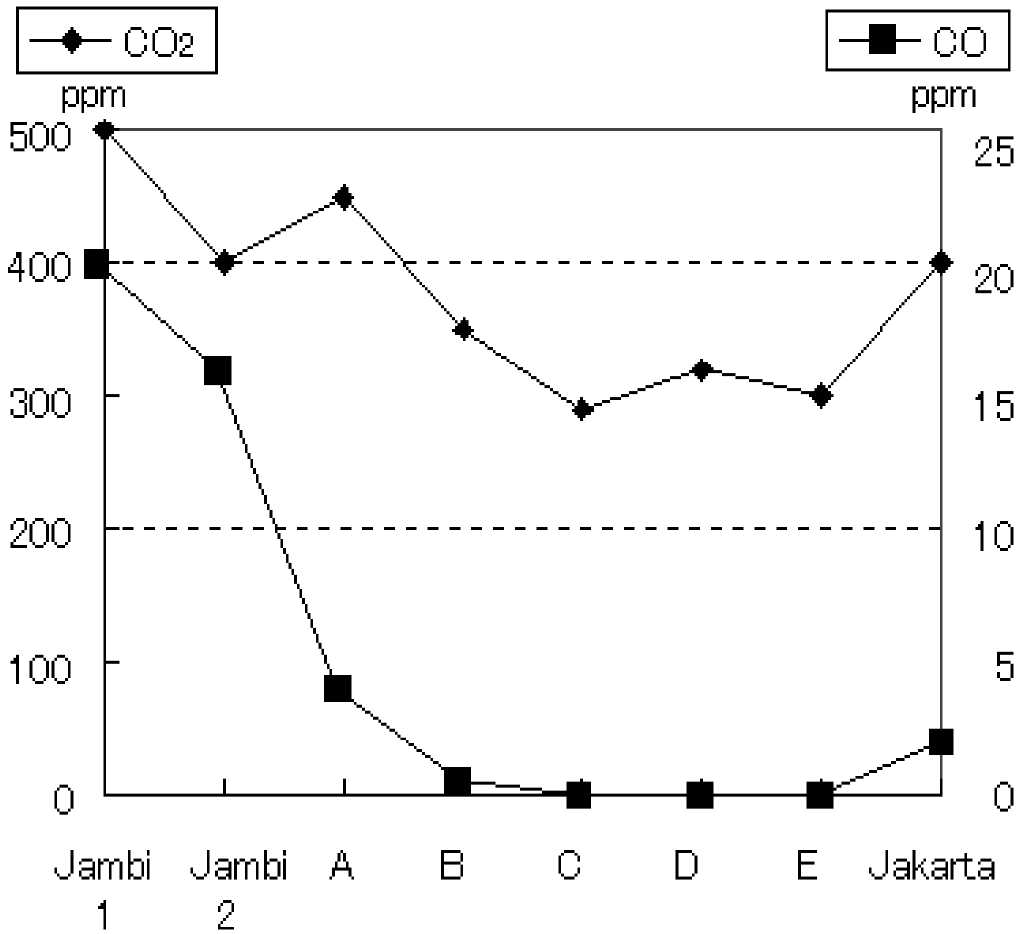

Figure 3
Number of reported hospitalised cases with pneumonia in Central Kalimantan, Indonesia, 1995-1997

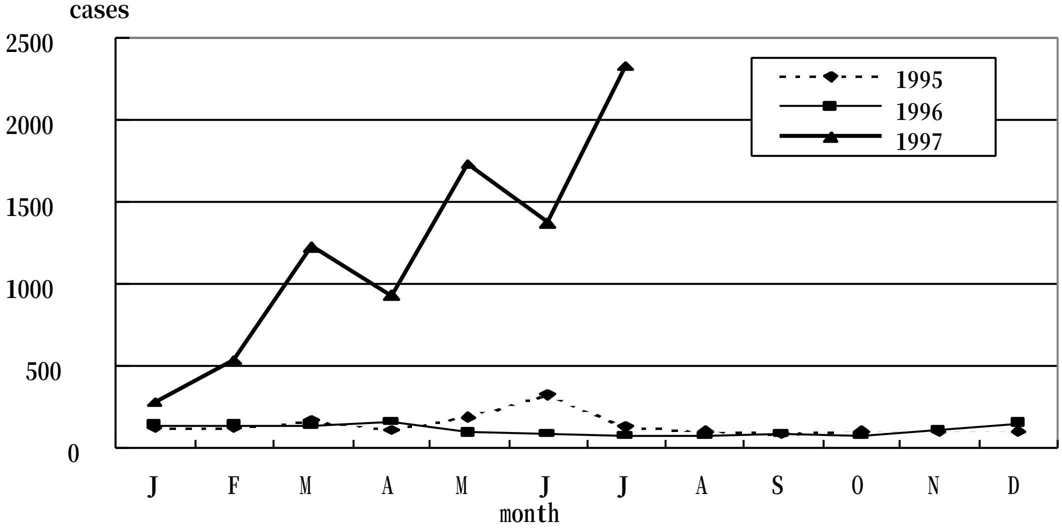

Figure 4
Lung function tests for persons with respiratory symptoms

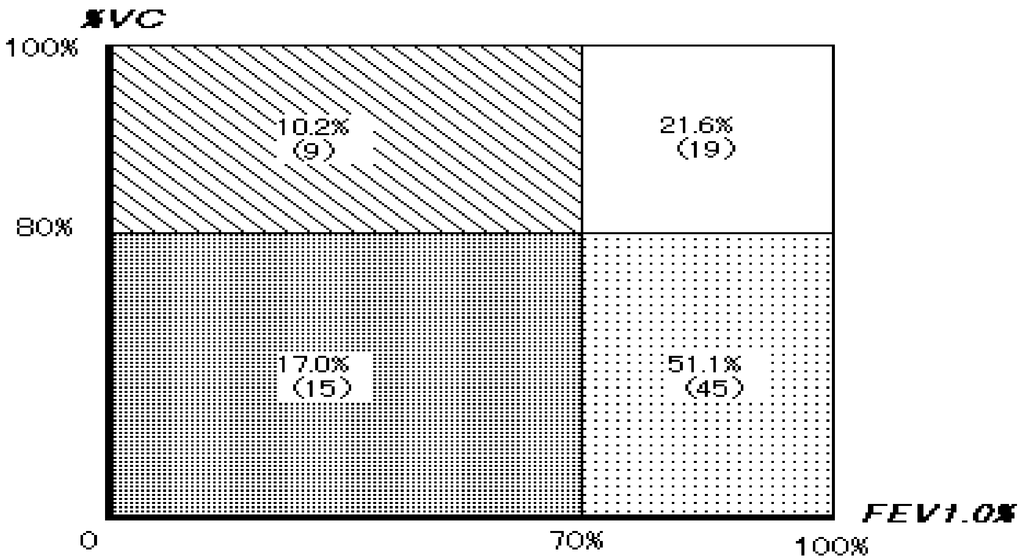

Table 1
Air pollutants measured in 3 sites in Jambi, Indonesia, 3-5 Oct, 1997

	Site 1	Site 2	Site 3	Unit	PSI
SO_2	0.01	0.01	0.01	Ppm	18
NO_2	0.01	0.02	0.004	Ppm	-
O_3	0.03	0.03	0.06	Ppm	54
CO	20	20	20	Ppm	247
PM_{10}	1684	1635	1864	? g/m^3	1584

Table 2
Concentrations of inorganic ions in suspended particulates

Sample no		Cl^-	NO_3^-	SO_4^{2-}	NH_4^+
I	µg/m^3	4.98	5.23	37.98	0.69
	mg/g dust	4.09	4.30	31.19	0.57
II	µg/m^3	3.07	4.68	46.85	0.76
	mg/g dust	2.62	4.00	40.05	0.65

Table 3
Concentrations of carcinogenic substances in suspended particulates

	Jambi	Jakarta	Molecular weight
Particle (µg/m^3)	1707	167	
Fluoranthene	16.7	0.255	202.3
Pyrene	21.1	0.396	202.3
Triphenylene	20.2	0.411	228.3
Benz(a)anthracene	16.8	0.438	228.3
Chrysene	41.7	0.910	228.3
Perylene	2.60	0.219	252.3
Benzo(e)pyrene	14.7	1.22	252.3
Benzo(b)fluoranthene	15.1	1.62	252.3
Benzo(k)fluoranthene	6.45	0.793	252.3
Benzo(a)pyrene	15.3	1.05	252.3
Indeno(1, 2, 3 – cd) pyrene	11.1	2.24	276.3
Benzo(ghi) perylene	12.8	1.78	276.3
Dibenz(a, c) anthracene	0.428	0.158	278.4
Dibenz(a, h) anthracene	0.823	0.120	278.4
Benzo (b) chrysene	1.66	0.164	278.4
Coronene	0.914	0.121	300.4
Dibenzo(a, e) pyrene	3.15	-	302.4
Air volume (m^3)	565	1,995	
Collected amount of particles (g)	0.9646	0.3338	
Sampling time (hours)	5.2	23.8	

Table 4
Prevalence and severity of reported symptoms which developed after exposure to the haze

Symptoms	n	%	mild	moderate	severe
Eye irritation	425	78.9	276	135	14
Cough	415	77.0	231	155	29
Sneezing	385	71.4	286	94	4
Headache	331	61.5	199	119	14
Fatigue	280	52.0	206	67	7
Running nose	272	50.5	171	93	8
Sputum	253	47.0	175	67	11
Breathless (walking)	239	44.4	155	77	8
Sore throat	234	43.5	152	74	9
Breathless (during hard work)	192	35.7	109	71	12
Chest discomfort	175	32.5	109	59	6
Fever	161	29.8	107	49	4
Anorexia	151	28.0	108	39	4
Insomnia	129	23.9	84	38	7
Nausea	126	23.3	101	23	2
Palpitation	121	22.5	88	33	0
Abdominal pain	121	22.4	88	28	4
Depression	95	17.7	55	32	8
Wheezing	78	14.5	45	25	8
Dizziness	22	4.1	1	17	5
Diarrhoea	16	3.0	12	4	1

Table 5
Changes in general health condition of respondents by age

Age group	Worst	Worse	Unchanged	Better	Total
0-15 years	13 (5.0)	154 (59.2)	38 (14.6)	55 (21.2)	260 (100)
16-59 years	18 (9.8)	137 (74.5)	24 (13.0)	5 (2.7)	184 (100)
≥ 60 years	10 (17.2)	34 (58.6)	14 (24.1)	0 (0)	58 (100)
Total	41 (8.2)	325 (64.7)	76 (15.1)	60 (12.0)	502 (100)

Figures in brackets denote per cent

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

SMOKE EPISODES AND ASSESSMENT OF HEALTH IMPACTS RELATED TO HAZE FROM FOREST FIRES: INDONESIAN EXPERIENCE

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INTRODUCTION

Uncontrolled forest fire in Indonesia has caused smoke pollution in the country as well as other countries in this particular part of the world. The haze episodes in the Southeast Asian region constituted a substantial health risk to the public in 1997 and early 1998 This was evidenced by widespread increases of health-related ambient air quality standards and guidelines for particulate matter. In 1997, in relation to clinical indicators of health, this risk was reflected in increased respiratory-related hospital visits in the most heavily impacted areas during the peak period of the haze.

Forest fires have been occuring almost yearly, especially during the dry season, at certain locations in Indonesia including Kalimantan, Sumatera, Java, Sulawesi, Maluku and Irian Jaya. From July to the beginning of October 1997, smoke haze from uncontrolled forest fires had spread throughout some neighbouring countries such as Brunei Darussalam, Malaysia, Southern Philippines, Singapore and Southern Thailand. The Coordinator Minister of Social Welfare of Indonesia declared these uncontrolled forest fires, especially in Sumatera and Kalimantan, as national disaster.

In a WHO meeting on the health impacts of haze in June 1998, it was mentioned that the severity and extent of the smoke haze pollution were unprecedented, affecting an area with a population of 300 million people across the region. It was also stated that at least 20 million Indonesians were affected by the haze from forest fires. The actual amount of economic losses suffered by countries during this environmental disaster were enormous and are yet to be fully determined. The countries most affected were Indonesia, Malaysia and Singapore as they had experienced extended period of high particulate levels and severe reduction in visibility. Among the important sectors severely affected were air and land transport, shipping, construction, tourism and agriculture-based industries. The haze pollution had also resulted in considerable public health impacts, and the long-term health effects are yet to be determined.

From the public health aspect, the disastrous forest fires lead to a negative influence on the ecological system and the health status of the community in the affected area since air, water and soil were significantly polluted. The acute and chronic effects of haze include elevated morbidity and mortality of respiratory diseases.

INDONESIA AT A GLANCE

Indonesia is the largest archipelago in the world with a total population of more than 200 million people living in an area of 1.9 million km^2. It consists of five major islands; ie. Sumatera, Kalimantan, Java, Sulawesi and Irian Jaya, and more than 17,000 small islands. Rapid increase in population, industrial development and transportation has caused considerable pressure on the Indonesian environment, and pollution of air, water and ground resources has potential effects on human health.

Indonesia is a rich country in term of natural resources. Agriculture, forestry and fisheries are still the main sources of economic growth. However, due to its location near the Western Pacific region. Indonesia is directly affected by the El Niño phenomenon. Observations over the past several decades have showed that, during El Niño events, most parts of the country received below normal rainfall. This has considerable environmental impact as common forestry and agriculture practices will exacerbate the problem of smoke and fires.

Fires in Indonesia have resulted in human exposure to levels of air pollutants far in excess of those stipulated in the WHO guidelines. Chemical pollutants such as SO_2, NO_x, O_3 CO and respirable fine particulate are harmful to human health. Air quality monitoring data (PSI or pollutant standards index) obtained from various institutions during the peak haze period showed that in areas close to the fires, the levels of air pollutants were 4-8 times higher than the values which have a significant health impact. Data collected through active surveillance from September to November 1997 in eight provinces showed increases in the incidence of bronchial asthma and ARI (acute respiratory infection). According to the Indonesian Central Bureau of Statistics, among 12,360,000 people affected by the haze in 1997, there were about 1,802,340 cases of bronchial asthma, bronchitis and ARI.

In several provinces, the total suspended particulate (TSP) threshold limit of 260 $\mu g/m^3$ was exceeded; eg. in West Sumatera, by 5 - 10 times; in Riau, by 0.8 - 7 times; in South Sumatera, by 3.5 - 8 times; in West Kalimantan, by 0.5 - 7.3 times; and in Central Kalimantan, by 0.5 - 15 times.

SMOKE CHARACTERIZATION

Biomass smoke contains a large and diverse number of chemicals, many of which have been associated with adverse health effects. A summary of the major biomass pollutants is given by Brauer (see page 253). These include both particulate matter and gaseosus compounds such as carbon monoxide, formaldehyde, acrolein, benzene, nitrogen dioxide and ozone. Particulate matter is itself a complex mixture which is associated with a wide range of health effects. Elevated concentrations of particulate matter are consistenly observed in situations where biomass material is burned. Exposures to high concentrations of carbon monoxide and other pollutants are highly variable and occasionally observed in individuals such as wildland firefighters and people who cook with biomass fuels. Based on literature review as well as initial evaluation of the available air monitoring data from the 1997 haze episode, the air pollutant parameter most consistently elevated in association with biomass smoke is particulate matter.

Monitoring and managing the environmental impact of smoke from forest fires has been given the priority by the government of Indonesia even though air quality monitoring data are still limited due to lack of sampling devices and scarcity of other resources. Air quality monitoring stations are located in the capital cities of all 27 provinces and operated by Environmental

Impact Management Agency (BAPEDAL), Ministry of Health, Ministry of Transportation, local government etc. All heads of provincial health office are requested to monitor air pollutants of forest fires; ie. SO_2, CO, NO_x, O_3, and total suspended particulate matter (TSP), and send the results weekly to the Ministry of Health. However, due to lack of equipment and high operational budget, most of the provincial health offices are capable of monitoring only TSP which is a more important health hazard. Currently, the Environmental Management Center (EMC) at BAPEDAL is developing a simplified air quality monitoring method. With EMC coordinating the air quality monitoring in other sectors, appropriate data could be provided to assess the health risk of smoke haze.

Access to appropriate and accurate data is essential to guide the Ministry of Health in its immediate response and for future planning. Extensive TSP data are provided by the Ministry of Health and the Department of Meteorology and Geophysics. Unfortunately, this data cannot be directly used to assess the respirable particulate content of the air. To solve this problem, the Director of Environmental Health, Ministry of Health, has developed temporary guidelines on how to calculate and convert from TSP value to particulate matter 10 µm in diameter. Since November 1997, the Ministry of Environment has issued a new regulation on air pollutant standards index similar to the PSI used in most countries of the Association of Southeast Asian Nations (ASEAN).

The air quality monitoring data collected by the Directorate General of Communicable Disease Control and Environmental Health (CDC&EH), Ministry of Health (MOH), from provincial health offices showed different peak PSI in different areas at different time periods. The findings are compiled in Table 1 from which the peak periods in different provinces can be inferred:

North Sumatera: peak period occurred in the first week of October 1997. TSP levels were more than 3 times higher, while other parameters were below the standard values.

West Sumatera: peak period occurred at the second week of October 1997. TSP value was more than 10 times, while NO_x was more than 2.5 times the standard in the last week of September 1997.

Riau: peak period occurred in the last week of September 1997 with TSP value more than 7 times the standard. In the last week of November 1997, TSP value was still more than twice the standard.

Bengkulu: peak period occurred in the last week of October 1997, but the TSP value was below and CO slightly above the respective standards.

South Sumatera: peak period occurred in the first week of October 1997 with TSP value more than 8 times and NO_x slightly above the respective standards.

Jambi: peak period occurred in the second week of October 1997 when the TSP value was more than 15 times above the standard. However, the NO_x level was below the standard.

West Kalimantan: peak period occurred in the last week of September 1997 with TSP value more than 7 times the standard. At the end of October 1997, TSP value was still more than twice the standard.

Central Kalimantan: peak period occurred at the end of October 1997 with TSP value more than 15 times and CO more than 8 times the respective standards. As for other parameters such as SO_2 and NO_x, peak period was in the first week of October 1997, when the levels were more than 4 times the respective standards. At the end of October 1997, TSP value was still about 13 times above the standard.

South Kalimantan: peak period for TSP and CO value occurred at the last week of September 1997, with values almost 4 times to 15 times respectively, above the standard. On the first week of October 1997, the CO level was close to 29 times the standard. At the end of October 1997, TSP value was about 13 times above the standard.

East Kalimantan: peak period for CO value occurred at the second week of October 1997 when it reached more than 2.6 times the standard. In the third week of October, TSP was more than 1.3 times the standard while the other parameters were below the standard. At the end of October 1997, TSP value was still more than 1.3 times the standard.

Maluku and Irian Jaya: very limited air quality data were available.

The Ministry of Health reported that there was an increase in the number of cases of respiratory diseases such as upper respiratory tract

infection (URI) and asthma, in Pontianak and West Kalimantan. However, there was no significant increase in skin and eye diseases.

At the beginning of February 1998, forest fires started again in east Kalimantan, central Kalimantan and Maluku.

HEALTH IMPACTS

The WHO biregional meeting on health impacts of haze-related air pollution at Kuala Lumpur in 1998 concluded that the main constituent of the haze that adversely affects health is fine particulate matter. Based on extensive literature review regarding the health impacts of air pollution, the ambient concentration levels of PM_{10} (i.e. particles that are 10 microns or less in diameter) observed in Brunei Darussalam, Indonesia, Malaysia and Singapore during the 1997 and 1998 haze episodes are associated with:

- increased daily mortality;
- increased hospitalization;
- increased visits to emergency rooms;
- increased respiratory symptoms;
- exacerbation of asthma; and
- decreased lung function.

These impacts have been observed, primarily in the elderly, the very young and in individuals with pre-existing respiratory and/or cardiovascular illness.

From the existing body of knowledge that associates a range of adverse health impacts with urban particulate air pollution mixtures, there was no evidence that particles from different combustion sources have different impact on health. While particles generated by natural processes such as volcanic eruptions and wind-blown soil appeared to have less impact on health, there is little reason to expect that biomass smoke particles would be less harmful than other combustion-source particles. Available data strongly suggest that combustion-source particulates, including those produced during forest fires, are associated with a wide range of adverse health outcomes.

The risk of long-term health effects due to a single air pollution episode is difficult to detect, but repeated exposures to haze may result in a

wide range of adverse health outcomes and hence merit our attention. Existing data indicate that the potential carcinogenicity of biomass particulates is low relative to particulate emissions from diesel-run motor vehicles. Epidemiological studies have not demonstrated an increased risk of lung cancer in individuals with lifetime exposure to higher levels of biomass particulate than those measured in the 1997 and 1998 haze episodes. Therefore, the risk of cancer associated with biomass air pollution episodes may be considered as low relative to other enviromental risk factors.

The most significant immediate health impact of haze disaster observed in the affected areas in Indonesia are acute respiratory infection (ARI), bronchial asthma, diarrhoea, eye irritation, and skin disease. Comparing the data obtained from September 1997 to June 1998 with those obtained during the same period in 1995 and 1996, the number of ARI cases was generally below the average in some provinces, but it increased by 1.8 times in South Kalimantan province, and 3.8 times in South Sumatera. For other provinces, a significant increase occurred from October to November 1997. The number of ARI cases declined in parallel with the decrease in the incidence of forest fires. The health impact during the haze disaster in eight provinces is shown in Tables 2 and 3.

Medical experts of the Japan Disaster Relief Team (JDR) conducted field surveys to assess the enviromental and health effects on the people affected by the haze in Indonesia. They found not only increased hospital visits and admissions for conjunctivitis, bronchial asthma and pneumonia in the affected areas, but also increased severity of these medical conditons. Through community surveys, many symptoms of respiratory and digestive problems were reported within one month after the occurrence of the haze, and people with poor respiratory functions were also detected. The elderly and young children appeared to be more vulnerable in this hazardous situation.

Another survey conducted by a team from the Indonesian Association of Pulmonologists (East Java Branch), at the city of Samarinda (highly polluted area with NO_x 140 $\mu g/m^3$ and TSP 438 $\mu g/m^3$) and Bontang (relatively low polluted area with NO_x 36 $\mu g/m^3$ and TSP 198 $\mu g/m^3$) in central Kalimantan. No statistically significant difference was observed in the prevalence of bronchitis & bronchial asthma as well as the lung function parameter (FEV_1) among 127 high school students examined. There were significant differences in FVC and PFR in the male population. Seven out of 9 subjects who had obstructive changes showed signs of bronchial hyperreactivity.

Another team from the Indonesian Association of Pulmonologists conducted a survey at Palembang (South Sumatera) and Jambi. The TSP level at Palembang between 25 September to 4 October 1997 was around 1.047 - 4.86 mg/m^3; NO_x, 0.03 – 0.11 ppm; and SO_2, 0 – 0.19 ppm. Of the 212 patients examined, 158 (74.5 per cent) had no prior history of respiratory problems. Among the sample population, 81 per cent had complaints of cough; 24 per cent, dyspnoea; and 19 per cent, phlegm. However, from those who had a prior history of respiratory problems, 83 per cent complained of cough; 72 per cent, dyspnoea; and 29.6 per cent, wheezing.

A report from the Provincial Health Office in Jambi showed that there was an increase of 51 per cent for respiratory diseases in that area during the haze period. Bronchial asthma constituted 78 per cent of the respiratory diseases among patients treated at Jambi and Palembang. On the whole, 70 per cent of the patients with respiratory diseases reported that their symptoms worsened during the haze period. Data from the hospitals in Jambi showed two to four fold increase in mortality rate compared to the previous months. The main causes of death were respiratory failures in patients with advanced tuberculosis, severe chronic bronchitis, severe pneumonia and lung cancer.

STEPS TAKEN TO MINIMISE HEALTH IMPACTS

In order to minimise the health impacts of the haze from forest fires, campaigns to increase awareness of the community were undertaken by various institutions in the country, including the Directorate-General (DG) of Communicable Disease Control (CDC) and Environmental Health (EH) and health professional associations.

The Director-General of CDC & EH instructed the provincial health offices to:

- monitor air quality daily;
- strengthen surveillance activities for ARI, asthmatic bronchitis and eye irritation;
- protect the community, especially the high-risk groups (babies, the elderly, pregnant women), by introducing and distributing masks;
- alert local government and private health sectors to provide 24-hour services; and
- in case of emergency, the local authority could immediately decide to close down schools and offices activities and to selectively evacuate the high-risk groups to safer places.

Health profesional associations such as the Indonesia Medical Association, the Indonesian Pulmonologist Association, and the Environmental Health Association were involved in various activities such as provision of health services and health education in the affected areas. The Indonesian Association of Pulmonologists has contributed in the following activities:

- developed guidelines for physicians in handling cases with respiratory problems due to the haze from forest fire;
- sent a health team to the affected areas in Jambi and Central Kalimantan;
- conducted a small scale survey on the impact of haze on respiratory health; and
- developed a proposal for cohort study on the long-term impact on respiratory health of the community exposed to the haze (see Annex).

Other activities initiated by various non-government organisations included:

- distribution of masks to high risk groups;
- co-ordination with other sectors under the National Board for Disaster Management at central level as well as at provincial and district levels; and
- development of information system and early warning system for health impact during haze disaster.

The haze from forest fires in Indonesia had substantial impact on public health and the ecology in the affected areas. A lot more should be done to characterise the smoke composition, and its impacts on health, as well as its social and economic activities. It is important that the Indonesian Association of Pulmonologists plays an active role, especially in the health sector, by conducting research, strengthening capabilities of physicians, and producing guidelines for medical doctors and other health profesionals.

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

Annex

PROPOSAL FOR A COHORT STUDY ON LUNG AND RESPIRATORY TRACTS OF HUMANS DUE TO HAZE OR SMOKE FROM FOREST FIRES

Introduction

Forest fires that occurred in certain locations in Indonesia produced impacts which were not only felt in Indonesia, but also in the South East Asian region. Haze, produced by biomass burning, can cause lung and respiratory disorders and decreased lung functions; e.g. acute respiratory infection and acute excacerbation of asthma and chronic obstructive lung disease. It is still a big question as to whether the haze from forest fires can cause lung-cancer. However, acute or chronic exposure may influence the morbidity and mortality due to the haze-related respiratory tract diseases.

A study on the health effects of exposure to biomass-haze has been conducted before, but the period of exposure was relatively short compared to the situation in 1997. Based on the observations made, it was felt that a cohort study should be carried out to determine the short-term and long-term effects on the respiratory tracts following exposure to haze from biomass burning.

Objectives

- to study the effects of exposure to biomass-haze in relation to the pattern of lung and respiratory diseases;
- to evaluate the short-therm and long-term effects of haze on the respiratory tract;
- to develop an applicable but sensitive and valid for the detection of and monitoring for the pathogeneses of lung and respiratory diseases; and
- to provide training for professional health workers for the purpose of conducting the appropriate tasks.

Material and Methods

Material

- Sample size for a cohort (prospective) study
  (in each province of Sumatera and Kalimantan)

  a. Specific groups:

  Exposed group
  Junior high school students ≥ 13 years (100 persons)
  Elderly people (≥ 50 years) (100 persons)

  Non-exposed group
  Junior high school students ≥ 13 years (100 persons)
  Elderly people (≥ 50 years) (100 persons)

  b. Community (≥ 15 years and ≥ 50 years) (2 x 500 persons)
  (assumed that the sample changes every year)

  – Acute infection of upper respiratory tract
  – Acute exacerbation of asthma
  Chronic obstructive pulmonary disease (COPD)
  Mortality pattern due respiratory disease

- Equipment

  - Stethoscope (4 units)
  - Tensimeter (4 units)
  - Spirometer (8 units)
  - Oxymeter (4 units)
  - Peak flowmeter (60 units)

Methods

The measurements of lung and respiratory disorders; examinations of several kinds of diseases.

- History of illness by ordinary and structurized questionnaire

- Physical examination

- Measurements of lung function by using spirometer and peak-flowmeter (taken every year including period free of forest fire). The parameters will include:

  - VC
  - PVC
  - FEV_1
  - PFR

- Chest X-ray will be taken every year

- For specific small groups, examinations will be performed in more detail such as:

  - Fiberoptic bronchoscopy
  - BAL (Broncho-alveolar lavage)
  - Oxymetry
  - Bronchodilator test

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

Table 1
Weekly air quality data ($\mu g/m^3$) in some affected areas in Indonesia, Sept-Nov, 1997

Province	Parameter	24-28 Sept	29 Sept-4 Oct	5-11 Oct	11-18 Oct	19-25 Oct	26 Oct – 1 Nov
North Sumatera	Total dust	-	96-770	-	120-122	-	-
	SO_2	154.3	14-80	-	0.01-0.014	-	-
	NO_x	-	1.88	-	-	-	-
	CO	-	-	-	-	-	-
West Sumatera	Total dust	1,300-1,900	-	1,000-2,800	-	-	-
	SO_2	-	-	-	-	-	-
	NO_x	99.65-223.74	-	75.21-135.37	-	-	-
	CO	-	-	-	-		
Riau	Total dust	1,600-1,900	230-970	180-370	160-620	300-820	270-580
	SO_2	-	-	-	-	-	-
	NO_x	-	-	-	-	-	-
	CO	-	-	-	-	-	-
Jambi	Total dust	1,613.2-3,404.1	1,804.9-3,939.9	94.4-3,939.9	-	-	-
	SO_2	-	-	-	-	-	-
	NO_x	102.92-218.75	83.61-127.8	69.3-218.75	-	-	-
	CO	29,755.58-30,900.02	-	29,755.7-30,900.15	-	-	-
Bengkulu	Total dust	-	181.60	104.11-190.15	137.11-190.15	130-204,67	106
	SO_2	-	-	-	-	-	-
	NO_x	-	-	5.45	2.44	4,577.8	-
	CO	1,444.45	1,430.35-2,288.9	2,288.9	-	-	-
South Sumatera	Total dust	904-1,890	1,047-2,111	-	-	-	-
	SO_2	-	183.11	-	-	-	-
	NO_x	-	94.07-131.61	-	-	-	-
	CO	-	-	-	-	-	-

Table 1 (cont'd)
Weekly air quality data ($\mu g/m^3$) in some affected area in Indonesia, Sept-Nov, 1997

Province	Parameter	24-28 Sept	29 Sept-4 Oct	5-11 Oct	11-18 Oct	19-25 Oct	26 Oct – 1 Nov
West Kalimantan	Total dust	904-1,890	161-1,218	122-242	180-381	341-556	-
	SO_2	-	-	-	-	-	-
	NO_x	-	-	-	-	-	-
	CO	-	-	-	-	-	-
Central Kalimantan	Total dust	500-1,310	130-981	180-4,090	1,020	2,850-3,280	-
	SO_2	817	604.3-1,097.3	30.16-322.6	-	-	-
	NO_x	230	1,097.3	22.13-126.7	-	-	-
	CO	1,144.45	1,144.45-2,288.9	1,444.5-18,311.2	-	2,889 -9,155.6	-
South Kalimantan	Total dust	454-991	46-678	-	-	-	-
	SO_2	77-120	90-122	-	-	-	-
	NO_x	9.4-658.01	338.43-1,662.06	-	-	-	-
	CO	11,444.5-33,662.4	-	-	-	-	-
East Kalimantan	Total dust	-	333-833	66-321.1	32.6-346.5	-	-
	SO_2	-	-	1.05-6.02	8.11	-	-
	NO_x	-	6.02-11.09	10.15-17.11	0.37-23.69	-	-
	CO	-	3,662.24-4,577.8	4,511.4-5,998.06	3,951.56	-	-

Note :
Standard of TSP : 260 $\mu g/m^3$
Standard of SO_2 : 260 $\mu g/m^3$
Standard of NO_x : 92.50 $\mu g/m^3$
Standard of CO : 2,260 $\mu g/m^3$

Table 2
Number of cases of asthma, bronchitis, acute respiratory infection (ARI) and deaths in 8 provinces in Indonesia, September-November 1997

Province	Population at risk	Asthma	Bronchitis	ARI	Death
Riau	1,701,000	41,028	7,995	199,107	75
West Sumatera	2,411,000	58,164	11,332	282,087	106
Jambi	1,478,000	35,650	6,947	172,926	65
South Sumatera	2,355,000	56,803	11,069	275,535	104
West Kalimantan	1,478,000	44,574	8,686	216,216	74
Central Kalimantan	716,000	17,574	3,366	83,772	29
South Kalimantan	1,733,000	41,800	8,145	202,716	69
East Kalimantan	118,000	2,846	555	13,806	5
Total	12,360,000	298,125	58,095	1,446,120	527

Source: Directorate-General, Communicable Disease Control & Environmental Health, Ministry of Health, Indonesia

Table 3
Estimated health and social impacts during the haze episode in 8 provinces in Indonesia, September-November 1997

Province	Population at risk	No. of out-patient visits	No. of in-patient	No. of lost working days	No. of days with limited activities
Riau	1,701,000	5,018	2,177	336,670	654,885
West Sumatera	2,411,00	7,112	3,086	477,197	928,235
Jambi	1,478,000	4,360	1,892	292,533	569,030
South Sumatera	2,355,000	6,948	3,015	466,114	906,675
West Kalimantan	1,478,000	5,452	2,366	365,765	711,480
Central Kalimantan	716,000	2,112	917	141,714	275,660
South Kalimantan	1,733,000	5,112	2,218	343,004	667,205
East Kalimantan	118,000	348	151	23,355	45,430
Total	12,360,000	36,462	15,822	2,446,352	4,758,600

Source: Directorate-General, Communicable Disease Control & Environmental Health, Ministry of Health, Indonesia

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

SMOKE EPISODES EMISSIONS CHARACTERIZATION AND ASSESSMENT OF HEALTH RISKS RELATED TO DOWNWIND AIR QUALITY - CASE STUDY, THAILAND

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INTRODUCTION

With abnormally dry conditions from the 1997-98 El Niño/Southern Oscillation (ENSO) episode, widespread uncontrolled forest fires (originally as part of land clearing operations) occurred since June 1997 in Irian Jaya, Kalimantan (Borneo), Sulawesi, and Sumatra of Indonesia, a country in the South-East Asia region (1). Approximately one million hectares of forest were ablaze when most of the fires subsided three months later in November. From September, the thick haze due to fine particles suspended in the air from smoke and soot had darkened skies across the region—Malaysia, Indonesia, Singapore, Brunei, southern Thailand and parts of the Philippines. Indonesia declared a state of national emergency in September 1997. The Malaysian Government also declared a state of emergency in Sarawak on Borneo Island on 19 September. All private and public offices and schools in Sarawak were closed and the people advised to stay indoors.

An increase in the number of people who required clinic (outpatient) visits or hospital admissions for various haze-related illnesses was reported from Malaysia, Singapore, and Thailand. More than 20,000 cases were reported from Malaysia, a surge of 20 percent was recorded in Singapore, and

several thousands cases were estimated to have occurred in Thailand. Most of the cases complained of upper respiratory symptoms, bronchitis, asthma, conjunctivitis, and eczema. The haze was responsible not only for health problems, but visibility as well, making airlines cancelling flights to several airports in the region. Poor visibility was implicated as a factor in the crash of a commercial aircraft in Sumatra on 26 September 1997, that killed all 234 people aboard, and was blamed for a series of fatal ship collisions in that period.

The spreading of the smoke to the Malayan peninsula, including southern Thailand, was helped by the prevailing synoptic scale winds, as indicated by the low-level southerly wind circulation in that period. Transboundary transport of smoke, causing the haze effects to the Malayan peninsula in 1997 was, in fact, not the first occurrence of this type of episode. Similar phenomena occurred sporadically in the past (2).

This paper reviews the situation and activities carried out in response to the haze event in Thailand during and after the late September–October 1997 period. At the same time, a retrospective study on health and environmental impacts from the haze in southern Thailand and its findings are described (3). Data collected and analysed involved health statistics in terms of out-patient visits and hospital admissions, air quality monitoring, and local meteorological conditions that have been recorded in the southern provinces of Thailand. An assessment of the past activities as well as recommendations on what more could be done to better protect public health in terms of mitigation and prevention measures in the next haze episode are presented in the last section of this paper.

SOUTHERN THAILAND

Thailand is located in the heart of the mainland of South-East Asia, covering an area of 513,115 km^2. The current population is 60.6 million (4). The country consists of 4 natural regions: the North, the Central plain, the Northeast, and the South or Southern peninsula. Thailand is a warm and rather humid tropical country. Its climate is monsoonal, marked by a pronounced rainy season lasting from May to September and a relatively dry season for the remainder months of the year.

The Southern region occupies an area of 70,715 km^2 with a population of 8.6 million (Figure 1). Rainfall generally continues until November or December, resulting in higher average annual rainfall (2741 mm with 176 rainy days and 1697 mm with 147 rainy days in the west coast and east coast, respectively), higher relative humidity (80 per cent), and lower average temperature (27.5 °C) than the rest of the country. Administratively, the region is divided into 14 provinces; each has its own governor appointed by the central government. Densely populated areas (>200 per km^2) are concentrated in the east coast on the gulf of Thailand, in Nakhon Si Thammarat, Songkhla, Pattani and Narathiwat, except Phuket, a small island province in the west.

The health service systems in the southern region are mainly under the public sector (5); each province has general hospitals in large cities, community hospitals at the district level, and health centres in sub-districts (6). However, services provided by the private sector (clinics and hospitals) are common in urban areas. Computerized data processing based on the International Classification of Diseases (ICD-10) has just been introduced into a few city hospitals, and are serving only a portion of daily in- and out-patients. Data processing in medium/small hospitals and health centres is still being done manually.

The Ministry of Science, Technology and Environment (MOSTE) maintains a network of air quality monitoring stations in three southern cities: Hatyai, Phuket, and Surat Thani since 1996. Each site monitors a number of specific pollutants (hourly and 24-hourly) as well as local weather conditions using the following methods: beta attenuation for particulate matter equal to or less than 10 μm in diameter (PM_{10}), gravimetry for total suspended particulate (TSP), atomic absorption spectrometry for lead, non-dispersive infrared detection for carbon monoxide (CO), chemiluminescence for nitrogen dioxides (NO_2) and ozone, and UV-fluorescence for sulphur dioxide (SO_2) (7). A monitoring station at Prince of Songkhla University (PSU) in Hatyai supplements this network. The ambient air quality standards for Thailand are shown in Table 1.

The Meteorological Department has an extensive network of weather stations in both the east and west coasts of the region and at all airports (8). These 14 stations report 3-hourly data of local wind speed and direction, pressure, rainfall, relative humidity, temperature, cloud cover, and visibility. Meteorological variables are measured according to the World Meteorological Organization's guidance (9).

Surface wind direction is read from a wind vane or from the records of Dine pressure-tube anemograph. Wind speed is read from either anemograph or pressure-plate or cup anemometer. Wind instrument is set at approximately 10 metres above ground. Upper-level winds are measured by the sounding equipment, such as a radiosonde or rawindsonde. Only Phuket Airport and Songkhla operate the upper-air radiosonde sounding. Wind speed is reported in 0.5 ms^{-1} or in knots to the nearest unit, and represents, for synoptic reports, an average over 10 minutes. Wind direction is reported in degrees to the nearest 10 degree, and represents an average over 10 minutes. Wind direction is defined as the direction from which the wind blows, and is measured clockwise from geographic north. The wind category "calm" is reported when the average wind speed is less than 1 knot.

Surface pressure is obtained from mercury barometer and given in hecto-pascal (hPa) corrected for temperature, latitude, and mean sea level. Relative humidity (per cent) is obtained from wet and dry bulb thermometers. Rainfall is measured from a cylindrical rain-gauge with brass rim of 20.3 cm in diameter. A visibility value is obtained by visual observation with the reference to the well-marked landscape within the radius from the station. The lowest visibility within the observing circle is reported. In practice, a report of the visibility of 10 km or greater is considered as "good visibility", and the stations at the airport are generally more concerned with the visibility within 10 km.

RESEARCH ON AIR POLLUTION AND HEALTH IN THAILAND

Research on air pollution and health in Thailand using modern study design and methodology has just begun in the last few years with support of the World Bank (10, 11). The Hagler Bailly and Radian International studies were intended to assist policy-makers in setting priorities among many competing environmental and public health issues. Specifically, these were attempted to find out whether health effects of particulate matter are occurring in Thailand as have been observed in other cities worldwide. They also presented options for the government's action plan in reducing air pollution from particulate matter in Bangkok.

Although there were problems and limitations in data collection and analyses, the Hagler Bailly study (10) was the first attempt to quantitatively

evaluate health effects and characterize certain exposure aspects of Bangkok population to particulate matter. Time-series analysis showed that a 30 $\mu g/m^3$ increase in PM_{10} was associated with a 3 per cent increase in daily mortality, or between 1,000 and 2,000 premature deaths each year. As for hospital admissions, a 30 $\mu g/m^3$ change in PM_{10} was associated with 18 per cent and 11 per cent increase in respiratory admissions for elderly and all-age patients, respectively. Based on a study on diary records of acute daily respiratory symptoms maintained by an adult population group, a 30 $\mu g/m^3$ increase in PM_{10} was associated with a 19 per cent increase in lower respiratory symptoms (Table 2). In non-airconditioned premises with some indoor sources of pollution, such as cigarette or charcoal smoke, the indoor PM_{10} concentrations were as high or even higher than those measured outdoors. In locations where there was some air conditioning and with no notable indoor sources of pollution, indoor PM_{10} concentrations were between 50 per cent and 100 per cent of those outdoors.

Based on the chemical analysis of ambient and source samples and chemical mass balance receptor model, the Radian International study (11) indicated that mobile source emissions and reentrained road dust accounted for majority of PM_{10} levels in Bangkok. The source samples covered power plants, steel mills, road dust, motorcycles, light-duty diesel vehicles and heavy-duty diesel vehicles. In the study, a comprehensive list of emission sources and activity factors for the major pollutants in the area were developed and compiled. Air dispersion modelling was employed in evaluating alternative control measures and their effectiveness in improving air quality. Several cost-effective control measures were recommended for each major source category. These included complete changing over from 2-stroke to 4-stroke motorcycles, improving fuel quality such as use of natural gas for all city buses, ensuring an effective inspection and maintenance programme, covering open trucks, chemical spraying on unpaved roads and construction areas, and vacuum sweeping of streets.

ACTIVITIES AND MITIGATION MEASURES DURING AND AFTER THE 1997 ASEAN HAZE

Activities and mitigation measures implemented at the local and central levels by all related agencies during and after the 1997 haze are described below.

During the haze event

Early response at local and central levels

Because of the abrupt nature of the haze and the lack of previous experience, the response occurred relatively late. Songkhla responded first with a press conference on air quality levels and health advice on 30 September, followed later by the other provinces. One consequence was a great demand on local air quality data. Emphasis tended to be placed on air monitoring stations (both mobile and permanent) rather than mitigation and prevention measures for the public or on how to deal with the root cause of the problem; ie. uncontrolled forest fires in Indonesia. Some conflicting information was generated from different agencies in this early period; eg interpretation of air quality and rainfall acidity data. At the central level, the Cabinet in Bangkok had ordered the Ministry of Public Health to set up a coordinating centre for public assistance during the haze event and a committee was appointed on 3 October 1997. The Ministry distributed 140,000 masks that are protective against particles larger than 3 microns to all 14 southern provinces in early October 1997.

Coordinating Center for Public Assistance during the haze

The Coordinating Center for Public Assistance during the haze convened its first and only committee meeting on 3 October 1997, and appointed a subcommittee on information which also had the first meeting on the same day.

The name of the subcommittee reflected previous conflicts and confusions and the need to coordinate air quality, health risk communication and public advice on protective measures. The subcommittee produced a set of guidelines for public assistance during the haze in late October 1997.

Guidelines for public assistance during the haze

The contents of the guidelines are as follows:

- Air quality monitoring and upper respiratory symptoms reporting during the 1997 haze.
- Review of impacts on visibility and health.
- Health risk communication and public advice on protective measures.
- Role and functions of each agency in public assistance during the haze.
- Air quality monitoring guidelines.
- Rainwater quality monitoring guidelines.
- Press conference and public information suggestions.
- Reporting of respiratory diseases

An effort to set up a reporting system of respiratory diseases from southern provinces, in addition to the routine reporting system, worked partially only for the first month—September 1997. Ten of 14 provinces reported 500-800 cases of upper respiratory diseases in September. There was no any subsequent report after October. The data coming in were too crude and incomplete for any conclusion to be drawn on health impacts of the 1997 haze.

Health risk communication and public advice on protective measures

The protective measures are generally similar to those of other ASEAN countries, covering suggestions for the susceptible population groups (asthmatics and chronic bronchitis, elderly, infants and children, persons with underlying lung or heart disease, and smokers) and the general population. These include avoiding strenuous activities and smoking, staying indoors, drinking clean water and temporarily refraining from rainwater, seeking care when having symptoms or attacks, and wearing protective masks outdoors in severe haze.

Assessment of public health impacts from the 1997 haze

To assist the Coordinating Center in producing guidelines for assessing public health impacts that can be conducted locally in each province, the Health Systems Research Institute convened a technical meeting on 10 October 1997. The meeting included participants with expertise or interest in air pollution and health research, health information system and meteorology. The guidelines were produced and distributed in mid-October. So far, there are only two local studies from Songkhla looking at the number of outpatients and in-patients with respiratory and/or cardiovascular diseases in September 1997.

Post-haze activities

Coordinating Center for Public Assistance during the Haze

The Coordinating Center's subcommittee had another meeting on 9 April 1998 to update activities and information from its members. The Pollution Control Department of the Ministry of Science, Technology and Environment and the Meteorological Department will continue to supply the Center their air quality monitoring and meteorological data for haze warning system.

Air quality information

After the air pollution episode throughout southern Thailand from the Indonesian forest fires, the Pollution Control Department has set up an Internet homepage called Air Quality in Southern Thailand to inform the public of air quality within the region, especially from particulate matter (PM_{10}). The URLs for accessing the information are: http://www.pcd.go.th and http://www.aqnis.pcd.go.th.

Meteorological information

The Meteorological Department was involved in several committees set up by the Thai government to deal with the Indonesian haze and other forest fires. It also took part in seminars or technical meetings concerning the phenomenon. The department was represented at various international meteorological meetings on Indonesian haze problems and was involved in establishing a more efficient co-ordination among meteorological services in the region.

NATIONAL HAZE ACTION PLAN

The experience of the haze impacts from Indonesian forest fires in 1997 has stimulated the response of the public sector. The Prime Minister directed the Ministry of Science, Technology and Environment to formulate the National Haze Action Plan to prepare for and mitigate the impacts from future forest fires in the region. The Thai Committee on ASEAN Haze Mitigation (TAHM) was then set up and chaired by the Deputy Permanent Secretary of the Ministry of Science, Technology and Environment. The TAHM consists of the following government agencies:

- Royal Thai Army, Royal Thai Navy, and Royal Thai Air Force, Ministry of Defence
- Public Relations Department, Office of the Prime Minister
- Bureau of the Royal Rain Making and Agricultural Aviation Division, Ministry of Agriculture and Cooperatives
- Royal Forestry Department, Ministry of Agriculture
- Department of Health, Ministry of Public Health
- Meteorological Department, Ministry of Transport and Communications
- Ministry of Foreign Affairs
- Department of Public Welfare, Ministry of Labor, Social and Welfare

- Pollution Control Department, Ministry of Science, Technology and Environment

The role of the TAHM is to formulate the plan for immediate response and to accelerate necessary actions to mitigate/minimize impacts from the ASEAN forest fires. The National Haze Action Plan has already been prepared and is currently in the process for approval from the Cabinet. Actions under the Plan are activities inside the country (local action plan) as well as the potential cooperation that can be provided to other ASEAN member countries (ASEAN coordination) in case of the occurrence of the forest fires.

ASOEN TASK FORCE ON TRANSBOUNDARY POLLUTION AND ASEAN MINISTERIAL MEETING ON HAZE

The regional haze events of 1991 and 1994 triggered a series of regional measures towards cooperation in fire and smoke management. In 1992 and 1995, regional workshops on transboundary haze pollution were held in Indonesia and Malaysia, respectively. This was followed by the establishment of a Haze Technical Task Force (HTTF) during the sixth meeting of the ASEAN Senior Officials on the Environment (ASOEN) in September 1995. The task force is chaired by Indonesia and comprises senior officials from Brunei Darussalam, Indonesia, Malaysia and Singapore. The objective of the work of the task force is to operationalize and implement the measures recommended in the ASEAN Cooperation Plan on Transboundary Pollution relating to atmospheric pollution, including the problem of fire and smoke (1). In response to the ASEAN Environment Ministers' Jakarta Declaration on Environment and Development on 18 September 1997, the Asian Development Bank (ADB) has provided funds through a Regional Technical Assistance (RETA) grant to assist ASEAN in strengthening cooperation among the fire- and smoke-affected countries.

The first two ASOEN HTTF meetings were limited to only four countries: Brunei Darussalam, Indonesia, Malaysia, and Singapore. The other ASEAN members, such as Thailand and Philippines, were invited to participate in the third meeting in November 1997 in Kuala Lumpur, Malaysia, to review the steps and measures taken to deal with the haze pollution affecting the region. Singapore hosted the fourth meeting and the first ASEAN Ministerial Meeting on Haze (AMMH) in December 1997. The

fourth ASOEN HTTF meeting had finalized the Regional Haze Action Plan (RHAP) and the proposal for support from the ADB, and submitted both to the AMMH on the following day. At this meeting, the ASEAN Ministers endorsed the RHAP. The Plan mainly focussed on the development of three programmes: (i) preventive measures (Malaysia as the focal point); (ii) establishment of operational mechanisms and monitoring measures (Singapore); and (iii) strengthening of forest fire-fighting capability and other mitigating measures (Indonesia).

The fifth ASOEN HTTF meeting was held in Indonesia in January 1998 to discuss the progress of implementation of the three programmes in the RHAP. The meeting also discussed the proposed scope of ADB's RETA project. Malaysia hosted the sixth ASOEN HTTF meeting in Kuching on 24 February 1998, followed by the second AMMH on 25 February 1998. During the second AMMH, the progress of the RHAP and ADB's technical assistance project in support of the RHAP was reported. The ASEAN Specialized Meteorological Center (ASMC) has also informed the Ministers of the regional meteorological forecast activities. The seventh ASOEN HTTF meeting and the third AMMH were arranged and hosted by Brunei Darussalam from 3-4 April 1998. The eighth ASOEN HTTF meeting and the fourth AMMH were held in Singapore from 18-19 June 1998.

HEALTH AND ENVIRONMENTAL IMPACT ASSESSMENT

A multidisciplinary retrospective research to assess the environmental and public health impacts from the 1997 haze in the southern provinces of Thailand has been carried out since early 1998. The main objective was to evaluate the relationship between changes in meteorological and air quality conditions and their health impacts in order to prepare better mitigation and preventive measures in the future.

Methods

For the purpose of health and environmental impact study, data on morbidity and mortality, air quality, and meteorology including visibility in 14 southern provinces during 1996-1997 were collected and analyzed. The focus was on the identification of changes in air quality and meteorological conditions, and the related impacts on morbidity and mortality during the haze event. Hatyai, the largest city of the region, was selected for a more detailed study as its health, air quality and meteorological data were the most complete.

Meteorological data

Meteorological data from the archives of all 14 stations south of 11°N latitude covering southern Thailand were used in the study. These included weather charts, digitized data, and satellite images. Weather charts, and surface and upper-air data were used in investigating the synoptic situation, especially during the critical period.

The 3-hourly data of pressure, wind speed and direction, temperature, relative humidity, rainfall and visibility were included in the analysis. The data for the years 1996 and 1997 were used in comparing each meteorological variable at each station. Time series data of the daily mean of each variable were plotted and compared between the two years.

The GMS-5 Japanese geostationary meteorological satellite visible images were used as a supplement in identifying the affected areas. These images were available only during the daytime.

Air quality monitoring data

The daily air quality levels of PM_{10} and other criteria pollutants from three permanent stations in the south maintained by the Ministry of Science, Technology and Environment were collected and analyzed. Similar analysis was carried out for the air quality monitoring data of Prince of Songkhla University.

Health data

A provincial summary of the number of outpatients and in-patients by diagnosis group is routinely reported every month as part of the activity report for health care facilities under the Ministry of Public Health's monthly morbidity report. There are 21 diagnosis groups for outpatient visits and 75 for hospital admissions. The 1996 and 1997 data were analyzed and compared. Similar data in the upper northern region were also analyzed and used as a control group.

A more detailed time-series study of both outpatient visits and admissions was carried out in two public hospitals that serve Hatyai City (Hatyai Hospital and Prince of Songkhla University Hospital). The 1996 and 1997 data were analyzed by month or day and by diagnosis.

The Hatyai hospital mortality and death registration data were also collected and analysed. Nationwide electronic data processing of death certificates is now carried out centrally at the Information Technology Center, Ministry of Interior (MOI), with a lag-time of 4-6 months. Although the Hatyai hospital mortality data are readily available, the 1997 death registration data have not yet been completed and are not available for analysis.

The morbidity studies were focussed on the following disease conditions:

- accidents (ICD-10: V01-V99);
- respiratory diseases (upper respiratory tract infection, pneumonia, asthma, bronchitis, and others, ICD-10: J00-J99);
- cardiovascular diseases (ischemic heart diseases and others, ICD-10: I00-I99); and
- irritation and infection of eye and skin (ICD-10: H10-H13, and L20-L30, L50-L54).

RESULTS

Meteorological findings

Monthly surface meteorological observations, daily surface meteorological observations in September and October 1996 and 1997, and 10-day wind rose analysis in September–October 1997 for Hatyai are shown in Figures 2 to 4. Examples of wind circulation at 600 metres above sea level and satellite images are shown in Figures 5 and 6.

The synoptic weather of southern Thailand in 1996 and 1997 did not differ much from each other. The effects of the 1997 El Niño phenomenon to the weather pattern in southern Thailand, as well as other parts of the country in 1997 were not very distinctive from the normal dry year. Rainfall pattern for the year 1997 did not indicate a large deviation from the 30-year mean and the year 1996 values. Temperature as well as relative humidity did not show much difference between the two years. The average daily wind speed and direction from 1997 to 1996 were relatively similar. A large number of calm winds were reported at each station. All monthly mean visibility reported at the stations in southern Thailand showed marked deterioration, deviation or shift from the patterns of previous months as well as the values in 1996. This pattern coincided with the reports of other air quality parameters.

During the last week of September 1997, all stations south of 10°N latitude reported a steep decline in visibility. The patterns differed significantly from the visibility report for the corresponding period in the previous year. Daily values indicated some of the synoptic weather patterns that could favour the spreading of the smoke haze from the area south of Thailand. From 20 September 1997, the general synoptic weather over Thailand was under the influence of the active low-pressure trough over central Thailand, with the quite active low-pressure cell off the coast of Vietnam at approximately 15 °N and 100 °E. This active low-pressure cell was later transformed into a tropical depression, followed by tropical storm "Fritz" (9722) on 23 September 1997. The presence of the low-pressure cell or tropical storm near the coast of Vietnam often causes the cross-equator flows in the direction feeding into the centre of the storm. In this case, the low-level flows (i.e. at 850 hPa) during that time has a southerly direction for stations south of Surat Thani, and veering to southeast for stations at Surat Thani on the north.

On 22 September 1997, the sounding analysis at Songkhla Station indicated the low-level inversion layer up to 850 hPa. This indicated the existence of a stable layer close to the ground, favourable to the building up of smoke concentration. Later, on 23 September 1997, the anticyclonic circulation was found at 600 metre above ground covering the area between Songkhla and Surat Thani. Again, the presence of the low-level anticyclonic circulation could induce the subsidence of the air favouring accumulation of the smoke concentration.

During the first week of September 1997, the surface wind pattern of all the stations throughout southern Thailand had the south-southwest, west, and northwest directions. The 10-day wind roses indicated that during the period 11-20 September 1997, the stations in the east coast of southern Thailand, except Narathiwat, had the southerly or southwesterly wind components while the west coast stations had more components in southwest or west direction. Phuket stations (downtown and airport) had mostly west direction. In the following week (21-30 September 1997), the surface winds had more northerly direction. At most of these periods, the stations in Malaysia reported calm or southerly winds. The daily wind-rose for Hatyai in September indicated the southerly wind component most of the time prior to 21 September when the visibility was reported to be worsening.

Air quality levels

PM_{10}

After reports in international news media and warning from the Meteorological Department, the Indonesian forest fires haze was first visibly observed in the southern provinces of Thailand on 22 September 1997, with a 20 $\mu g/m^3$ increase in PM_{10} from the previous day in Hatyai. The first peak of this episode occurred between 22 and 29 September with a maximum during 24-25 September, followed by the lower second peak during 6-8 October 1997 (Figures 7). However, the highest 24-hour average PM_{10} observed at Prince of Songkhla University station was 218 $\mu g/m^3$ on 26 September, with missing data of the previous 3 days. Although the forest fires in Sumatra and Borneo continued for the next several months, there was no other transboundary haze event in Thailand after this.

The monthly 24-hour average of PM_{10} in Hatyai in both 1996 and 1997 do not differ much and indicate the relatively clean background levels in the city (43 $\mu g/m^3$). The abrupt but short duration of haze and air quality

deterioration in late September 1997 resulted in a moderate increase of PM_{10}, 69 μg/m^3, compared to the same month in 1996 (Table 3). Even though the 24-hour average close to or more than 200 μg/m^3 were observed for 3 days in late September 1997, this dilution effect suggests the need to pay more attention at the daily 24-hour average. PM_{10} levels in the south seem to increase from June to August, a pattern different from what has been observed in Bangkok (the capital city) where air pollution is higher from December – February.

Other gas pollutants (CO, NO_2, and SO_2)

The monthly 24-hour average of NO_2 in Hatyai for both 1996 and 1997 were not different (Table 4, Figure 8). Similar trend was observed for SO_2. Only CO showed a two-fold increase of monthly 24-hour average in September and October 1997 compared to the same period in 1996. However, all their concentrations were much lower than the national and US air quality standards. The US standards for these pollutants using the same volumetric units are: 9 ppm (8-hour maximum) for CO; 53 ppb (annual average) for NO_2; and 140 ppb (24-hour average) for SO_2 (mixed units are shown in Table 1).

HEALTH IMPACTS FROM THE 1997 HAZE

The Ministry of Public Health monthly morbidity study

Monthly outpatient visits (OPD) reported from all 14 southern provinces during 1996-97 were in the range of 700,000-800,000, or almost 10 per cent of the regional population. Of these visits, respiratory disease was the most common and accounted for about one third, followed by digestive ailments and skin plus eye diseases (Table 5). Monthly inpatient admissions (IPD) reported from all 14 southern provinces were between 50,000-60,000 or almost 1 per cent of the population hospitalized each month. Respiratory disease was the second most common at 14 per cent of all admissions (Table 5). Other regions of Thailand also showed similar pattern (11).

Among outpatient visits, there seemed to be a seasonal trend of respiratory diseases in early rainy (June-July) and colder (December-January) seasons in the south (Figure 9a). This trend changed in 1997 with respiratory illness rising in August and peaking in September when the haze

hit the area. Compared with the control area in the far north, respiratory disease visits showed an increase in September 1997 but peaked a month later in October (Figure 9b). Among IPD admissions, a similar seasonal trend of respiratory illness in early rainy season (June-July) was observed in the south (Figure 10a). This trend changed in 1997 with respiratory diseases rising in August and peaking in September when the haze hit the area. In the control area in the north, IPD respiratory disease category showed an increase in September 1997 but continued to peak in October (Figure 10b).

For respiratory disease admissions, a seasonal trend of pneumonia can be observed during the months of September to October for both the south and the upper north regions (Figures 11a and 11b). Reported monthly pneumonia admissions displayed a sharp increase in September 1997 when the haze appeared in the south, followed by smaller peaks of bronchitis/chronic obstructive pulmonary disease (COPD), and asthma in the same month. For the control area in the north, which was not affected by the haze, smaller peaks of pneumonia and bronchitis/COPD were observed a month later in October 1997.

This common mode of surging in respiratory diseases in both the south and the north suggested that there might be some widespread respiratory tract diseases not related to the haze occurring in Thailand during that period. Therefore, in southern Thailand, the haze event was not a sole cause but an additional cause for these respiratory illnesses.

Other than respiratory diseases, reported outpatient eye and skin diseases as well as cardiovascular diseases and accidents did not show a marked increase in the south during the haze episode in September-October 1997. For inpatient cases, these diseases also did not reveal any obvious increase; all remained rather stable during the same period (Figures 9 - 11). Consequently, the analysis of health impact from the 1997 haze focused only on respiratory effects.

During the 2-month period covering the haze episode from September-October 1997, a substantial increase in respiratory morbidity of both OPD visits and IPD admissions was observed in the study area of southern Thailand. The differences in OPD visits/IPD admissions between the southern and the northern (control) regions were: 26 per cent vs 18 per cent for all respiratory disease visits, 33 per cent vs 26 per cent for all respiratory disease admissions, 36 per cent vs 18 per cent for pneumonia admissions, 40 per cent vs 28 per cent for bronchitis/COPD admissions, and 12 per cent vs 9

per cent for asthma admissions (Table 6). Hence, the net health impacts from the 1997 haze are 8 per cent and 7 per cent increases in respiratory disease visits and admissions, respectively. It is interesting to observe that the percentage of net haze impacts is higher in two specific respiratory diseases, pneumonia and bronchitis/COPD. From this finding and the monthly report of respiratory disease morbidity, the increase during the 1997 haze would be approximately 45,000 visits and 1,500 admissions in southern Thailand.

Regression analysis demonstrates significant associations between almost all categories of monthly respiratory disease admissions and monthly PM_{10} levels (Table 7). For each 1 $\mu g/m^3$ increase in the monthly PM_{10}, there were about 85, 28, 13, and 13 monthly admissions for all respiratory illness, pneumonia, bronchitis/COPD, and asthma, respectively. Relative humidity is the only weather variable significantly associated with pneumonia admissions. For each percentage change in the monthly relative humidity, there was 178 pneumonia admissions. The R^2 or the proportion of variance of illness that is accounted for by the predictor variables of the models, varied from 0.45 in bronchitis/COPD to 0.80 for pneumonia cases.

Daily hospital morbidity and mortality study in Hatyai

Daily hospital morbidity and mortality study in Hatyai was based on pooling data from the two city hospitals, Hatyai Hospital and Prince of Songkhla University (PSU) Hospital. Respiratory diseases generally accounted for 15 per cent of OPD visits and 12 per cent of IPD admissions. Daily respiratory illness visits and admissions in Hatyai city during September-October 1997 are shown in Figure 12. The number of cases fluctuated according to the working hours. It was higher during the weekdays, then dropped during the weekend. The 7-day moving average showed different period of increase; for OPD visits, in early October, while for IPD cases, in late September.

For respiratory illness visits, a rise and widening of upper respiratory tract infection (URTI) cases can be observed during the haze episode between late September and early October 1997, compared to the year before (Figure 13). There seemed to be no increase of other respiratory categories in OPD visits. Of respiratory admissions, some increases of pneumonia and acute bronchitis as well as bronchitis/COPD were observed during the first peak of the haze episode, although the overall numbers were small (Figure 14).

During the 2-month period covering the haze episode in September-October 1997, significant increases in OPD visits for respiratory illness and admissions for bronchitis/COPD were observed in Hatyai city (Table 8). The increases were 11 per cent for outpatient visits and 8 per cent for hospital admissions, compared with the reference of increased trend of hospital visits and admissions, of 4 per cent and 7 per cent, respectively. The net health impacts from the 1997 haze were 7 per cent and 1 per cent increases in respiratory illness visits and admissions, respectively. These increases support the results of the region-wide study described in the previous section. Among OPD visits, the net increase was most pronounced for URTI (15 per cent) and bronchitis/COPD (although not statistically significant), while other categories showed a decrease. For hospitalization, the net haze impacts was highest for bronchitis/COPD (49 per cent), while pneumonia cases increased slightly and asthma cases declined (both not statistically significant). Using this finding and the respiratory illness statistics in both hospitals, the increase in service load during the 1997 haze would be approximately 1,600 outpatient visits for URTI and 40 hospital admissions for bronchitis/COPD in a city with 260,000 population.

Regression analysis was carried out for the category daily visits for all respiratory illness and URTI. Significant association between deviation from daily average visits for all respiratory illness and URTI and daily PM_{10} levels was demonstrated (Table 9). For each 1 $\mu g/m^3$ increase in daily PM_{10}, there was 0.2 deviation from daily average visits for all respiratory illness and URTI. This conclusion is based on the background information on hospital utilization and practice in Hatyai. No weather variable was found to be significant in the analysis. However, their R^2 or the proportion of variance of illness that is accounted for by the predictor variables of the models, are only 0.08 and 0.12 for all respiratory illness and URTI, respectively.

To identify the vulnerable groups during the haze episode, hospital utilization by age for both outpatients and inpatients were analyzed. For OPD visits, there was a slight increase in those <5 years of age (2 per cent), but a slight decrease in those in the older age group (-2 per cent) during the period September-October 1997 when the haze hit the area, after adjusting for increases in other months (Table 10). On the contrary, among IPD admissions, there was a marked decrease in young patients (-8 per cent), but an increase in older patients (3 per cent) during the haze period, after adjustment with the reference period.

There were 1746 deaths in both hospitals in Hatyai city in 1997. There seemed to be a pattern of higher mortality in the first half of each year. In 1997, a small rise in mortality occurred in July, September and November. The increase in September, which was the month of the haze episode, was due to a rise in the number of deaths from respiratory diseases. No such increase was observed in 1996. During the two-month period September-October 1997, increases in hospital mortality were observed, although all were not statistically significant (Table 11). The highest increase was deaths from respiratory diseases.

CONCLUSIONS AND RECOMMENDATIONS

Widespread uncontrolled forest fires, which originated from agricultural land clearing, occurred since July 1997 in several major islands of Indonesia, under the abnormally dry conditions from the 1997-98 El Niño/Southern Oscillation (ENSO) episode. The fires sent thick smoke haze across the sky of most countries in the region—Malaysia, Indonesia, Singapore, Brunei, southern Thailand and parts of the Philippines in September 1997. Indonesia and Malaysia had to declare a state of national emergency in the same month.

The fundamental cause of the problem is not haze but uncontrolled forest fires due to shortcomings of proper forest management and practice. This phenomenon is still very common in some Southeast Asian countries, including Thailand. To effectively address this issue in the broader context of sound forest management remains difficult. However, there is no other easy way. The 1997 haze confirmed its large-scale and huge impacts on the environment, economy, health, and society, when good forest management failed.

Uncontrolled forest fires from Indonesia under favourable meteorological condition resulted in rapid air quality deterioration over South-East Asia region. The transboundary transport of smoke caused the haze effects not only in Indonesia, but also all over the Malayan peninsula in 1997. The spreading of the smoke to the peninsula, including the southern Thailand, was helped by the prevailing synoptic scale winds, as indicated by the low-level southerly wind circulation. During the days with high PM_{10} in September 1997, wind speeds were very weak and thus helped in accumulating high levels of particles.

The 1997 haze has proved once again that improper land clearing practices, compounded by the El Niño climatic factors, could produce a large-scale air pollution episode. In Thailand, the air pollution episode occurred in two peaks over a rather short period. Fine particulate matter was the main pollutant in this event: other air pollutants generally remained low. The first peak of PM_{10} occurred between 22 and 29 September, with the maximum level recorded during 24 and 25 September, followed by a lower second peak during 6 and 8 October 1997. The highest 24-hour average PM_{10} observed that of the 218 $\mu g/m^3$ on 26 September 1997 in Hatyai. At this level, it was 4-5 times higher than normal air quality in the region.

Compared to forest fires in other continents in the past, the 1997 haze from Indonesia was unique. Because of its wide coverage of densely populated areas in South-East Asia region, almost 100 million populations in five countries were exposed to the smoke. With a large number of population at risk, its impact on health could be readily observed. Retrospective data showed elevated and widespread short-term respiratory health effects during the same period. In relatively clean areas, an air pollution episode with particulate matter rising abruptly to moderate levels can still have major impacts upon health. At the regional level, a substantial increase in OPD visits and IPD admissions for respiratory illness was observed in southern Thailand. The increases were significant for OPD visits for all respiratory diseases and IPD admissions for almost all categories of respiratory diseases: pneumonia, bronchitis/COPD, and asthma. At the elevated levels of fine particles, the net health impacts from the 1997 haze were estimated as 8 per cent and 7 per cent increases in OPD visits and IPD admissions for respiratory diseases, respectively. At the city level, the health impact estimated from the 1997 haze was 7 per cent increase in OPD visits for respiratory diseases. However, the increases were significant only for OPD visits for all respiratory diseases and IPD admissions for bronchitis/COPD. The significant effect of the haze in terms of daily PM_{10} was that for each 1 $\mu g/m^3$ increase, there was 0.2 deviation from daily average OPD visits for all respiratory diseases and URTI.

The PM_{10} level in this haze episode (200 $\mu g/m^3$, 24-hour average) was about twice that of the national ambient air quality standards of Thailand (120 $\mu g/m^3$). At this low to low-moderate increase, the health effects can be clearly and readily observed in large population at the regional level. However, the effects may be less likely or more difficult to be detected in smaller area, such as Hatyai city. Pooling of data from several cities may be needed in evaluating the health impacts.

The 1997 haze was one of the large-scale forest fires and transboundary air pollution. Activities and mitigation or prevention measures implemented during the haze episode provided valuable experience for Thailand and other ASEAN countries in dealing with widespread forest fires.

The attempt on source control proved difficult, especially in transboundary transport of haze, when the source was in Indonesia but the effects were felt in other countries. National efforts as well as international or regional cooperation and actions were too late and modest compared to the magnitude of the fires. It took almost 6 months before most of the fires subsided at the end of 1997.

Health risk communication and public advice on personal protective measures, within the framework of inter-agency coordination, were applied in most ASEAN countries, including Thailand. These measures covered suggestions for the susceptible population groups (asthmatics and chronic bronchitis, elderly, infants and children, persons with underlying lung or heart disease, and smokers) and general population. The health advisory includes avoiding strenuous activities and smoking, staying indoors, drinking clean water and temporarily refraining from rainwater, seeking medical care when having respiratory and cardiovascular symptoms or attacks, and wearing protective masks outdoors in severe haze. Because of poor visibility during the haze period, emphasis on awareness and prevention of traffic accidents was also included.

Some preventive measures recommended during the haze period may be inadequate or inappropriate, and may not be fully justified based on the best available knowledge (3, 12). There are as yet no clear answers to several prescribed mitigation/protective measures and more research is clearly needed. Who are actually the sensitive population groups? How many are they? Do asthmatics or chronic bronchitis need prophylactic medication before or during the haze event? Are protective masks for the general public really effective? Are there benefits of staying indoors? What is the difference between indoor and outdoor pollution levels? Other appropriate measures such as the use of public shelter or public place during the haze need further investigations.

The question of how we can better prevent and prepare for future haze event has to be answered before future action and recommendations are made. The primary focus should be on prevention. That is the integrative and region-wide approach of medium-, and long-term measures towards the real

solution—sound forest management. Measures to control forest fires need to be strengthened, including regulations, incentives and enforcement, and fire control operation. Complementary measures of community participation and public education on the serious health and socio-economic impacts of uncontrolled forest fires, NGOs involvement, and inter-sectoral cooperation are necessary. Regional agreement and cooperation have been initiated in ASEAN countries. It remains to be seen how these concerted efforts will help reduce this problem in the South-East Asia region.

For preparedness, recommendations on immediate haze-related activities in many fronts are urgently needed in order to protect health and quality of life. Rapid detection capability for uncontrolled forest fires using available and advanced monitoring system needs to be established. National environment and health response plans has to be developed. The plan should include establishment of an early warning system based on air quality and meterological data procurement of emergency supplies and equipment, and health surveillance. Close monitoring of the haze situation through data collection is essential to provide feedback on the health advisory issued and the mitigation measures implemented.

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Table 1
Ambient air quality standards for Thailand and the United States ($\mu g/m^3$)

Pollutant	Averaging Time	Thailand	United States
PM_{10}	24-hour average	120	150
	annual average	50	50
Lead	monthly average	1.5	-
	quarterly average	-	1.5
CO	1-hour average	50000	40000
	8-hour average	20000	10000
NO_2	1-hour average	320	-
	annual average	-	100
SO_2	1-hour average	300	365
	annual average	100	80
Ozone	1-hour average	200	235

Table 2
Percent change in mortality and morbidity (daily admissions, daily symptoms) from respiratory and cardiovascular diseases per 30 mg/m^3 increase in PM_{10} in Bangkok and some selected cities

(a) Mortality

	General population	Persons with respiratory diseases	Persons with cardiovascular diseases	Elderly
Bangkok, Thailand	3.0	16.4	4.3	3.3
Philadelphia, USA	3.6	10.2	5.2	5.2
Santiago, Chile	3.0	3.9	2.4	2.7

(b) Daily hospital admissions

	All ages		Elderly	
	Respirator y diseases	Cardiovascular diseases	Respiratory diseases	Cardiovasc ular diseases
Bangkok, Thailand	11.0	5.3	17.6	7.6
Detroit, USA	-	-	4.7	2.1
Toronto, Canada	13.2	1.1	-	1.1

(c) Daily respiratory symptoms

	Adults		Children	
	Upper respiratory symptoms	Lower respiratory symptoms	Upper respiratory symptoms	lower respiratory symptoms
Bangkok, Thailand	26	19	12	13
Los Angeles, USA	NS	23	-	-
Provo, USA	-	-	11	16

NS = not significant

Table 3
Monthly 24-hour average of PM_{10} ($\mu g/m^3$) in Hatyai, 1996 and 1997.

	1996	1997
January	-	43
February	-	43
March	-	45
April	28	45
May	34	34
June	60	60
July	-	32
August	54	-
September	48	69
October	48	38
November	41	31
Dec	32	28
Average	43	43

Table 4
Monthly 24-hour average of other gas pollutants in Hatyai, 1996 and 1997.

Month	CO (ppm)		NO_2 (ppb)		SO_2 (ppb)	
	1996	1997	1996	1997	1996	1997
January	-	0.4	-	5	-	2
February	-	0.4	-	5	-	3
March	-	0.3	-	8	-	2
April	0.5	0.4	6	3	2	2
May	0.5	0.4	5	4	3	2
June	0.7	0.7	7	7	2	1
July	0.6	0.8	10	13	3	4
August	0.4	0.6	9	10	4	4
September	0.3	1	9	11	3	4
October	0.3	1	8	8	2	3
November	0.3	0.5	8	6	4	2
Dec	0.2	0.3	7	5	4	1

Table 5
The 5 leading causes of outpatient (OPD) visits and inpatient (IPD) admissions in southern Thailand, 1996-97

Rank	Diagnosis group	Percent
	OPD visits	
1	Respiratory diseases	30
2	Digestive system diseases	12
3	Eye/Skin diseases	10
4	Infectious diseases	7
5	Musculoskeletal system diseases	6
	Others	35
	IPD admissions	
1	Pregnancy-related conditions	23
2	Respiratory diseases	14
3	Infectious diseases	13
4	Digestive system diseases	8
5	Accidents	6
5	Cardiovascular system diseases	6
	Others	30

Table 6
Changes in respiratory disease morbidity in southern and upper northern Thailand and the net health impacts from the haze, September-October 1997

	South	North	% net haze impacts	P-value [1]
OPD visits				
All respiratory diseases	26	18	8	<0.01*
IPD admissions				
All respiratory diseases	33	26	7	<0.01*
Pneumonia	36	18	18	<0.01*
Bronchitis/COPD	40	28	12	0.01*
Asthma	12	9	3	NS

[1] Chi-square goodness of fit test, using contingency table analysis (2 × 2) for each condition   * Significant   NS = Not significant

Table 7
Regression analysis of monthly respiratory illness with PM_{10} levels and weather variables in southern Thailand, 1997

	R^2	Coefficient	P-value
OPD visits			
All respiratory diseases	0.32		
PM_{10}		1372	0.21
Relative humidity		2420	0.54
Temperature		-1506	0.33
IPD admissions			
All respiratory diseases	0.53		
PM_{10}		85	0.07
Relative humidity		305	0.08
Temperature		-76	0.90
Pneumonia	0.80		
PM_{10}		28	0.02*
Relative humidity		178	0.002*
Temperature		-96	0.54
Bronchitis/COPD	0.45		
PM_{10}		13	0.04*
Relative humidity		14	0.50
Temperature		7	0.92
Asthma	0.64		
PM_{10}		13	0.006*
Relative humidity		-7	0.60
Temperature		-25	0.64

* Significant

Table 8
Changes in outpatient visits and hospital admissions for respiratory illness and the net health impacts from the 1997 haze, Hatyai, September-October 1997

	% change	% net Haze impacts	P-value [1]
OPD visits			
All respiratory diseases	11	7	<0.01
URTI	19	15	<0.01
Pneumonia/acute bronchitis	-4	-8	<0.01
Bronchitis/COPD	12	9	NS
Asthma	2	-1	NS
Reference	4		
IPD admissions			
All respiratory diseases	8	1	NS
Pneumonia/acute bronchitis	11	4	NS
Bronchitis/COPD	56	49	0.01
Asthma	-7	-14	NS
Reference	7		

[1] Chi-square goodness of fit test, using contingency table analysis (2×2) for each condition

NS = Not significant

Table 9
Regression analysis of daily outpatient visits for respiratory diseases with PM_{10} levels and weather variables in Hatyai city, September-October 1997

OPD visits	R^2	Coefficient	P
All respiratory diseases	0.08		
PM_{10}		0.2	0.05*
Relative humidity		-0.5	0.66
Temperature		3.1	0.70
URTI	0.12		
PM_{10}		0.2	0.02*
Relative humidity		-0.9	0.35
Temperature		0.3	0.96

* Significant

Table 10
Changes in the age distribution among hospital outpatient and inpatients in Hatyai during September-October 1997

	% change	% net haze impacts	P-value [1]
OPD visits			
<5 years of age	11	2	NS
Reference	9		
≥60 years of age	7	-2	NS
Reference	9		
IPD admissions			
<5 years of age	-2	-8	0.05
Reference	6		
≥60 years of age	5	3	NS
Reference	2		

[1] Chi-square goodness of fit test, using contingency table analysis (2 × 2) for each condition
NS = Not significant

Table 11
Changes in hospital mortality in Hatyai during September-October 1997

	% change	% net haze impacts	P-value [1]
All causes	5	5	NS
Deaths from cardiovascular diseases	7	7	NS
Death from respiratory diseases	30	30	NS
Reference	0.1		

[1] Chi-square goodness of fit test, using contingency table analysis
(2×2) for each condition

NS = Not significant

Figure 1
Map of Southern Thailand

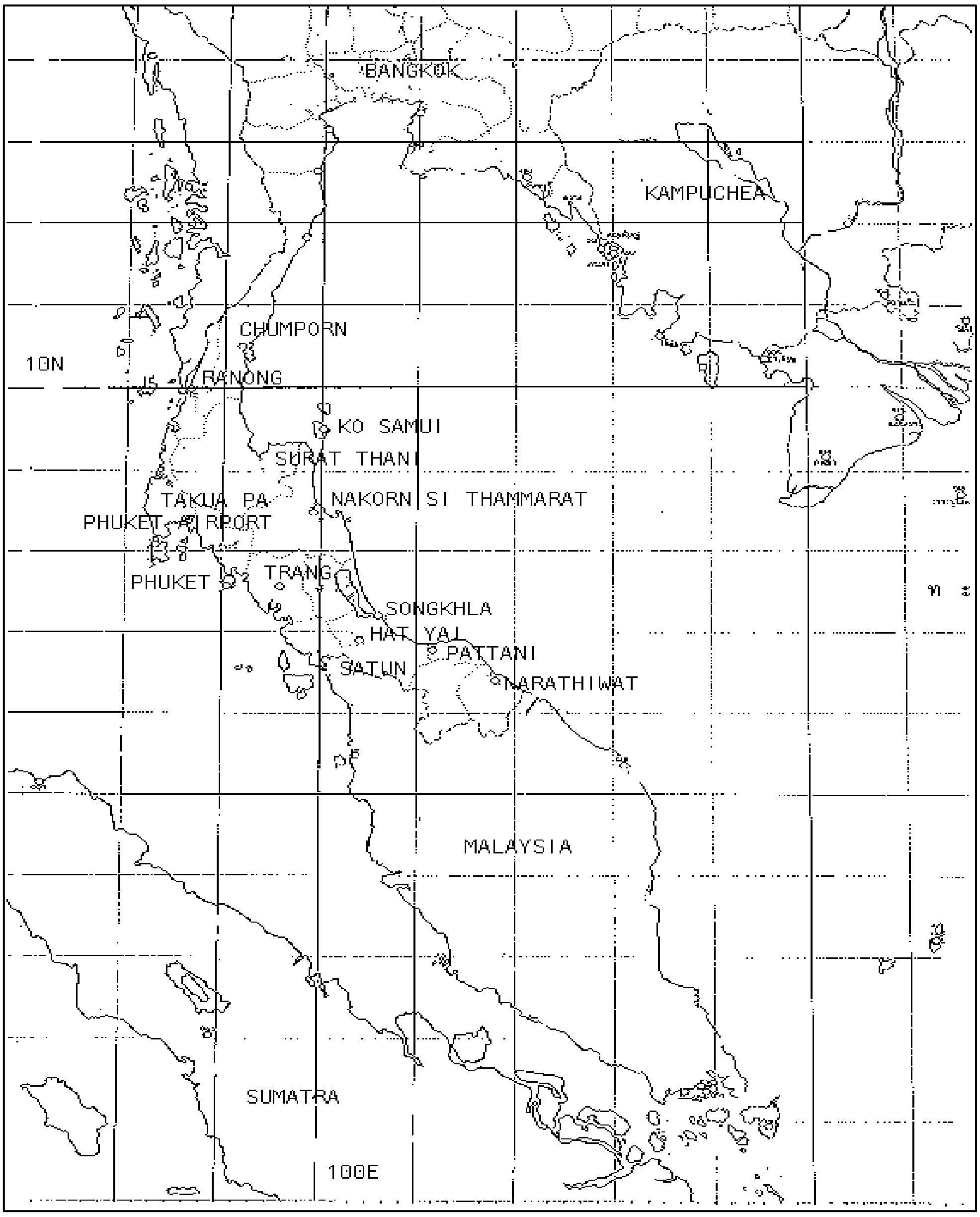


Figure 2
Monthly surface meteorological observations for Hat Yai in 1996 and 1997 compared with the 30-year mean

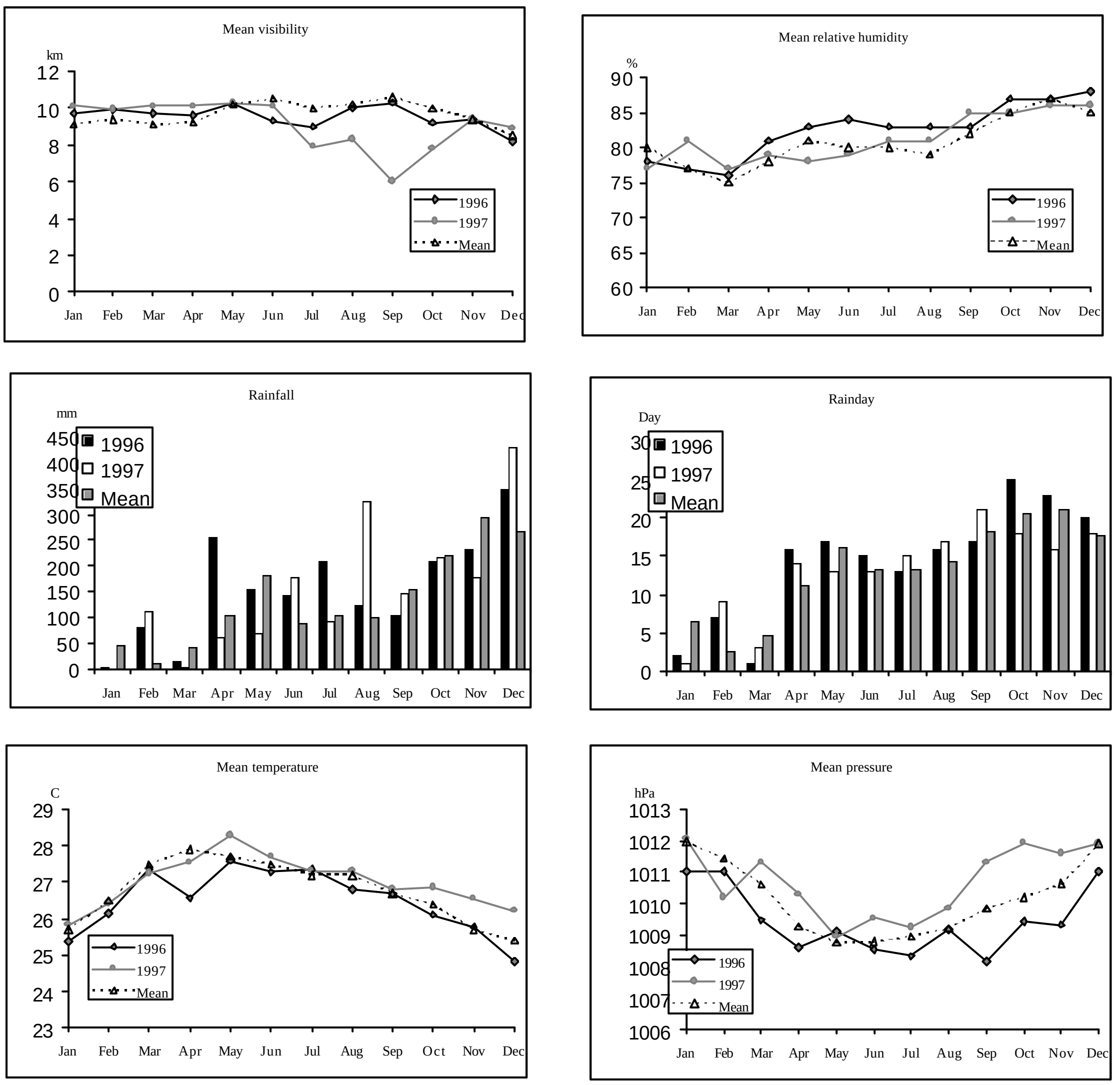


Figure 3
Daily surface meteorological observations for Hat Yai in the months of September and October 1996 and 1997.

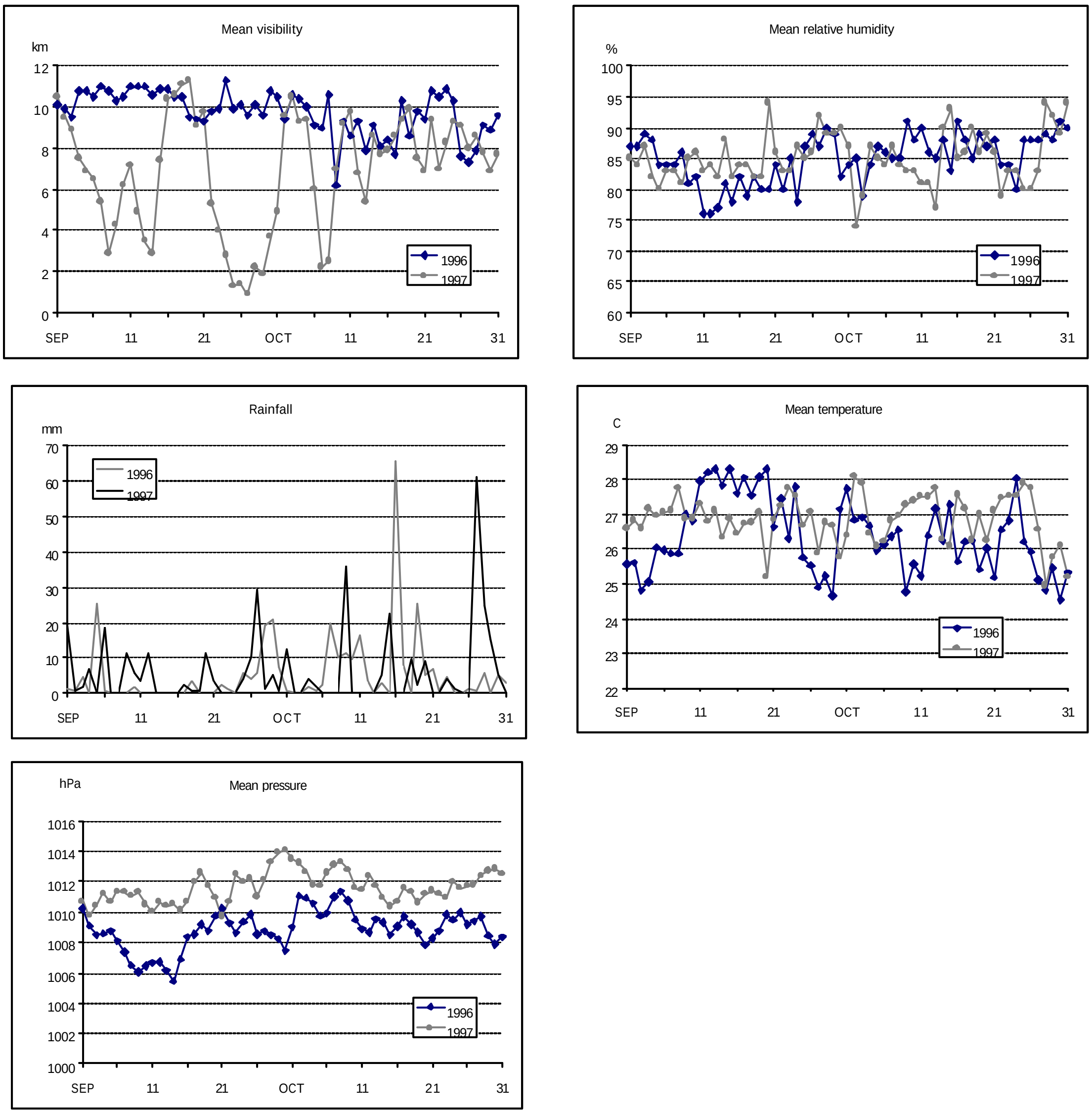


Figure 4
10-day wind rose analysis for Hat Yai, September–October 1997.

HAT YAI

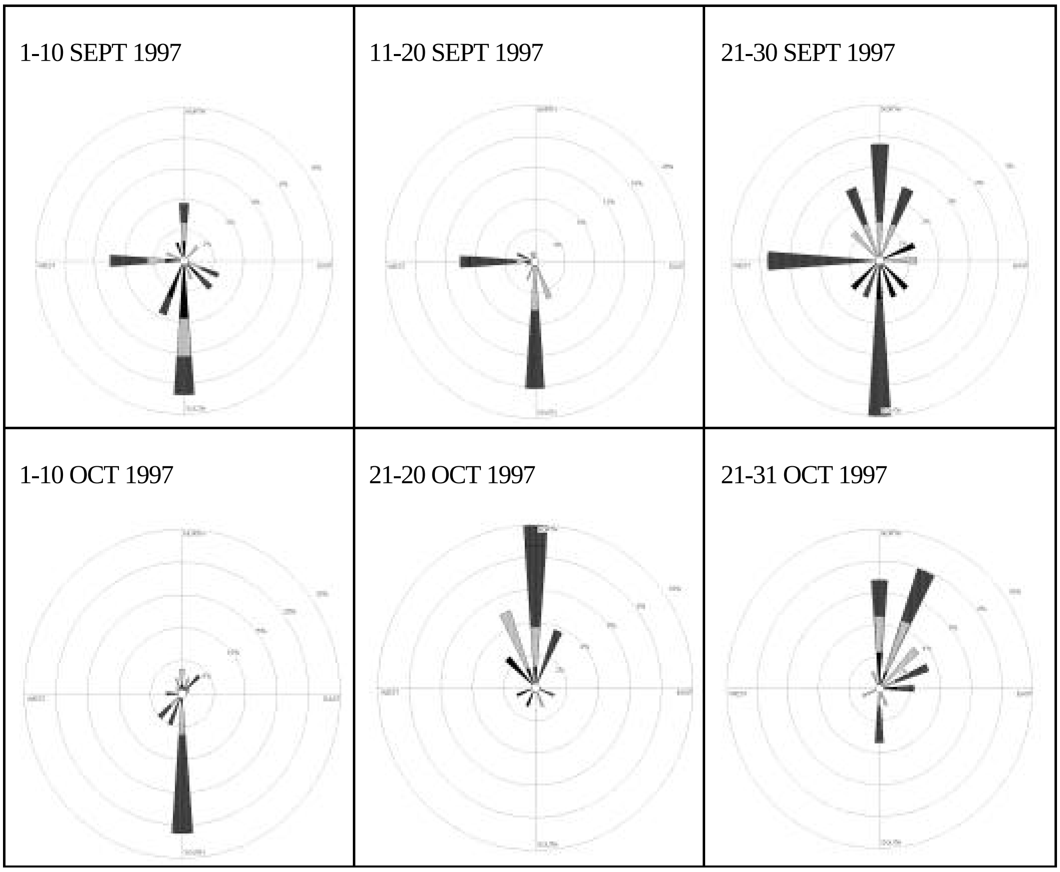


Figure 5
Wind circulation at 600 metres above sea level on 23 September 1997.

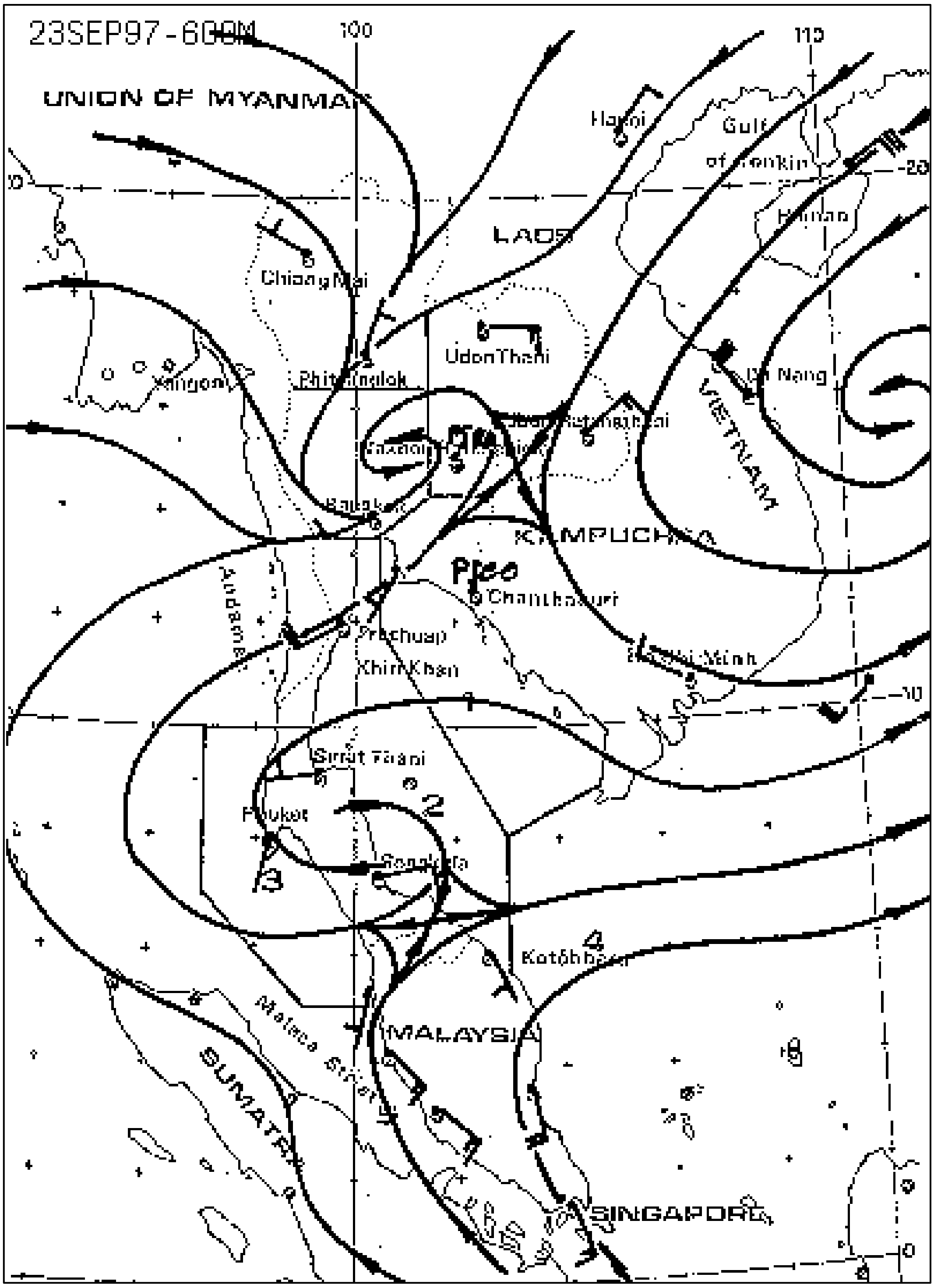


Figure 6
Selected GMS-5 satellite visible images during 21-25 September 1997.

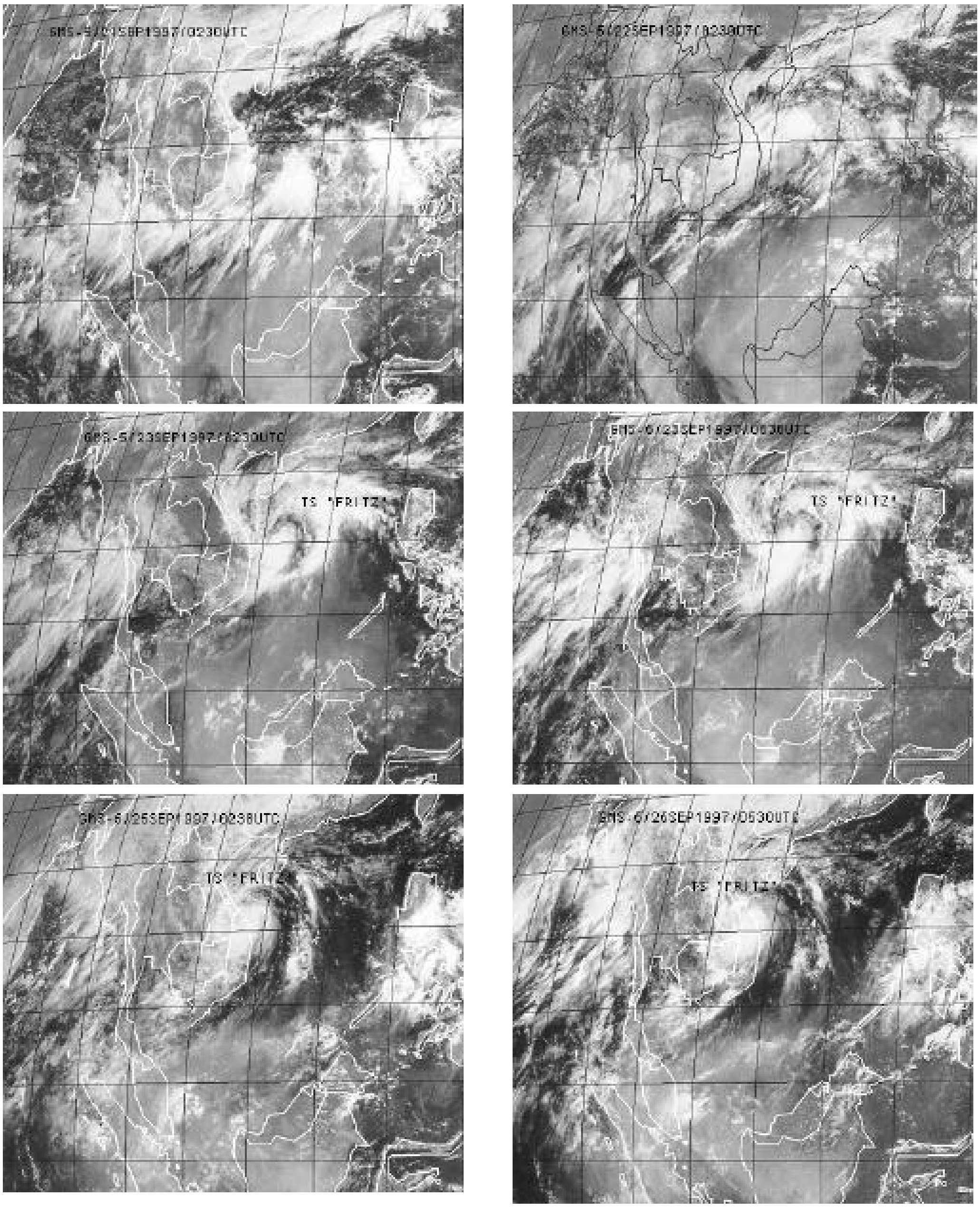
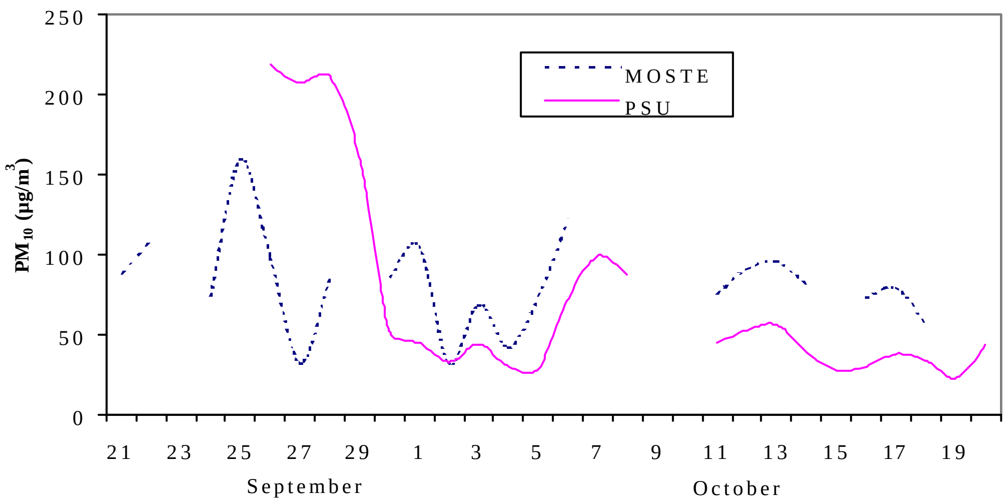


Figure 7
Daily PM_{10} (mg/m^3), monitoring in Hatyai, Phuket and Surat Thani, 21 September – 20 October 1997

(a) Hatyai (MOSTE and PSU sites)



(b) Phuket and Surat Thani

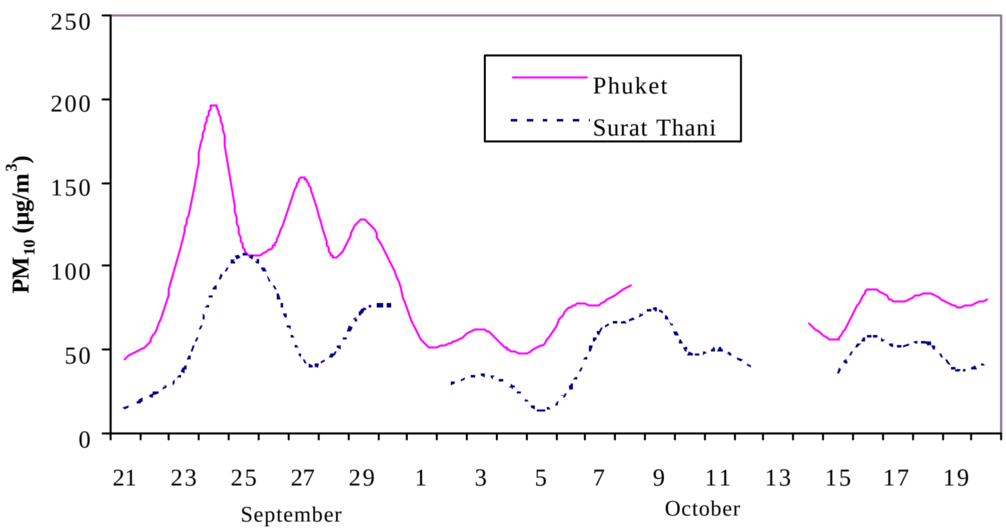
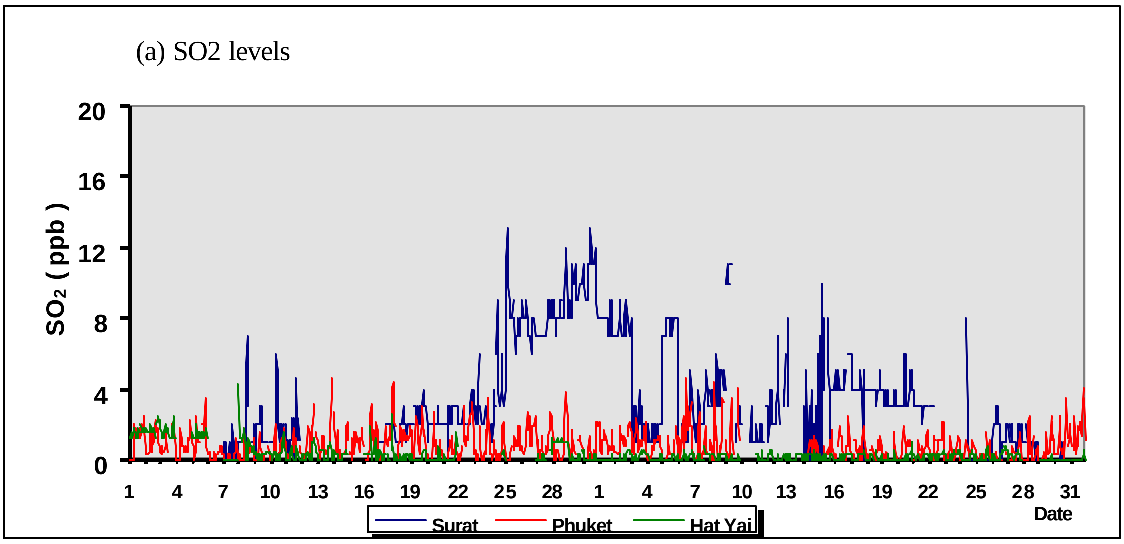


Figure 8
Hourly SO_2 and NO_2 monitoring in Hatyai, Phuket and Surat Thani, September-October 1997.



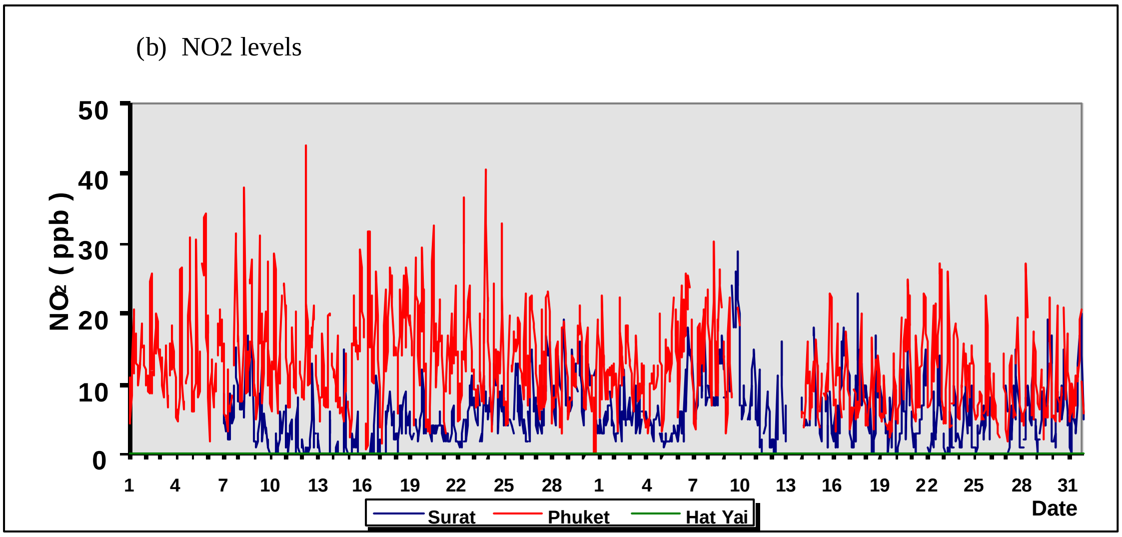
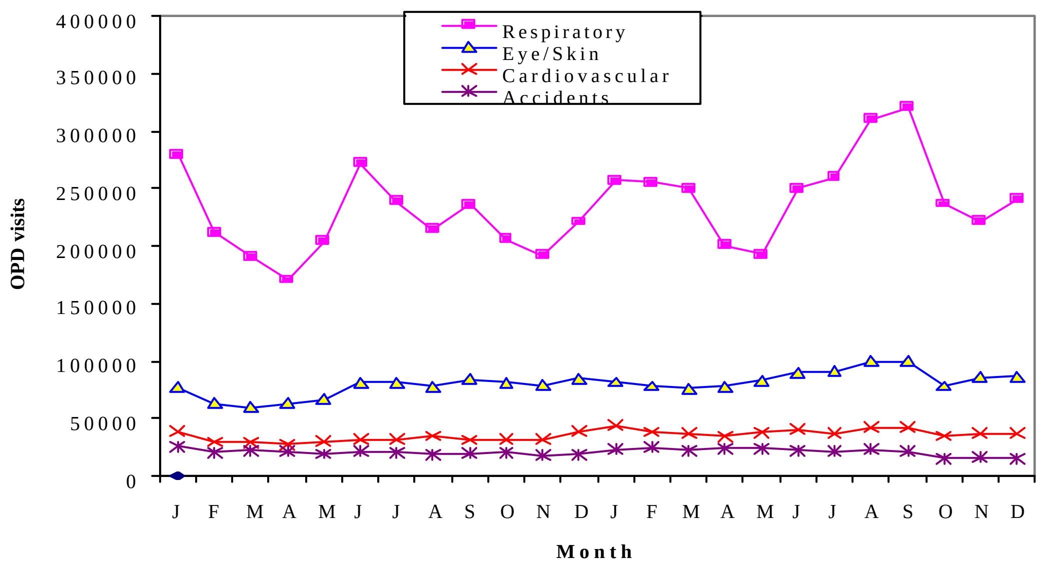


Figure 9
Reported monthly OPD visits in southern and upper northern Thailand, 1996-97.

(a) southern Thailand



(b) upper northern Thailand

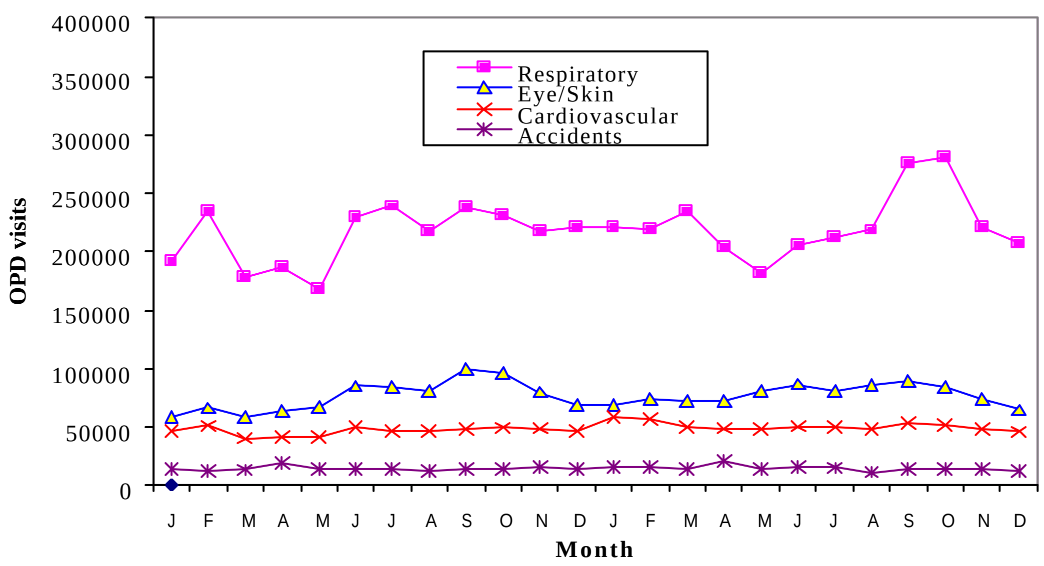
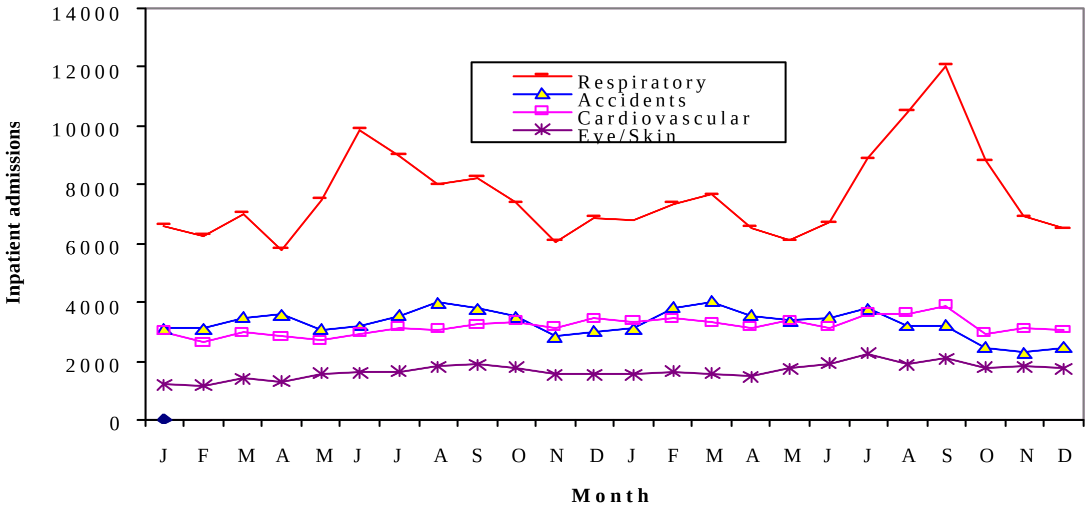


Figure 10
Reported monthly IPD admissions in southern and upper northern Thailand, 1996-97.

(a) southern Thailand



(b) upper northern Thailand

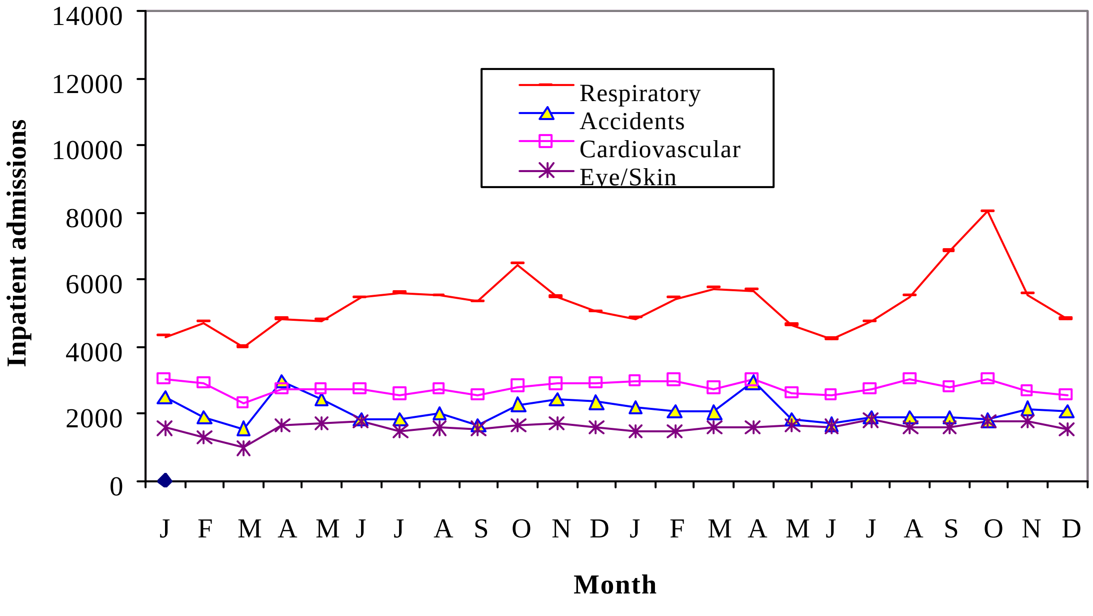
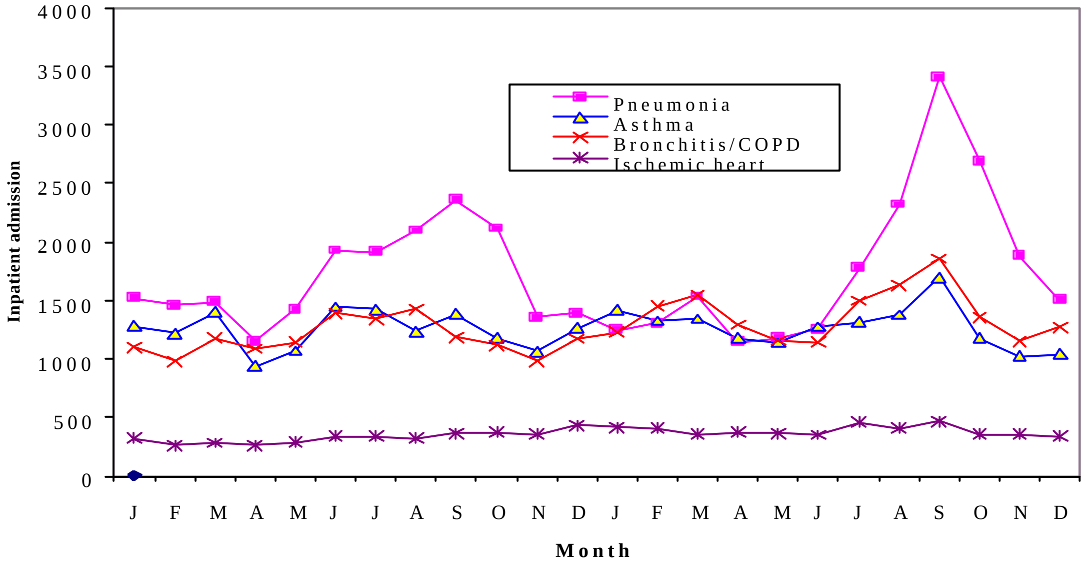


Figure 11

Reported monthly selected IPD admissions in southern and upper northern Thailand, 1996-97.

(a) southern Thailand



(b) upper northern Thailand

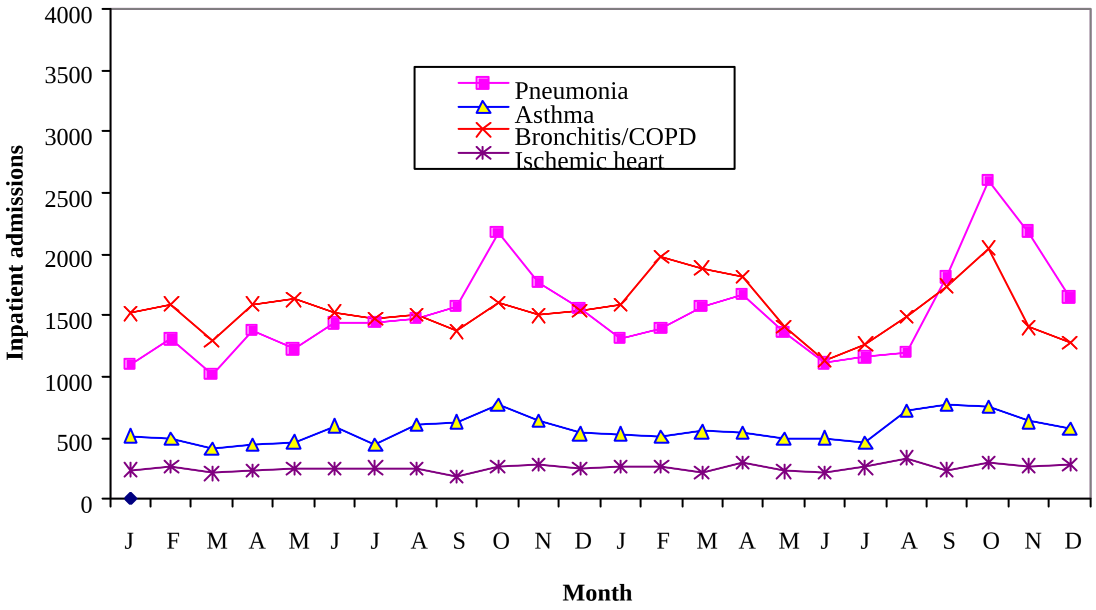
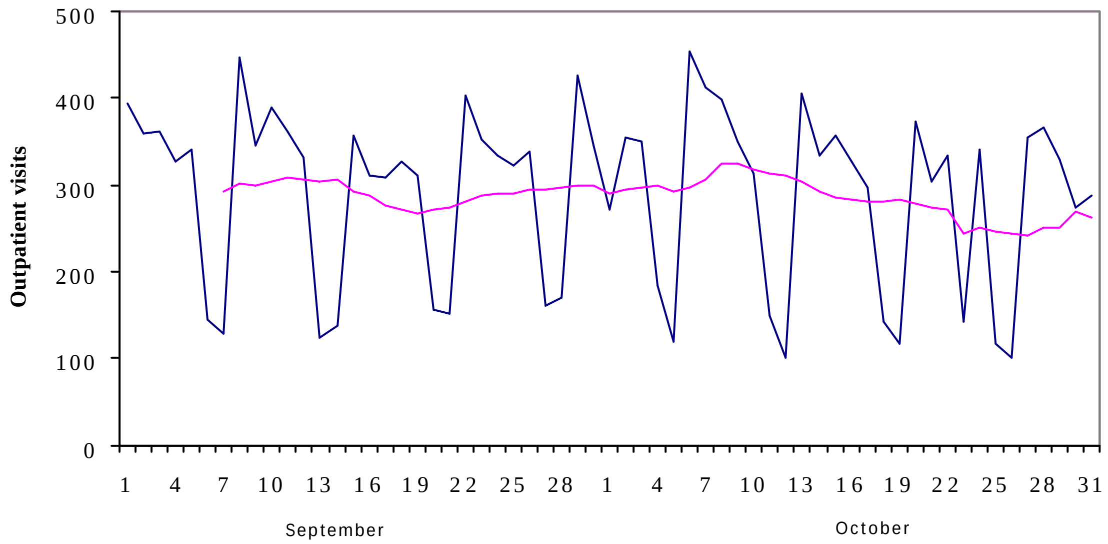


Figure 12
Daily OPD visits and IPD admissions for respiratory illness and their 7-day moving average in Hatyai city, September-October 1997.

(a) OPD visits



(b) IPD admissions

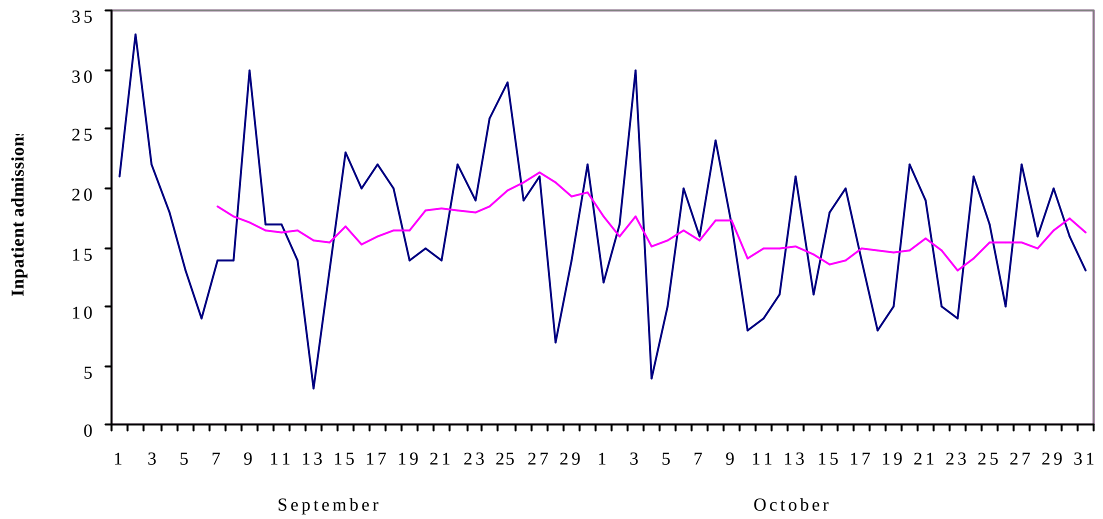
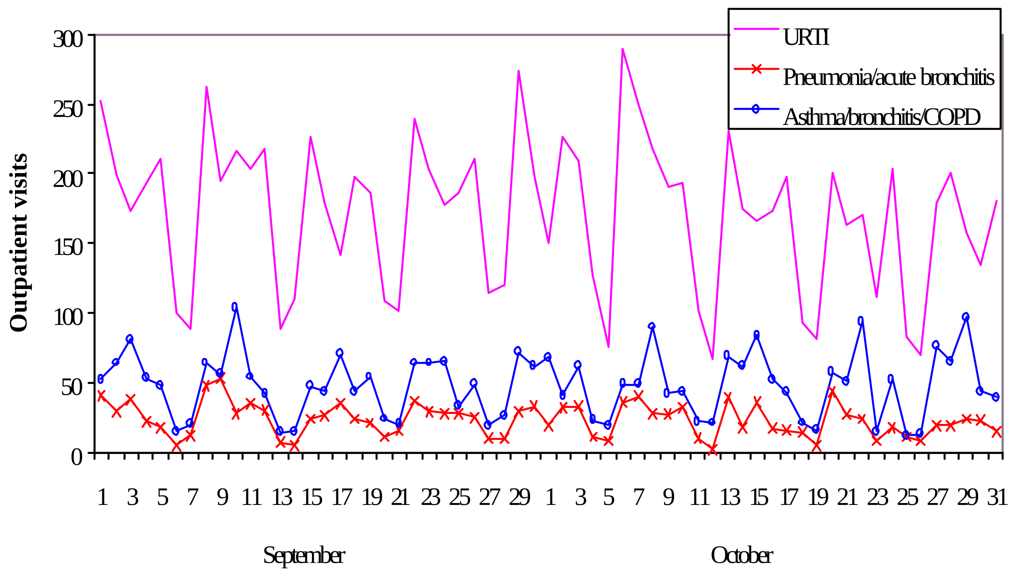


Figure 13
Selected daily OPD visits for respiratory illness in Hatyai city, September-October 1996 and 1997

(a) September-October 1996



(b) September-October 1997

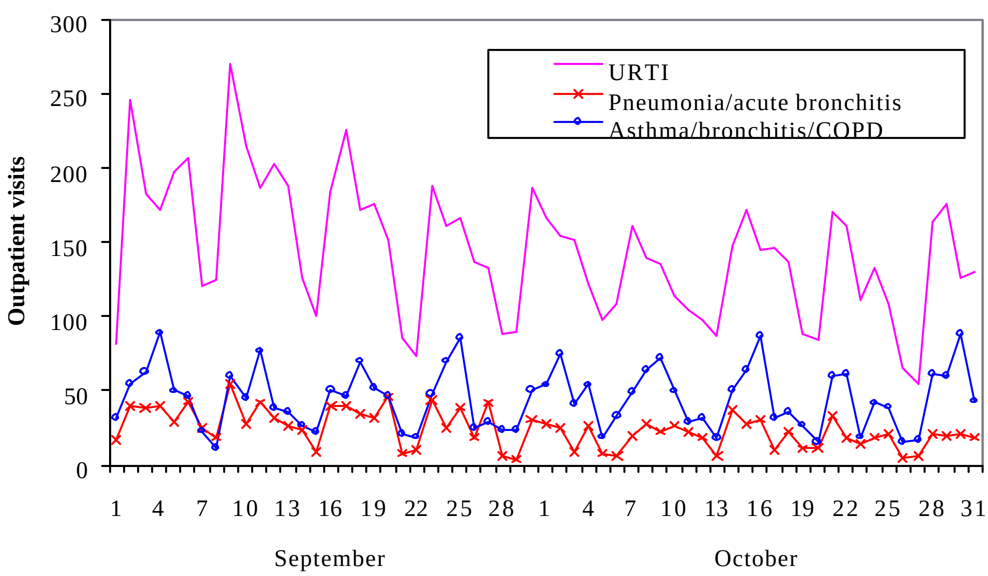
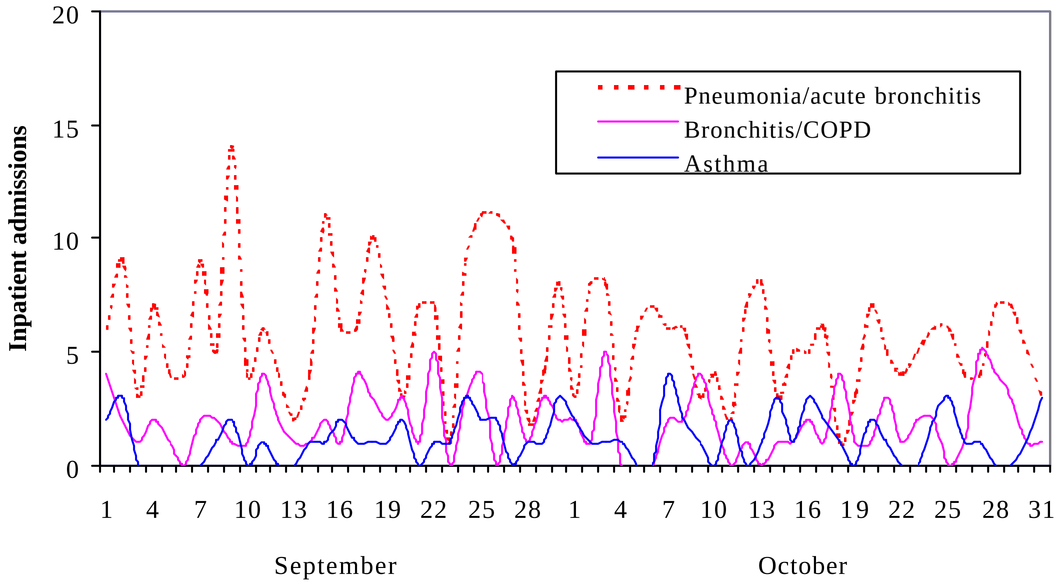


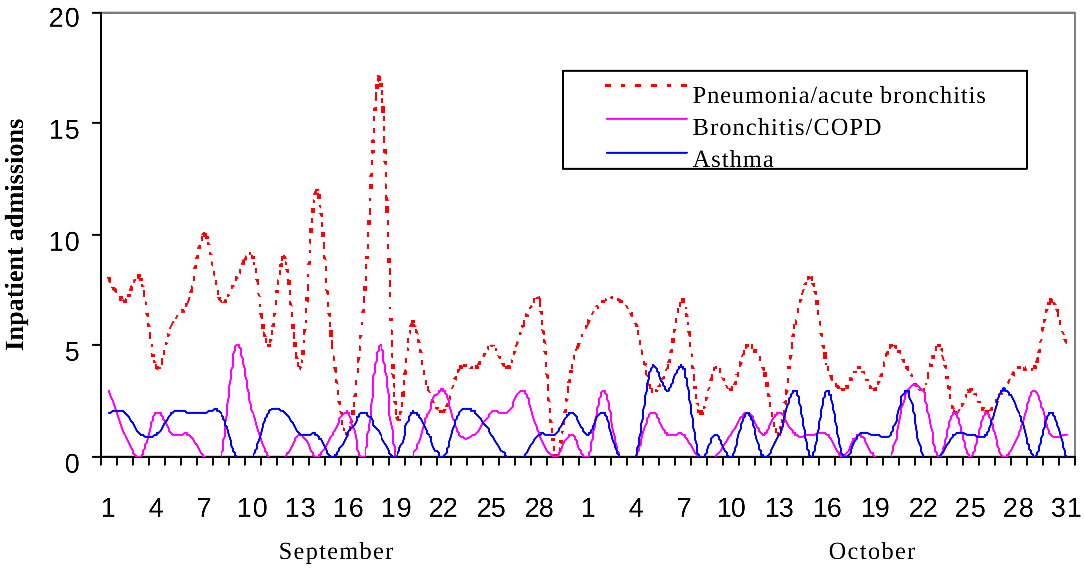
Figure 14

Selected daily IPD admissions for respiratory illness in Hatyai city, September-October 1996 and 1997

(a) September-October 1997



(b) September-October 1996



Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

REVIEW OF GOVERNMENT ENVIRONMENTAL & HEALTH POLICIES, LEGISLATION AND EMERGENCY RESPONSE MECHANISMS

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INTRODUCTION

In the Southeast Asian region, there is an old saying "api: kecil, jadi kawan; besar, jadi lawan" (fire: small, a friend; big, a foe). Thus, prevention is better than cure. Prior assessment is a prerequisite to effective management. The required assessment would call for regular monitoring of sources of fire and other haze-causing sources, air quality and visibility, meteorological and weather conditions, and building up advance predictions and an early warning system. The necessary management must be in place in terms of legislation, institutional arrangements, financial resources, and technical support (1). Such a set of strategies has to be supported by clear objectives and guided by consistent policies.

This review is largely based on various national haze action plans of member countries of the Association of Southeast Asian Nations (ASEAN) and the report of the Asian Development Bank (ADB)-(ASEAN) preparatory meeting on national haze action plans (2), held in Manila, Philippines, from 8 to 9 June 1998. It covers aspects relating to policies and strategies in terms of assessment and management, particularly those concerning emergency response mechanisms and possible legal issues. It also highlights the need not only to address the causes and impacts of fire, as external sources of haze and pollution, but also to take into account the local pollution, particularly in those places affected by forest fires.

POLICY REVIEW

All countries of the region have introduced their respective policies, as part and parcel of their national action plans to prevent and mitigate land and forest fires.

Brunei Darussalam

The policy statements issued are as follows:

- obtain information on state of air quality as well as useful meteorological and weather information;
- determine source of haze;
- provide the public and relevant government agencies the necessary information on air quality and corresponding action;
- safeguard public health and safety;
- ensure there is adequate medical and health facilities;
- prohibit open burning during the dry period; and
- attend to local fires with the aim of achieving zero smoke emission.

The linkages of these policy statements to the objectives of Brunei Darussalam's national haze action plan are shown in Figure 1. It is clear that the policy is based on one of the Stockholm's principles on the human environment of 1972; ie. "assessment is a prerequisite to management". The other principle applied in introducing the policy is a "precautionary" one: "prevention is better than cure". The policy objective is also quite comprehensive; it does address other sources of pollution or haze. Indeed, the combination of all types and sorts of pollution should be the main concern relating to the need to protect public health and safety from any adverse impact of total and specific form of pollution.

Indonesia

The policy statement issued is to prevent and control fire and haze by:

- setting land conversion targets at environmentally sustainable levels;
- establishing incentives to optimise use of degraded land;
- minimising haze pollution by fuel management, including the use of controlled burning techniques and zero burning when and where required; and
- protecting communities and valued ecosystems at risk from the effects of fire and haze.

The source of the Indonesian policy is based on the principle of sustainable development. The principle is applied by setting up the targets for land conversion at sustainable level, establishing incentives for the utilisation of degraded land, and protecting communities and invaluable ecosystems that are vulnerable to the likely impact of fire and haze. Implicit in the policy is the need for prior assessment of the areas at risk, before an area can be considered for land conversion purposes. The other aspect of the Indonesian policy is on the management of land conversion, in terms of its timing and priority areas, including the application of both controlled and zero burning techniques. On the question of timing, there is no specific mention on the time period nor on the recommended season. (In this case, the policy of Brunei Darussalam is very specific: no burning allowed "during the dry period"). Also worth noting is the absence of any policy statement on other sources of pollution.

Figure 2 illustrates the linkages of the Indonesian policy, from the realisation of the sustainable development concept to land conversion management.

Malaysia

For the haze control, the following policies are endorsed:

- open burning is prohibited;

- agricultural waste disposal through open burning will be strictly controlled, and to be prohibited during haze period; and
- smoke and particulate emissions from mobile sources (motor vehicles) and stationary sources (industries) will be strictly controlled and monitored.

The objectives of these policies are:

- to prevent and control identified subsectoral activities which are contributory to haze episodes;
- to enhance operational mechanism by implementing an efficient air quality monitoring and reporting programme; and
- to strengthen inter-agency cooperation and support for combating haze.

The Malaysian policy is very specific to the established sources of haze and pollution. It underlines the importance of air quality monitoring (3) and reporting (4) as well as inter-agency cooperation on the control of agricultural waste disposal or the prohibition of open burning and the control of mobile and other stationary sources of pollution.

Figure 3 illustrates the Malaysian policy linkages, from air quality monitoring, assessment and reporting to the management of all sources of haze and pollution.

Myanmar

The following policies are recommended in the national haze action plan:

- to substitute slash and burn method of cultivation with sustainable agricultural method;
- to prohibit open burning except under proper control;
- to promote vigilance measures; and

- to prevent air pollution arising from land and forest fires.

The objectives are:

- to develop policies and strategies to prevent and mitigate land and forest fires and resulting smoke haze pollution;
- to strengthen inter-agency collaboration for implementing the policies and strategies;
- to mobilize resources to strengthen the capacity of agencies responsible for implementing the national action plan; and
- to develop a more effective mechanism for monitoring land and forest fires and air quality.

Figures 4 illustrates the linkages of various aspects of Myanmar's policy on its haze action plan. It is noted that the policy does introduce an additional aspect for the management of forest fires in the region by substituting slash and burn method of cultivation with sustainable agricultural method. Other aspects of the policy are quite common throughout the region.

Philippines

The policy on its haze action plan is derived from a number of Presidential decrees and a special order issued by the Department of Environment and Natural Resources (DENR). These are:

- creation of the Philippines Haze Task Force, headed by the Environmental Management Bureau, with the following functions:
  - monitor the movement of haze, and serve as official source of information;
  - determine the health hazards associated with haze; and
  - coordinate with all concerned agencies/entities.
- prohibition of open burning with some exceptions;
- control of smoke and particulate emission from stationary sources through specific emission standards;
- provision of ambient air quality guidelines and standards for PM_{10} and TSP, and air quality indices for TSP, SO_2, O_3 and CO;
- control of sulphur compound emissions from stationary sources; and
- control of particulate and gaseous emissions from motor vehicles through specific emission standards for smoke, HC, and NO_x.

Thus, the policy of the Philippines is quite comprehensive; it addresses both aspects of assessment and management as well as all significant sources of haze and pollution. Figure 5 illustrates the linkages of various aspects of the policy for the Philippines. It is noted that the policy makes explicit on the need to determine or assess the health hazards associated with haze, and to introduce provisions regarding ambient air quality guidelines and standards for primary pollutants. Thus, the objectives of the haze action plan are as follows:

- to prevent and monitor haze/transboundary air pollution in the country caused by forest fires and other sources such as mobile and industrial sources;

- to enhance the delivery of services, assistance, basic needs and information to the people and communities affected by haze and air pollution; and

- to promote co-operation among Asian nations in the field of information exchanges and technology transfer for the control, prevention and monitoring of haze/air pollution.

Singapore

Notwithstanding the fact that the country is a highly urbanised with very limited agricultural land and forest, Singapore has put in place a comprehensive policy to prevent and mitigate land and forest fires. It strictly prohibits open burning of all solid wastes, including agricultural wastes from farms, wood wastes from construction sites and trimmings of trees/shrubs. It has also set up a close surveillance system to prevent and detect fires, as well as operating procedures for rapid deployment of fire-fighting resources in the event that fires are detected. However, the policy is silent on the nature and extent of control required against local sources of pollution during the haze episodes but introduces a new management element for the region by introducing an infrastructure for solid waste disposal.

Figure 6 illustrates the linkages of the above aspects of the policy. The strategies to prevent air pollution from domestic, industrial and other premises are:

- prohibition of open burning;

- infrastructure for collection and disposal of solid wastes;

- enforcement of emission standards;

- ambient air quality monitoring;

- public awareness education and feedback;

- prevention and control of land and forest fires; and
- inter-agency cooperation and support.

Thailand

The policy for its haze action plan is targeted specifically at the Indonesian forest fires. The objectives are:

- to mitigate and minimize the environmental and health impact from the Indonesian forest fires; and
- to provide considerable support to its neighbouring ASEAN countries.

The specific strategies are: legislation, enforcement and surveillance; air quality monitoring and reporting; institutional set up and strengthening; cooperation plans; public awareness, education and feedback; arrangements for intra-agency cooperation and support; operational procedures for mobilisation of resources for combating haze; and agricultural wastes management, especially utilisation.

Figure 7 illustrates the linkages of the various strategic aspects of the policy on forest fire in Thailand. It is noted that the Thai policy is similar to that of Singapore.

Vietnam

Vietnam is in the process of finalizing its national haze action plan.

National policies on haze and its control

As summarised and outlined in Table 1, it is clear that Indonesia sets itself a higher set of policy objectives by introducing the development aspects in its policy. It specifically establishes land conversion targets set at sustainable levels. Implicitly, it sets aside areas that are invaluable in biodiversity or protects those communities at risk from the impact of forest fires and haze. Its management is quite focussed. It narrows down to the need for effective fuel management through controlled burning, but it is silent on the timing of such a practice which should not be recommended especially during the dry period.

Among seven of the eight ASEAN countries, the most common policy objective is “to prevent and control fire and haze” with minor variations, in terms of emphasis. Only four countries; namely Malaysia, Myanmar, Philippines and Singapore have introduced and enforced policy on strict prohibition of open burning. In Brunei Darussalam, the prohibition is enforced only during the dry period. Such a policy is highly recommended for Indonesia and other countries in the region.

On the need to address other local sources of haze and pollution, five countries; namely, Brunei Darussalam, Malaysia, Philippines, Singapore and Thailand have established and enforced their respective emission standards for motor vehicles, industries and other domestic sectors. Controlling local sources of pollution, particularly during the haze episodes, is equally critical, in order to safeguard public health and safety, and other environmental concerns.

On the assessment aspect of the policy framework, all the seven ASEAN countries, except Indonesia, have given importance to the need for ambient air monitoring and reporting. Monitoring and reporting are basic to assessment and management functions. In addition, Brunei Darussalam sets itself to “determine source of haze”, while the Philippines, “ to determine health hazards” as part and parcel of the assessment aspect of their respective policies.

On management, greater focus is on the need to introduce and strengthen legal and institutional arrangements at both national and regional levels. All the seven ASEAN countries, except Brunei Darussalam, have given emphasis on the capability and capacity for regional cooperation, particularly in the deployment of fire fighting resources. Of course, the need

to provide the public and other relevant agencies information on the episodes and responses is important and specifically emphasised by at least three countries; namely, Brunei Darussalam, Singapore and Thailand. Management specifics that have been introduced by certain countries and of significant relevance to others are:

- to establish incentives to use degraded land (Indonesia);
- to substitute slash and burn method with that of sustainable cultivation technique (Myanmar);
- to promote the utilisation of agricultural wastes (Thailand);
- to provide infrastructure for collection and disposal of solid wastes (Singapore); and last, but not least, and perhaps, the most important of all;
- "to minimise haze pollution by fuel management" through controlled burning (Indonesia).

LEGISLATION ON THE CONTROL OF LAND AND FOREST FIRES AND AIR POLLUTION

All ASEAN countries have some form of general or specific laws and regulations which are applicable for the control of forest fires and air pollution to protect public health and the environment from the impacts arising from these sources. For example, in Malaysia, the specific laws and regulations come under the Environmental Quality Act (1974, Amendments 1996) which includes:

- Environmental Quality (Clean Air) Regulations 1978 - emissions standards for stationary and mobile sources;
- Environmental Quality (Amendment) Act 1998 (Act 1030) - new provisions prohibiting open burning; and
- Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987.

There are many other laws and provisions in Malaysia which are relevant and applicable for the control and mitigation of land and forest fires and air pollution from various sources. These include acceptable practices in forest management, land development, solid waste disposal, etc.

EMERGENCY RESPONSE MECHANISM

A review of the various aspects and components of the existing emergency response mechanisms at both national and subregional levels within the Southeast Asian region provides the basis towards the formulation of an overall response mechanism for the region. Essentially, the required mechanism, as shown in Figure 8, involves the following functions, in decreasing order of priority:

(i) early fire (hot spot and smoke) detection;
- satellite monitoring
- aerial surveillance
- ground surveillance
- weather forecasting
- surface-based atmospheric modelling

(ii) fire fighting;
- coordination at national level
- coordination and assistance at subregional level
- action at local level

(iii) communication links;
- internet
- intranet
- telephone/telefax
- radio

(iv) enforcement;

(v) public education and awareness campaigns;

(vi) air quality monitoring;

(vii) studies of health and other socio-economic impacts;

(viii) fire danger rating system; and

(ix) land-use planning.

CONCLUSIONS

Generally, ASEAN countries have already in place, to a more or lesser extent, some forms of policies, legislation and emergency response measures to control and combat forest fires and air pollution, and to minimise the impacts arising from these occurrences. The attempt to develop a common set of health guidelines for the interest of all the countries involved would be most timely. In order to achieve the objectives, mechanisms to provide assistance to the respective countries to incorporate the guidelines into their existing policy, legislation and emergency response, and thereby identifying and strengthening areas of inadequacy, would be most important.

In terms of policies, the essential elements to be incorporated can be extracted and combined with approaches developed by the individual countries. With regards to policy objectives, the elements identified are:

- to prevent and control land and forest fires;
- to safeguard public health and safety in such occurrence;
- to prohibit open burning;
- to introduce and implement ambient air quality guidelines and standards; and
- to strengthen control on emissions from mobile and stationary sources.

The elements with respect to policy on development are:

- to set land use planning based on sustainable development principle; and
- to protect communities and ecosystems at risk from fire and haze effects.

The elements with respect to policy on assessment include:

- to monitor and report on air quality;
- to develop an effective mechanisms for monitoring land and forest fires;
- to develop capability for forest fires and haze detection and predictions; and
- to monitor the health and environmental impacts of haze.

The management policies focus on the following aspects:

- to provide the public and the authority information on air quality and action to be taken;
- to advise the public on actions to be taken for health protection;
- to ensure medical and health supplies and facilities to mitigate health impacts;
- to provide support to countries in need and to promote cooperation among Asian countries;
- to minimise haze pollution from fuel burning;
- to strengthen capabilities of the relevant agencies; and
- to strengthen inter-agency cooperation and support.

On the legislation aspects, all ASEAN countries have in place some form of general or specific laws and regulations for the control of forest fire and air pollution to protect public health and the environment from the impacts arising from haze episodes. The present needs lie in identifying areas of weakness and in further establishing the means to strengthen enforcement.

A framework for the formulation of emergency response mechanisms can be derived from the cooperative experience among the three countries most affected during the 1997 haze episode; namely, Indonesia, Malaysia and Singapore. The framework encompasses coordination bodies, monitoring and detection of fires, fire fighting, communication channels, enforcement, monitoring or air quality and health impacts, public education and awareness campaigns, and land-use planning and fire danger rating.

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Table 1
Summary of national policies relating to haze in the Southeast Asian region: objectives, development, assessment and management

Objectives

- To prevent and mitigate land and forest fires (Brunei);
  To prevent and control fire and haze (Indonesia);
  To prevent and control activities contributing to haze episodes (Malaysia);
  To develop policies and strategies to prevent and mitigate land and forest fires resulting in smoke haze pollution (Myanmar);
  To prevent air pollution arising from land and forest fires (Myanmar);
  To prevent and monitor haze/transboundary air pollution (Philippines);
  To prevent and control land and forest fires (Singapore);
  To mitigate, minimise the environmental and health impact from the Indonesian forest fires (Thailand).

- To safeguard public health safety (Brunei);

- To prohibit open burning (Malaysia, Philippines, Singapore);

  To prohibit open burning, except under proper control (Myanmar);

- To control emission from mobile and stationary sources (Brunei);
  To control smoke and particulate emissions from mobile and stationary sources (Malaysia);
  To control various sources of air pollution: mobile and stationary (Philippines);
  To enforce emission standards (Singapore);
  To carry out enforcement (Thailand).

- To introduce provisions of ambient air quality guidelines and standards (Philippines).

Development

- To set land conversion targets at sustainable levels (Indonesia);

- To protect communities and valued ecosystems at risk from effects of fire and haze (Indonesia).

Assessment

- To obtain information on the state of air quality (Brunei);
  To monitor and report on air quality (Malaysia);
  To develop a more effective mechanism for monitoring lands and forest fires and air quality (Myanmar);
  To monitor haze/transboundary air pollution (Philippines);
  To monitor haze movement and report (Singapore);
  To carry out air quality monitoring and reporting (Thailand).

- To determine source of haze (Brunei);

- To monitor smoke and particulate emissions from mobile and stationary sources (Malaysia);

- To determine health hazards (Philippines);

- To promote vigilance measures (Myanmar);
  To carry out close surveillance system to prevent and detect fires (Singapore);
  To carry out surveillance (Thailand).

Management

- To provide the public and the authority information on air quality and action taken (Brunei);
  To promote public awareness, education, and feedback (Singapore, Thailand);
  To enhance the delivery of services, assistance, basic needs and information to the public and communities affected (Philippines).
- To ensure adequate medical and health facilities (Brunei);

- To provide considerable support to neighbouring ASEAN countries (Thailand);
  To promote cooperation among Asian countries (Philippines).

- To minimise haze pollution by fuel management (Indonesia);

- To strengthen inter-agency cooperation and support (Malaysia);
  To strengthen inter-agency collaboration and to mobilize resources to strengthen the capacity of agencies responsible for the plan (Myanmar);
  To coordinate with all concerned agencies (Philippines);
  To establish arrangements for inter-agency cooperation and support (Singapore);
  To establish institutional set-up and to strengthen cooperative procedures for mobilization of resources for combating haze (Thailand);
  To establish operating procedures for rapid development of fire fighting (Singapore).

Figure 1
Policy linkages from objective to assessment and management of forest fires and other sources of haze, Brunei Darussalam

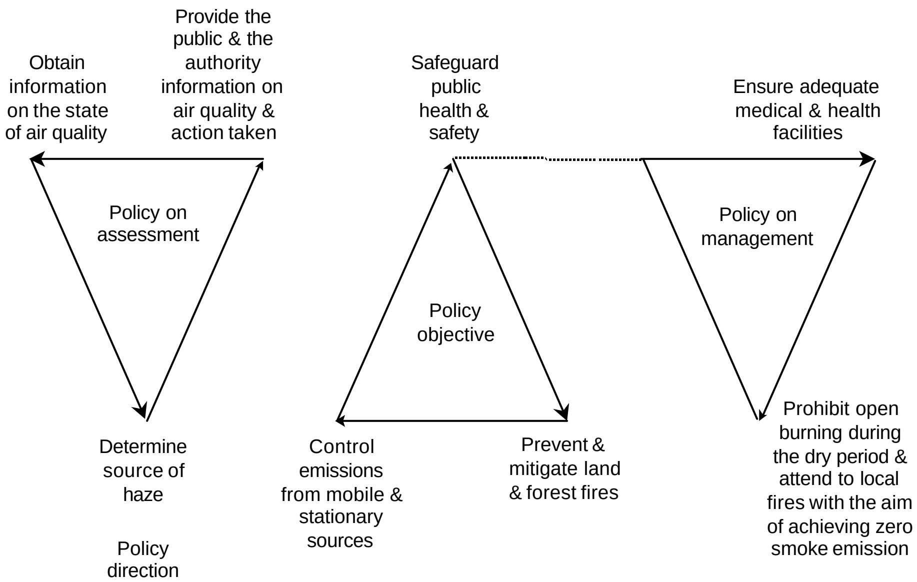


Figure 2
Policy on prevention and control of fire and haze, Indonesia

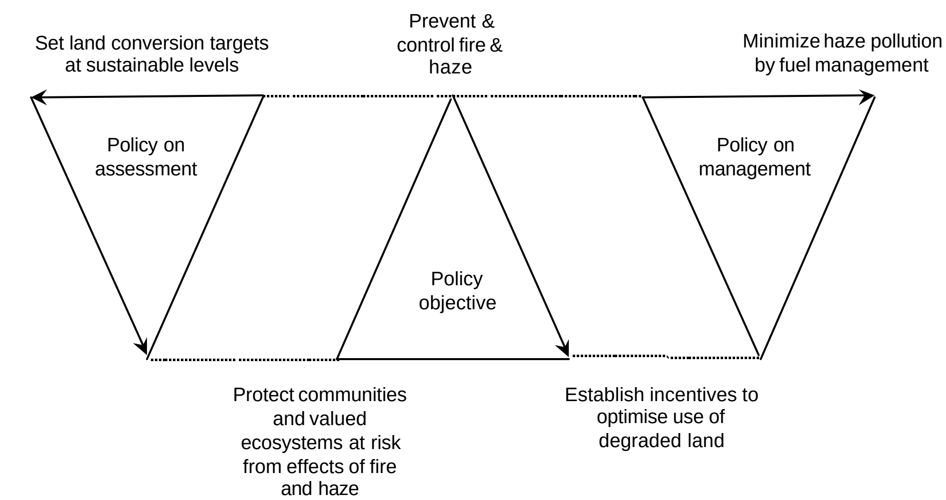


Figure 3
Policy on haze and control of its sources, Malaysia

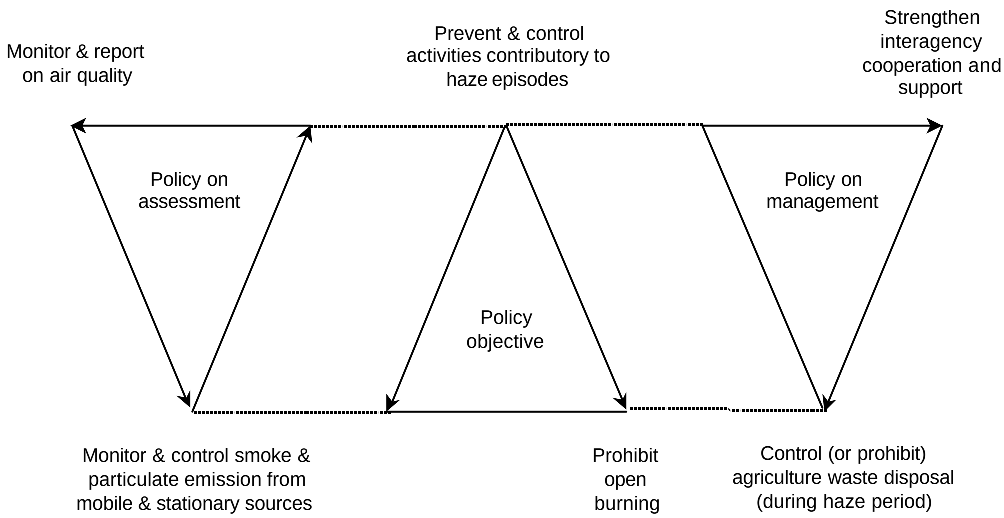


Figure 4
Policy on national haze action plan, Myanmar

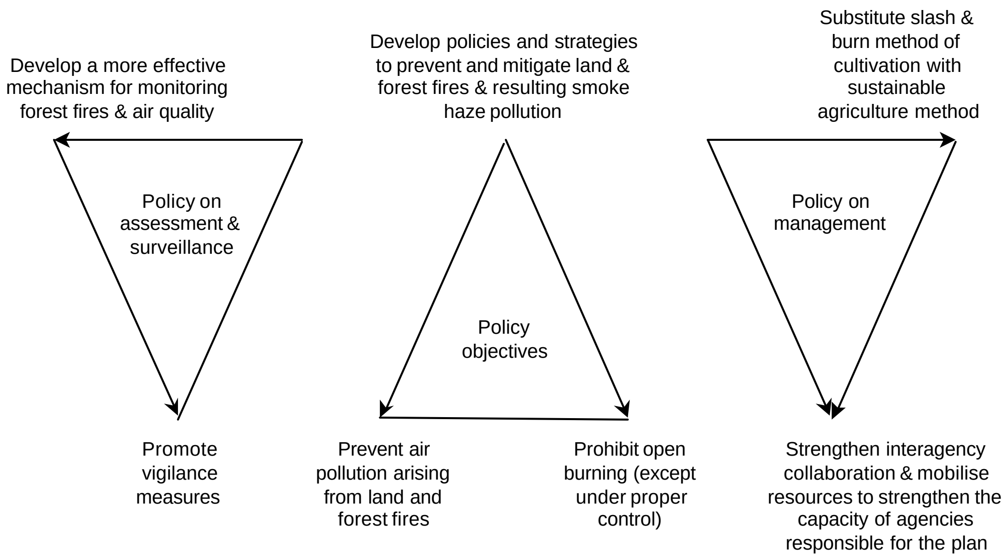


Figure 5
Policy on haze and its control, Philippines

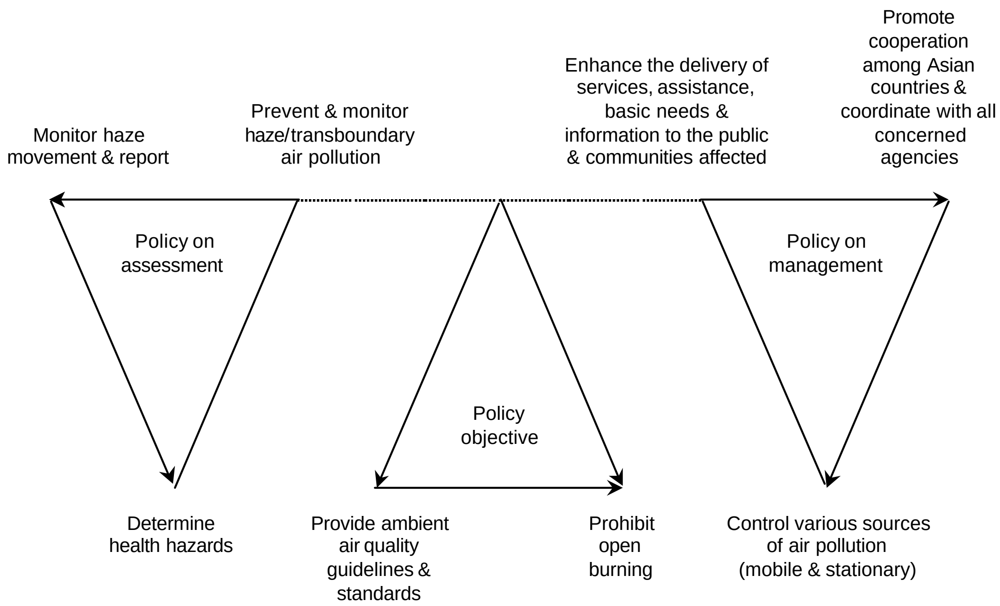


Figure 6
Policy on prevention & control of land & forest fires and control of other emissions, Singapore

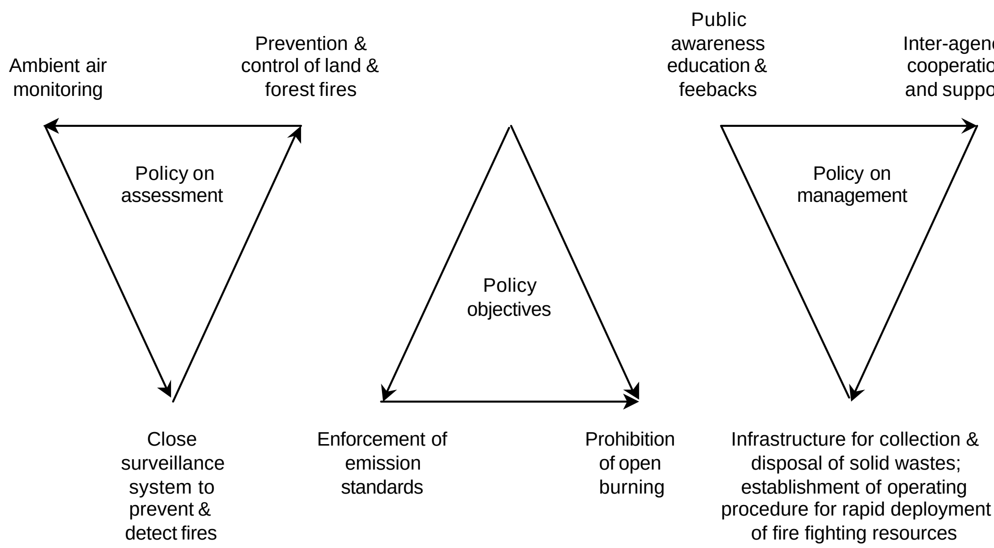
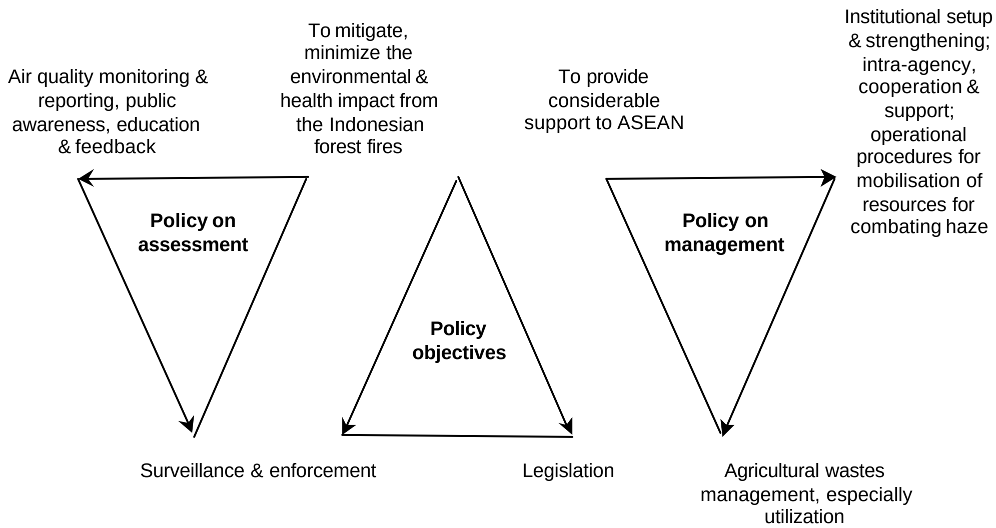


Figure 7
Policy on Indonesian forest fires, Thailand



Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

ROLE OF THE FOREST FIRE EMERGENCY STANDARDS

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HOW TO USE AND APPLY THESE STANDARDS

Every country has some type of organisation to face natural emergency situations (floods, earthquakes, slides, etc) or those caused by human beings (railway and airplane accidents, multiple highway accidents, chemical spill, etc), which often occur.

Sensitisation of the authorities

The first recommendation is that great effort should be made so that national institutions include forest fire emergencies in their planning and work. Although it is a subject which has had enormous environmental, economic and social impact in recently affected countries, it is considered a remote topic, something almost anecdotal that occurs in other latitudes, but not in our region. Hence, necessary incentive has not been received to consider them within the lines of action of emergency systems.

An important aspect of the "WHO Health Guidelines for Episodic Vegetation Fire Events" must then include motivations of the authorities so that they may integrate this subject with its diverse dimensions and complexities.

A strategy aiming at sensitising decision-makers regarding the real magnitude and difficulties that the problem can become in each of our countries, according to previous years' experiences , must be prepared. It is therefore, important to primarily identify and work with the "Authority Sector"; ie. the authority that has an effective legal power which could integrate other public services and institutions under its coordination.

Emphasis on the prevention of forest fire emergencies

To avoid forest fires, an adequate prevention and control strategy must be put in place. It is very important to include the various representatives of the community in order to educate the population to collaborate in the prevention of these emergencies.

Adaptation of plans to local situation

If the methodology can be adapted and incorporated into each country's strategy, the national authorities could be oriented regarding the steps to follow to achieve an adequate coordination, planning, and action in the implementation of these standards.

Sensitisation of the competent technical agencies

Besides sensitisation of the authorities, it is necessary to motivate the services and technical groups, defined as those with effective technical aptitudes, responsibility, knowledge and resources. This process can be achieved through adequate and permanent technical assistance that international organisations can provide, promoting local efforts, registering progresses, collecting and providing feedback data, and disseminating to other countries the successful initiative.

There is a special interest in establishing technical assistance and training procedures in complex subjects, such as the assessment of impact on health or the transportation of forest fire pollutants, which might require specific regional technical meetings.

PREPARATION OF A NATIONAL POLICY AND STRATEGY THAT RESPOND TO FOREST FIRE EMERGENCIES

Structuring the authority

Once motivation of the national authorities (authority sector) has been achieved, incorporation of the forest fire emergency plan should follow. New areas to consider should include the impact on health in the national emergency programmes. The latter will be integrated into the national civil defence system (coordination group) or another national organisation with the same objective. The competent technical agencies (technical group) will be summoned to provide the expertise.

The forest fire emergency standards can then be inserted and applied in accordance to the institutional and legal system of each country. This will ensure the commitment and coordinated participation of the various institutions with clearly identified responsibilities. An adequate organisation and preparation of the forest fire emergency plan will then be obtained.

Preparation of a strategic plan by the technical agencies

Under the instructions of the authority, the agencies in charge of the national emergency programmes will first identify the main technical bodies related to:

- forest fire prevention and control (agriculture, natural resources);
- health services, with its diverse complex levels (health centres and hospitals), epidemiological and environmental surveillance networks;
- air quality surveillance systems; and
- meteorological services.

They will then be called upon to review or to formulate the forest fire prevention programmes. The purpose is to adapt them according to new technical contributions, aimed at obtaining a strategic plan as the final product. Contributions from other agencies should also be incorporated. These agencies will be summoned in the implementation stage.

It would be desirable to organise inter-institutional workshops on strategic planning or other related methodologies. These will allow exchange and development of specific commitments; i.e. training plans, on-site work, drills, information exchange and establishment of communication systems. A greater commitment by all the participating institutions on the actions to be taken can be achieved, thus clearly establishing the role that each one must fulfill in case of an incident of this nature.

These working activities will permit specific tasks to be outlined, a plan of activities to be established, goals to be achieved, a timetable with exact dates designed, and the financial support of each activity to be determined.

Other relevant entities

Once the strategic plan has been established, and to further improve on it, it is suggested that other public and private institutions be called upon at another stage to review the work plan. These new entities include:

- universities, [schools of medicine; centres of environmental studies (air pollution analytical capacity)]; institutes for natural and forest resources; meteorological services (monitoring systems, meteorological variations, aerial and satellite information);

- private business associations linked to the forest or agriculture;

- aerophotometry services (air force)

- public security institutions (police); and

- armed forces (army and air force).

More information on the data collected as well aptitudes, functions and resources of these entities may be obtained through questionnaires.

Replication of the strategic plan at regional and local levels

Once the preparation of the strategic plan has been concluded by the national entities, the authority will have to instruct those in the regional and local levels to repeat this work in their respective territorial area. An adequate and permanent feedback of information on the progress and difficulties encountered should be maintained, together with an evaluation of the goals achieved.

HOW TO OBTAIN AND USE THE DATA FOR DECISION-MAKING IN THE ENVIRONMENTAL HEALTH ACTION PLANS

Available database

Once the strategic plan has been developed, it is necessary to design a database of the available technical information collected routinely by different entities. The objectives are: (i) to strengthen the forest fire prevention and control programmes; and (ii) to ensure that those responsible for dealing with this type of emergencies adopt the most appropriate measures on time. Based on the first stage of the preparation process of the plan, the technical agencies will then elaborate a database with the available information. Consultation will be made directly with other relevant entities, through a questionnaire sent by air mail or internet, and if the response is not timely, through direct inter-institutional interviews.

In designing the database, the following points will have to be specified:

- how is it compiled?
- with what periodicity and since when registries are available?
- is it possible to strengthen the frequency to comply with the needs of the plan?

- are there any requirements to improve them?
- is it subject to quality control systems? which particular ones?
- is the system going to be modified?

Analysis of the available information

Once this information is compiled, an evaluation must be made on:

- data quality: is it reliable?
- availability: is it of easy access and acceptable costs?
- frequency: is it appropriate to the needs of the plan?
- needs for complementing with other techniques, such as new air pollution monitoring systems, aerophotography, satellite images.

Once this review is done, procedures must be established to improve on such information which is inconvenient to obtain. Financial sources will also be searched. To compete with other new local projects, specific project design or international collaboration is necessary.

These plans are more likely to be accepted, if mechanisms for transferring or complementing information are proposed at national as well as international levels.

Generation of information systems for decision makers

With this background, and having developed the strategic plan, an information system will have to be organised so that the goals and objectives can be successfully met.

A surveillance programme for the environmental conditions that determine a greater forest fire hazards will have to be developed and periodically evaluated. It should be located close to thick forest areas in the direction of the prevailing winds. Topographical and climatological

conditions that hinder the dispersion of air pollutants, fire hazards, such as prolonged summer season, sharp increases in temperatures or drought conditions, should be provided.

Air quality data

The air quality needs to be characterised, with periodic measurements for comparison at any time and according to the season of the year. In this case, it is desirable to have complete measurements during periods when forest fire hazard is greater (dry season of the year, smaller rainfall and higher temperatures).

Meterological and modelling data are required to analyse possibilities of increase or reduction in the intensity of pollution. These include winds, moisture, temperature, maximum impact points of pollution and pollutant dispersion conditions.

Information on forest fire hazards

Information on forest fire hazard levels should be obtained from state agencies in charge of preventing and fighting this type of incidents, as well as from private enterprises in forestry or agriculture.

Databases about the size of the forest or thicket close to populated centres which are in danger of forest fires should be elaborated.

In cases of declared fires, it is important to obtain aerial photographs and satellite images of the affected areas, to evaluate the magnitude and risks of the incidents, and to generate information for decision-makers.

Health data

Data on respiratory diseases in susceptible population (children) should be collected. It should be noted that while lower respiratory diseases are clinically more objective, respiratory diseases as a group are subject to a number of variables and their relationship to forest fires is difficult to evaluate. However, surveillance for respiratory diseases is useful to verify the damage or evaluate the impact on health in case the emergency continues. This is because the effect on health is observed days after the fire impacts on the air quality. To reduce costs, sentinel groups should be chosen, and

information of the affected population from some representative health centres collected.

Data of population exposed to forest fire pollution

This type of information is useful to estimate the needs for support or reinforcement from health workers, or to plan resources in a better way regarding evacuation of the place (shelter planning). Data should be obtained on the extent of the population exposed to poor air quality, location, access roads, nearby health care services and population structure (sex, age, education level).

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

GUIDANCE ON MEASURES IN FOREST FIRE EMERGENCY CASES

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INTRODUCTION

This paper specifically addresses guidance for the prevention and control of wildland fires, the use of protective devices, and contingency planning. Before successful prevention or control of wildland fires can be achieved, basic knowledge of how fires burn and why fires spread is necessary.

PREVENTION AND CONTROL OF FIRES

How fires burn

When enough heat is applied to a fuel in the presence of air, combustion will result. Within a wildland fire, the processes of pyrolysis and combustion occur simultaneously.

Pyrolysis

When first heated, fuels produce water vapour and mostly noncombustible gases. Further heating initiates pyrolysis, the process by which heat causes chemical decomposition of fuel materials, and yielding organic vapours and charcoal. At about 204° C, significant amounts of combustible gases are generated. Also at this temperature, chemical reactions start to produce heat, causing pyrolysis to be self-sustaining if heat loss from the fuel is small. Peak production of combustible products occurs when the fuels are about 316° C.

Combustion

Combustion is the process during which combustible gases and charcoal combine with oxygen and release energy that was stored in the fuel as heat and light. Most observers of wildland fires can distinguish between flaming and smouldering combustion. Flaming combustion is characterized by the movement of visible flame through the fuel; smouldering combustion is a more general and loosely defined term associated with the die-down of a fire after the flame front has passed. It is more logical to consider fire in four phases: pre-ignition; flaming; smouldering; and glowing (Figure 1).

(i) Pre-ignition phase

In this phase, heat from an ignition source or the flaming front heats adjacent fuel elements. Water evaporates from fuels and the process of pyrolysis occurs, the heat-induced decomposition of organic compounds in fuels.

(ii) Flaming phase

Combustion gases and vapours resulting from pyrolysis rise above the fuels and mix with oxygen. Flaming occurs if they are heated to the ignition point of 427°C to 482°C, if they come into contact with something hot enough to ignite them, such as flames from the fire front. The heat from the flaming reaction accelerates the rate of pyrolysis. This causes the release of greater quantities of combustible gases, which also oxidize, causing increased amounts of flaming.

(iii) Glowing phase

When a fire reaches the glowing phase, most of the volatile gases have been driven off. Oxygen comes into direct contact with the surface of the charred fuel. As the fuel oxidizes, it burns with a characteristic glow. This process continues until the temperature drops so low that combustion can no longer occur, or until all combustible materials are gone.

(iv) Smouldering phase

Smouldering is a very smoky process occurring after the active flaming front has passed. Combustible gases are still being released by the

process of pyrolysis, but the rate of release and the temperatures maintained are not high enough to maintain flaming combustion. Smouldering generally occurs in fuel beds with fine packed fuels and limited oxygen flow such as duff and punky wood. An ash layer on these fuel beds and on woody fuels can promote smouldering by separating the reaction zone from atmospheric oxygen.

Fire is basically a chemical reaction called rapid oxidation. Fire is produced only when heat, fuel, or oxygen are present in the right amounts. Fire cannot exist if any one of the elements is absent. The basic principle of fire control is to remove one or more of these elements in the quickest and most effective manner. Heat is the causal agent in the start of any fire. Once a fire has started, it can produce its own life-giving heat.

Why fires spread

The environment in which the fire is burning dictates how it will behave (Figure 2). The fire environment includes topography (slope, aspect, elevation, and configuration), fuels (type and characteristics, fuel moisture, fuel temperature, and fuel loading) and weather (air temperature, wind, relative humidity, air stability, clouds, and temperature inversions). Fire is influenced by many factors, most of which are subtle in their effect. The key to predicting fire behaviour is understanding how these factors combine and change burning patterns.

Prevention

There are three components of a wildland fire prevention programme: education, engineering, and enforcement. Key elements and examples are given in Table 1.

The purpose of a fire prevention programme is to eliminate or reduce risk (fire cause) and hazards (where and what it burns). There are several things that can be done to prevent fire in the wildlands. The first step in developing a fire prevention plan is to determine what the specific risks and hazards are. In some areas, the predominant cause is debris burning or equipment use; in other areas, it may be lightning or arson. Once it has been determined what are the causes of the fires, and in which fuels they have started, a plan to reduce these incidents should be developed. If the predominant cause is debris burning, a campaign targeting at those who are doing the burning should be started. The damage caused by these fires and the

cost of putting them out should be pointed out. Safe burning should also be encouraged.

If the cause is logging or farming activities, these causes can be reduced by education of the workers, by installation of spark arrestor on machinery, or by restricting the hours of work during periods of high fire danger. The hazard may also be reduced by having fuel breaks constructed around operational areas or along roads.

The key to prevention is working with people. Education will go a long way, but if the local laws prohibit these types of fires, start prosecuting offenders. Law enforcement is the last element of prevention. It should only be used when everything else fails.

There are a number of reference materials that provide excellent guides to developing a fire prevention programme (1-3).

Control

To "control" a fire, the "fire triangle" must be broken (Figure 3). Water, chemicals or dirt serve to cool or smother the fire; a fire line can be cut with hand tools or equipment; and one can use the fire itself. The method or methods chosen will depend on the type of fuel, the fire behaviour, the terrain, and the firefighting resources that are available.

Use of water

Water cools the fire, breaking the heat side of the fire triangle. It can also dilute the oxygen side of the fire triangle when water vapour is created. Water, however, will be most effective if applied as part of an overall strategy that includes a fire line cut to mineral soil. A wet line as the final control line should never be considered. One volume of water will cool 300 volumes of burning fuel, if applied properly.

Use of chemicals

Water is a very effective fire-suppressing agent. However, water with a suppressant added can increase its effectiveness by a factor of 10. Suppressant is a substance that extinguishes the flaming and glowing phases of combustion by direct application to burning fuels. This is accomplished by

coating and cooling the burning fuels. The following are examples of suppressants.

(i) *Wetting agents* can be added to water to reduce the surface tension of water and increase penetration and spreading capabilities. This is very effective during mop up. It is ineffective once the water has evaporated.

(ii) *Class A foams* are also very effective in controlling wildfires. By adding foam to water, all three sides of the fire triangle can be broken. Foam will cool, smother, and insulate the fuels. The aerated, water-containing bubble structure is effective only until the water has evaporated, and is, therefore, useful in direct attack, but not indirect attack.

(iii) *Retardants* are substances that reduce or inhibit the flammability of combustibles by chemical or physical action even after the water they originally contained has evaporated. The rate of spread of the flame is thereby slowed or retarded. Retardants are effective line-building tools for indirect attack, when applied following the ? 10 Principles of Retardant Applications (4, 5).

Fire line construction

A fire line is constructed for two purposes: to create a safe strip from which to start burning out to remove fuels between the fire line and advancing fire; and to isolate the burned area from the unburned area. The objective is to create a gap in the flammable materials. Fire line can be constructed using hand tools or mechanized equipment. The width of the fire line is dictated by the fuel, topography and fire behaviour. As a general rule, the fire line width should be at least 1½ times the height of the predominant fuel type. Table 2 provides general guidelines for the width of a fire line.

Use of fire

The use of fire to fight fire is very common in wildland firefighting. There are two types of uses: burning-out and backfiring. Burning-out involves the use of fire to remove the unburned fuels between the fire's edge and the control line. The fire can be used to great advantage in cleaning up and straightening line and widening natural or existing barriers. Backfiring is a special technique which requires extensive planning. Backfiring is used to control or turn a high-intensity fire front that will overrun fire lines if it

cannot be slowed or stopped. The key to a successful backfire is that the main fire draws the backfire to it.

PROTECTIVE DEVICES

To lessen the health effects of air pollution caused by wildland fires, we must first understand the emissions resulting from these fires. The mixture of particles, liquids, and gaseous compounds found in smoke from wildland fire is very complex. The potential for long-term adverse health effects is much greater because of this complex mixture. The particles are known to contain many important organic compounds, some of which condense to form tarry droplets over a substrate material of ash or graphic carbon or both. The size distribution of smoke particles is such that a large percentage are respirable. Gaseous compounds in the air adjacent to fires in association with the particles include carbon monoxide, methane, oxides of nitrogen and many organic compounds, some of which are carcinogens and many of which are irritants. Some semi-volatile compounds have a significant vapour pressure at ambient temperature and pressure which results in a gas phase emission and many of these compounds are important from a health standpoint, but have not been adequately quantified. With the additional data of today, we still do not know what the overall toxicity of smoke is from wildland fires or how this toxicity varies from fire to fire (6). There are few studies which evaluate adverse health effects resulting from exposure to wildland fire smoke. Although many studies have been conducted on smoke constituents, there remains significant uncertainty with regard to the actual effects of that combination of pollutants which characterize wildland fire emissions. However, certain generalisations regarding adverse health effects of smoke and an analysis of the toxicity of the individual chemical compounds found in wood smoke can be useful in evaluating public health risks.

Breysse (7) discusses health hazards associated with smoke. The following information is based on his article and is quoted from the Prescribed Fire Smoke Management Guide, (8).

"Inhalation of smoke from whatever source can cause acute or chronic damage to health. The acute, or immediate symptoms are caused by exposure to high concentrations of smoke over short periods. Manifestations range from irritation of the eyes and respiratory tract to impaired judgement, semiconsciousness, unconsciousness, and even death.

More insidious are repeated exposures to relatively low concentrations. These may result in respiratory allergies, bronchitis, emphysema, and cancer. Chronic health hazards are by far the most significant, because 15 or more years usually pass before the victim is disabled.

Hazards vary with the kind of smoke inhaled. Smoke is a complex mixture whose components depend in part on the type of fuel, its moisture content, additives in the fuel (for example, pesticides sprayed on trees or foliage), and of course, the temperature of combustion. Burning forest fuels discharge hundreds if not thousands of chemical compounds into the atmosphere - including carbon monoxide, total suspended particulates, hydrocarbons, nitrogen oxides, and water vapour. Also released by burning vegetation are complex organic materials which are absorbed in, or on, condensed smoke particles. Penetration of these particles into the lung increases the chemicals' toxicity. Researchers consider particles with diameters of less than 10 µm to be inhalable. Researchers also consider particles with diameters less than 2.5 µm in diameter to be respirable. Over 90 per cent of particulate emissions from forest fires are 10 µm or less in diameter. The difference between the mass of particles produced that are less than 2.5 µm in diameter to the total mass of particulate matter increases proportionally to fire intensity.

In addition, nitrogen oxides and hydrocarbons produced by the fire react together in the presence of sunlight to produce ozone and organic oxidants. Both of these are potent irritants."

A recent study by Sharkey (9) states that smoke from wildland fires contributes to short-term and intermediate health effects. The effects have been shown to be reversible in most cases. Long-term exposure has the potential to cause or exacerbate health problems such as coronary artery disease, chronic obstructive pulmonary disease, and cancer. Individuals with asthma, allergies, or the capacity to develop reactive airways are more likely to be susceptible to the effects of smoke.

The common recommendations made to the general public to lessen the health effects of air pollution are: (i) stay indoors as much as possible if your indoor environment is air conditioned, keep windows and doors closed; (ii) wear respiratory masks if appropriate; and (iii) seek medical advice when called for.

Respiratory masks

The Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) are updating the standards that regulate the use and certification of respirators. Under the new regulations (42CFR Part 84), NIOSH will certify three classes of filters (N, R, and P) with three levels of efficiency (95, 99, and 99.97 per cent) in each class. The efficiency indicates the degree to which the filter removes small (0.3 µm) particulates. N series (not resistant to oil) particulate respirators are for protection from particulates that are free of oil or other severely degrading aerosols. These respirators have no time limitations and are suitable for wildland fire smoke. It should be noted that removing carbon monoxide from the breathing air currently requires converting of CO to CO_2 in an exothermic reaction. The process adds additional breathing resistance, increased respiratory work with the respiratory stimulus of carbon dioxide, and increases heat stress with the breathing of hot air. No currently available device protects the individual from all the hazards in smoke. Home-made or other commonly available masks may provide some relief but will not provide very little in terms of health protection.

Classification and description of respirators by mode of operation

Atmosphere-supplying respirators

A respirable atmosphere independent of the ambient air is supplied to the wearer.

Self-contained breathing apparatus (SCBA)

A supply of air, oxygen, or oxygen-generating material is carried by the wearer. It is normally equipped with full face piece, but may be equipped with a quarter-mask face piece, half-mask face piece, helmet, hood, or mouthpiece and nose clamp.

(i) Closed-circuit SCBA

These devices work with oxygen only, and produce either negative pressure in respiratory-inlet covering during inhalation or positive pressure in respiratory inlet covering during both inhalation and exhalation.

(a) Compressed or liquid oxygen type

It is equipped with a face piece or mouthpiece and nose clamp. High-pressure oxygen from a gas cylinder passes through a high-pressure reducing valve and, in some designs, through a low-pressure admission valve to a breathing bag or container. Liquid oxygen is converted to low-pressure gaseous oxygen and delivered to the breathing bag. The wearer inhales from the bag, through a corrugated tube connected to a mouthpiece or face piece and a one-way check valve. Exhaled air passes through another check valve and tube into a container of carbon-dioxide removing chemical and reenters the breathing bag. Make-up oxygen enters the bag continuously or as the bag deflates sufficiently to actuate an admission valve. A pressure-relief system is provided, and a manual by-pass system and saliva trap may be provided depending upon the design.

(b) Oxygen-generating type

It is equipped with a face piece or a mouthpiece and nose clamp. Water vapour in the exhaled breath reacts with a chemical in the canister to release oxygen to the breathing bag. The wearer inhales from the bag through a corrugated tube and one-way check valve at the face piece. Exhaled air passes through a second check valve/breathing tube assembly into the canister. The oxygen-release rate is governed by the volume of exhaled air. Carbon dioxide in the exhaled breath is removed by the canister fill.

(ii) Open-circuit SCBA

This devices works with compressed air, compressed oxygen, liquid air or liquid oxygen. A bypass system is provided in case of regulator failure except on escape-type units.

(a) Demand type

This type is equipped with a face piece or mouthpiece and nose clamp and with a demand valve that is activated on initiation of inhalation and permits the flow of breathing atmosphere to the face-piece. The demand valve permits oxygen or air flow only during inhalation. Exhaled breath passes to ambient atmosphere through a valve in the face piece. On exhalation, pressure in the face piece becomes positive and the demand valve is deactivated.

(b) Pressure-demand type

This type is equipped with a face piece only. Positive pressure is maintained in the face piece by a spring-loaded or balanced regulator and exhalation value. The apparatus may have provision for the wearer to select the demand or pressure-demand mode of operation; in which case, the demand mode should be used only when donning or removing the apparatus.

Supplied-air respirators

(i) Hose mask

This type is equipped with a face piece, a breathing tube, a rugged safety harness, and a large-diameter heavy-duty non-kinking air-supply hose. The breathing tube and air-supply hose are securely attached to the harness. The face piece is equipped with an exhalation valve. The harness has provision for attaching a safety line.

(a) Hose mask with blower

Air is supplied by a motor-driven or hand-operated blower. The wearer can continue to inhale through the hose if the blower fails. Up to 91 metres of hose length is permissible.

(b) Hose mask without blower

The wearer provides motivating force to pull air through the hose. The hose inlet is anchored and fitted with a funnel or like object covered with a fine mesh screen to prevent entrance of coarse particulate matter. Up to 23 metres of hose length is permissible.

(ii) Air-line respirator

Respirable air is supplied through a small-diameter hose from a compressor or compressed-air cylinders. The hose is attached to the wearer by a belt or other suitable means and can be detached rapidly in an emergency. A flow-control valve or orifice is provided to govern the rate of air flow to the wearer. Exhaled air passes to the ambient atmosphere through a valve(s) or opening(s) in the enclosure (face piece, helmet, hood, or suit). Up to 91 meters of hose length is permissible.

There are three types of air-line respirators: continuous-flow class, demand type and pressure-demand type.

(a) Continuous-flow class

It is equipped with a face piece, hood, helmet, or suit. At least 115 liters of air per minute to tight-fitting face pieces and 170 liters of air per minute to loose-fitting helmets, hoods, and suits is required. Air is supplied to a suit through a system of internal tubes to the head, trunk, and extremities through valves located in appropriate parts of the suit.

(b) Demand type

This type is equipped with a face piece only. The demand valve permits flow of air only during inhalation.

(c) Pressure-demand type

This type is equipped with a face piece only. A positive pressure is maintained in the face piece.

(iii) Combination air-line respirators with auxiliary self-contained air supply

These respirators include an air-line respirator with an auxiliary self-contained air-supply. To escape from a hazardous atmosphere in the event the primary supply fails to operate, the wearer switches to the auxiliary self-contained air supply. Devices approved for both entry into and escape from dangerous atmospheres have a low-pressure warning alarm and contain at least 15-minutes self-contained air supply.

Air-purifying respirators

Ambient air, prior to being inhaled, is passed through a filter, cartridge, or canister which removes particles, vapours, gases, or a combination of these contaminants. The breathing action of the wearer operates the nonpowered type of respirator. The powered type contains a blower - stationary or carried by the wearer - which passes ambient air through an air-purifying component and then supplies purified air to the respirator-inlet covering. The nonpowered type is equipped with a face piece or mouthpiece and nose clamp. The powered type is equipped with a face piece, helmet, hood, or suit.

(i) Vapour- and gas-removing respirators

It is equipped with cartridge(s) or canister(s) to remove a single vapour or gas (for example: chlorine gas), a single class of vapours or gases (for example: organic vapours), or a combination of two or more classes of vapours or gases (for example: organic vapours and acidic gases) from the air.

(ii) Particulate-removing respirators

It is equipped with filter(s) to remove a single type of particulate matter (for example: dust) or a combination of two or more types of particulate matter (for example: dust and fume) from the air. The filter may be a replaceable part or a permanent part of the respirator. The filter may be of the single-use or the reusable type.

(ii) Combination particulate- and vapour- and gas-removing respirators

It is equipped with cartridge(s) or canister(s) to remove particulate matter, vapours, and gases from the air. The filter may be a permanent part or a replaceable part of a cartridge or canister.

(iii) Combination atmosphere-supplying and air-purifying respirators

They provide the wearer with the option of using either of the two different modes of operation: (i) an atmosphere-supplying respirator with an auxiliary air-purifying attachment which provides protection in the event the air supply fails; or (ii) an air-purifying respirator with an auxiliary self-contained air supply which is used when the atmosphere may exceed safe conditions for use of an air-purifying respirator.

Respiratory protective equipment

The basic purpose of any respirator is to protect the respiratory system from inhalation of hazardous atmospheres. Respirators provide protection either by removing contaminants from the air before it is inhaled or by supplying an independent source of respirable air.

Air-purifying respirators

Ambient air, prior to being inhaled, is passed through a filter, cartridge, or canister which removes contaminants. Different filters are required to remove different contaminants.

(i) Nonpowered air-purifying respirator

The breathing action of the wearer operates the nonpowered type of respirator. Equipped with a tight-fitting face piece and filter(s), the respirator is secured to the face by means of a strap or harness. The wearer draws air through the filters during inhalation.

The dust mask is a single-use respirator generally approved only for nuisance dusts such as cement and hay dusts. These respirators should be discarded when resistance to breathing becomes excessive.

The half-mask and full face piece respirators provide greater protection than the dust mask because their design allows for a better fit. These respirators provide protection against dusts, mists, fumes, vapours, gases, or any combination of these contaminants depending on the type of filter used. The full face piece respirator provides the greatest degree of protection and protects the eyes as well.

Many different filter elements are available. Vapour cartridges should be changed when odours "breakthrough", and are noticeable inside the mask. Some chemicals, such as mercury, have no odour and require a special filter that has an end-of-service-life indicator. It is important to choose the right filter or combination of filters for a given job.

(ii) Powered air-purifying respirator (PAPR)

The powered type contains a portable blower which pushes ambient air through a filter and then supplies purified air to the wearer. The powered type is equipped with a tight-fitting face piece or a loose-fitting helmet, hood, or suit. The figure shows a tight-fitting face piece which provides a higher degree of protection than a loose fitting hood or helmet.

Atmosphere-supplying respirators

A respirable atmosphere, independent of the surrounding air, is supplied to the wearer. Atmosphere-supplying respirators provide a greater level of protection than air-purifying respirators because they do not rely on a filtering mechanism to provide clean air.

(i) Self-contained breathing apparatus (SCBA)

A supply of air, oxygen, or oxygen-generating material is carried by the wearer. The device is normally equipped with a full face piece, but may be equipped with a half-mask face piece, helmet, hood, or mouthpiece and nose clamp.

(ii) Air-line respirator

Respirable air is supplied through a small-diameter hose from a compressor or compressed air cylinder. The hose is attached to the wearer by a belt and can be detached rapidly in an emergency. A flow-control valve or orifice is provided to govern the rate of air flow to the wearer. Exhaled air passes to the ambient atmosphere through a valve or opening in the enclosure (face piece, helmet, hood, or suit).

(iii) Breathing air quality

Compressed air, compressed oxygen, liquid air, and liquid oxygen used for respiration shall be of high purity. Oxygen shall meet the requirements of the United States Pharmacopoeia for medical or breathing oxygen. Breathing air shall meet at least the requirements of the specification for Grade D breathing air (10). A compressor used to supply breathing air shall be a breathing air-type compressor. Compressors shall be constructed and situated so as to avoid entry of contaminated air into the system and suitable in-line air-purifying sorbent beds and filters installed to further assure breathing air quality.

Respirator programme equipment

Respirator selection

Respirators will be selected by a qualified safety and health professional. The following factors shall be taken into account when selecting the proper respirator:

Characteristics of hazardous operation or process

- Hot operations: welding, chemical reactions, soldering, melting, moulding and burning
- Liquid operations: painting, degreasing, dipping, spraying, brushing, coating, etching, cleaning, pickling, plating, mixing, galvanizing and chemical reactions
- Solid operations: pouring, mixing, separations, extraction, crushing, conveying, loading, bagging and demolition.
- Pressurized spraying: cleaning parts, applying pesticides, degreasing, sand blasting and painting
- Shaping operations: cutting, grinding, filing, milling, moulding, sawing and drilling

Nature of hazard

(a) Gaseous contaminants

- Inert gases (helium, argon, etc.), which do not metabolize in the body but displace air to produce an oxygen deficiency.
- Acid gases (SO_2, H_2S, HCl, etc.) which are acids or produce acids by reaction with water.
- Alkaline gases (NH_3, etc.), which are alkalies or produce alkalies by reaction with water.
- Organic gases (butane, acetone, etc.), which exist as true gases or vapours from organic liquids.

- Organometallic gases (tetraethyl lead, organophosphates, etc.), which have metals attached to organic groups.

(b) Particulate contaminants

- Dusts which are mechanically generated solid particulates (0.5 to 10 µm)
- Fumes which are solid condensation particles of small diameter (0. 1 to 1.0 µm)
- Mists which are liquid particulate matter (5 to 100 µm)
- Smoke which is chemically generated particulates (solid and liquid) of organic origins (0.01 to 0.3 µm)

Concentration of contaminant

(a) Immediately dangerous to life and health (IDLH)

These are conditions that pose an immediate threat to life or health or conditions that pose an immediate threat of severe exposure to contaminants, such as radioactive materials. Air-purifying respirators are never to be used in IDLH atmospheres.

(b) Short term exposure limit (STEL)

This refers to an exposure limit that is the maximum concentration to which workers can be exposed for a period of up to 15 minutes with no detrimental effects.

(c) Threshold limit value (TLV)

These are the upper exposure limits of airborne concentrations that are accepted as safe for employees to be exposed to on a day-in, day-out basis. The time weighted average (TWA) is the maximum concentration that employees working eight hours per day, forty hours per week can be exposed to with no adverse health effects.

Respirator design

(a) NIOSH/MSHA-approved respirators

All respirators used on campus must be approved by the National Institute of Occupational Safety and Health (NIOSH) or the Mine Safety and Health Administration (MSHA). NIOSH-approved respirators are labelled with a NIOSH ID number. Filters are labelled with the type of hazard the respirator is approved to protect against. Respirator replacement parts are labelled with part numbers and only approved replacement parts should be used. Any modifications that do not use approved replacement parts void the approval of the respirator.

(b) Enclosure design (Figure 4)

- Tight-fitting units: full face piece and half-mask
- Loose-fitting units: hood, helmet, and enclosed suit

Worker activity

- Duration of job
- Physical exertion: light, medium, heavy
- Temperature of job area

Training

Each wearer shall be given initial training by the ORCBS covering the following topics:

- respiratory hazards and health effects;
- how respirators work;
- engineering controls vs respirator use;
- medical evaluation;
- respirator selection rationale;
- fit testing;
- respirator donning & fit checks; and
- maintenance, cleaning and storage.

MITIGATION MEASURES

The knowledge of how wildland fire burns, occupancy, cultural use of fire, emission factors and rates, and dispersion are all critical in developing mitigation strategies. The following mitigation measures will focus on (i) emissions factors and rates; (ii) control strategies for agricultural burning; (iii) smoke monitoring and evaluation; and (iv) wildfire smoke emergency action plan guidance. Because most of the adverse impacts from wildland fire are caused by particulate matter in the smoke under adverse meteorological conditions, we must be able to estimate the amount of smoke that will be produced. The answer can be derived via two numerical terms, emission factor and emission rate (11).

Emission factors and rates

An emission factor for particulate matter (EFp) is defined as the mass of particulate matter produced per unit mass of fuel consumed; ie. g/kg. Emission factors reported in the literature for forest fuels range from four to 19 g/kg, depending on fuel type and arrangement and the manner of combustion. In general, fuels consumed by flaming combustion produce much less particulate matter than fuels consumed by smouldering combustion. Suggested EFp values for generalized fuels are listed in Table 3. These values can be used as a guide to develop regional expressions of the most common fuel and fire types. They can also be used by local air quality agencies that need emission inventory information. The emission factors are generalised estimates based on research data, combustion fundamentals and scientific judgement. They should be modified as needed in regional supplements to this guide in accordance with the latest information on fuels, firing technique, smoke particle size, etc.

Emission rate is defined as the amount of smoke produced per unit of time (g/min). Down wind concentrations of particulate matter in smoke are related directly to the emission rate at the fire source; the emission rate, in turn, is affected by the amount of fuel being burned, the rate at which it burns, and the emission factor of the fuel.

The amount of fuel actually consumed by a fire is called available fuel, and this fuel may be consumed by flaming or smouldering combustion. The unit of measure is usually in kg/ha. The land manager can make better estimates of emission rates from a fire if the amount of fuel consumption in each of the two types of combustion is known. Available fuel can be

estimated before ignition and is usually less than the total fuel loading. The rate at which fuel is consumed can be expressed as the area burned per unit of time (ha/min). The combustion rate can be calculated for backing or head fires in natural or in activity fuels.

Once estimates of the available fuel, the combustion rate, and the emission factor (g/kg) are made, the emission rate can be calculated by the equation:

Emission Rate (g/min) = available fuel (kg/ha) x combustion rate (ha/min) x emission factor (g/kg)

The emission rate is used to drive models that predict concentrations of particulate matter. These models are used to assess the impact of smoke on visibility in sensitive areas such as cities, highways, and airports.

Control strategies for agricultural burning

Avoidance, dilution, and emission reduction are ways to manage smoke from wildland fires. Avoidance is a strategy of considering meteorological conditions when scheduling fires in order to avoid incursions into smoke sensitive areas; for example, a populated area where any noticeable impact is objectionable. Dilution involves controlling the rate of emissions or scheduling for dispersion to assure a tolerable concentration of smoke in designated areas. Emission-reduction techniques minimize the smoke output and decrease the contribution to regional haze as well as intrusions into designated areas. One way to reduce emissions is to treat fuels and prepare seedbeds using treatments other than fire, including the option of no treatment.

Avoidance

Pollution can often be prevented by scheduling fires during conditions that make intrusions of smoke into smoke-sensitive areas unlikely. This approach is particularly useful when few burns need to be scheduled. The most obvious way to avoid pollution impacts is to burn when the wind is blowing away from all smoke sensitive areas. Most fires have an active burning period and a residual period. Wind direction during both periods must be considered. At night, drainage winds can carry smoke toward smoke sensitive areas. Residual smoke is especially critical at night.

A layer of stable air such as a temperature inversion, can isolate smoke originating above the stable layer from receptors below. In mountainous terrain, burning should occur when the stable air layer is below the elevation of the prescribed fire and other conditions are favourable. This is true even at night, except that a stable layer may not eliminate entertainment of smoke by drainage wind.

Dilution

Smoke concentration can be reduced by diluting smoke through a greater volume of air, either by scheduling during good dispersion conditions or burning at slower rates (burning smaller or narrower strips or smaller areas). Caution: Burning at slower rates may mean that burning continues into the late afternoon or evening, when atmospheric conditions become more stable.

The mixing-layer depth is the thickness of the layer of air into which the smoke is eventually diluted by atmospheric mixing. This depth depends on the stability of the lower atmosphere. Stability conditions favourable for burning are a weak or no-inversion condition at night and warm unstable air in the afternoon. A high-intensity fire may overcome some shallow low-level stable layers. The time of day at which ignition occurs is also an important consideration because mixing height and transport wind speed are likely to change during the day and night. Generally, a burn early in the day encounters improving ventilation rates; an evening burn encounters deteriorating ventilation rates.

Emission reduction

Emission reduction can be an effective control strategy for attaining smoke management objectives. Effective firing techniques and proper scheduling can minimize the smoke output per unit area treated. For example, backing fires minimize the inefficient smouldering phase of a prescribed fire. Scheduling prescribed fires for periods when duff and larger fuels are too wet to burn will assist in reducing emissions. Removing large material also reduces emissions since less smoke will be put into the air and less residual smoke will be present.

Techniques to minimise smoke production and impact

Prescribed burning, though necessary for accomplishing certain land use objectives, can degrade air quality. The practice of prescribed burning carries with it an obligation to eliminate or minimize any adverse environmental effects, including those caused by smoke. The following guidelines will help reduce impacts.

To have clear objectives

One should be clear of the land use objectives which consider the impact of smoke on the total environment - both on-site and off-site.

To obtain and use weather forecasts

Weather information and fire-weather forecasts are available. Be sure to use them to obtain forecast information. This weather information is needed to determine what will happen to the smoke, as well as to determine the behaviour of the fire.

Not to burn in special situations

When air stagnation advisories are in effect, during pollution episodes, or when temperature inversions exist, prescribed burning should not take place. Under such conditions, smoke tends to stay near the ground and will not readily disperse. Many fire-weather forecasters include this information in their regular forecasts or will provide it if requested.

To comply with air pollution control and smoke management regulations

When developing the prescription, the air pollution control regulations should be considered. Procedures for compliance may require notification to air pollution control authorities having jurisdiction in the area prior to igniting a prescribed fire.

To burn when conditions are good for rapid dispersion

If the atmosphere is unstable, smoke will rise and dissipate. A fire weather forecaster can help to determine whether the direction and volume of smoke will affect public safety on highways and public health in populated areas. If near or upwind of smoke-sensitive areas, special caution is necessary. Prescribed burning should be done when transport wind will carry smoke away from heavily travelled roads, airports, and populated areas.

To notify the local fire-control office, smoke management monitoring unit, nearby residents, and adjacent landowners

It is a requirement in most areas that all concerned parties should be informed that the prescribed burn is not a wildfire. It is important to get advance notice of any adverse public reaction. Test fires or helium-filled balloons to assess transport winds for smoke behaviour can be used. Test fires should be set in the area proposed for burning, away from roads, or other 'edge' effects.

To burn under favourable moisture conditions

Smoke can be reduced by selecting the correct combination of fuel moistures and burning only those fuels that must be removed to meet the burn objective. If the objective is to remove fine and intermediate fuels to reduce wildfire hazard, the burn should be accomplished when the relative humidity is low enough for fine and intermediate fuels to burn readily and larger fuels and the duff are wet. If the objective is to expose the mineral soil, the burn should be conducted when the larger fuels and the duff are dry enough to burn with a minimum of smouldering.

To use backing fires when applicable

Backing fires, with their slow rate of spread and relatively long residence time, cause a higher fraction of the fuel to be consumed in the flaming stage of combustion rather than in the smouldering stage. Since total

smoke production per unit of fuel burned is considerably less during flaming combustion, backing fires favour lower total smoke production.

To burn in small blocks when appropriate

The larger the area is being burned, the more visibility is reduced downwind as higher concentration of particulates are emitted. It may be better, however, to burn all the area needed when weather conditions are ideal for rapid smoke dispersion.

To mop-up

In order to reduce impacts of residual smoke on health and visibility, burn-out and early mop-up should be achieved.

To expand the burning season

An extended burning season may improve air quality because conditions may be more conducive to reduce smoke production and better lofting and smoke dispersion. The total impact on the air resource could thus be spread over a longer period, thereby reducing the possibility of a heavy smoke load during traditional burning seasons.

To be cautious when burning at night

Predicting smoke drift and visibility is more difficult at night. Winds may lessen or die out completely, and smoke will tend to stay near the ground. Although burning at night may help achieve other objectives, it may aggravate smoke management problems.

To have an emergency plan

The control of traffic on nearby roads if wind direction changes, the construction of control lines and the termination of prescribed burn if it is not burning according to plan or if weather conditions change are emergency measures to be taken.

To minimise emission

Dozer piles may produce fewer emissions than windrows due to more efficient combustion. Cover the tops of hand piles if there is no intention to burn them until surrounding fuels are wet or snow covered. Covered piles are drier, ignite more easily, are consumed more quickly, and produce less smoke than uncovered piles. Soil should be kept out of dozer piles and windrows by using take-type blades.

WEATHER INTERACTIONS

As weather patterns change, so does smoke behaviour. General pressure patterns and fronts have pronounced effects on transport wind and stability characteristics of the atmosphere and affect how well the smoke will disperse.

Fronts

Frontal activity plays an important role in smoke behaviour. Smoke movement and dispersion differ drastically with the type of front. The speed of an approaching front is an important consideration when executing burns. A slow moving front results in steadier wind speeds and gradually changing wind directions. A rapidly moving front has more sudden changes in wind speed and direction. By knowing how long a burn will last and how long a wind condition will exist, the likelihood of success in keeping smoke out of a sensitive area can be evaluated.

Cold fronts

It is important to know the type of front affecting an area. Wind and stability characteristics associated with different types of fronts vary considerably. Cold fronts typically have rapid wind shifts and gusty winds. Behind a strong cold front, the air mass is generally unstable, which

facilitates smoke dispersion and good visibility. Smoke impacts behind a strong cold front tend to be short, but high concentrations may occur locally. For some regions, it may be advantageous to burn just before passage of a cold front because smoke could be vented into a cloud layer and thus not create unacceptable smoke layers over sensitive areas. Control problems may be associated with strong cold-fronts, however. Dispersion patterns are not nearly so good behind weak, slow moving cold fronts. The inherent stability associated with the cold surface air mass often traps smoke near the ground. In a strong cold front, this effect is largely overcome by high surface wind speeds. In a weak cold front, the lower wind speeds do not overcome this effect.

Warm fronts

Burning associated with warm frontal activity can result in high smoke concentrations for long periods of time. Wind speeds are typically lighter and shifts in direction are more gradual compared to a cold front. This results in a given area being downwind of a burn for a longer period. Also, as a front approaches, upper stable layers descend, resulting in a lower mixing height and a smaller mixing volume for smoke. Normally, visibility decreases as rain and fog occur ahead of the front. Smoke, in the decreasing volume of air, will combine with the fog and rain to give extremely low visibility. Burning should be timed so that significant quantities of smoke are not present during the hours before frontal passage, when visibility could normally be expected to be reduced by rain or fog. Conditions can be expected to improve somewhat as the front passes, but overall dispersion would still be limited due to light wind speeds.

Stationary fronts

The variable and changing wind conditions that characterise stationary fronts make forecasting smoke movement difficult. Light wind generally blows in opposite directions on either side of the front. The front meanders, resulting in variable transport winds with no sustained or predictable directions. Poor mixing and dispersion can be expected near the front with light winds, precipitation, and reduced visibility. Burning should be limited because smoke will intensify frontal characteristics and naturally occurring poor visibility.

Pressure patterns

As discussed earlier, a key to managing smoke is evaluation of which way the wind will blow. Pressure patterns determine the wind fields and affect stability. This occurs because temperature affects pressure. As temperature changes, either diurnally, as a result of weather systems, or seasonally, so do pressure patterns, wind, and stability.

Coastal and mountainous areas are especially susceptible to diurnal changes in pressure and wind due to differential heating, which causes sea breezes and mountain-valley winds. These pressure changes completely reverse wind direction which means that a burn starting out with smoke blowing away from a sensitive area may end up with smoke blowing toward the area.

Another important consideration is the type of pressure system that is affecting the burn area. A high-pressure system (or ridge) is one of stable air, light wind, and poor dispersion. Generally, burning under such conditions should be limited, as should burning under forecast conditions of a rapidly building high pressure. When a high pressure is rapidly building, one could expect rapid stabilization of the air mass and trapping of smoke at low levels.

A low-pressure system (or trough) represents a more unstable atmosphere. Wind fields are stronger with a low pressure system than under a high pressure system, which results in better dispersion. Smoke impacts tend to be much briefer, if they occur at all, than they would be under a high-pressure system.

The frequency of highs and lows varies considerably with seasons. Burning opportunities could be enhanced by taking advantage of known seasonal variations in stability and dispersion. Fire-weather forecasters, local meteorologists, and the National Climatic Center provide valuable assistance in supplying information for planned burning activity.

A user-oriented computer system allows managers to quickly and easily analyse climatological data for the purpose of predicting the probable occurrence of desired conditions for prescribed fire (12).

Wind

The obvious first consideration in evaluating whether a burn will impact a sensitive area is to determine which direction the wind is blowing or will blow. Both the surface wind and wind aloft will affect fire behaviour.

Surface wind

Surface wind can result from general large-scale weather patterns or from local effects such as the sea breeze and mountain-valley flows mentioned previously. Local wind patterns are common in complex terrain or near water-land interfaces. They may extend for short distances or for distances up to 160 kilometers. The winds vary as to time of onset and decline in strength and depth, depending on aspect, time of the day, time of the year, and slope. Down slope or down valley winds can also affect the stability of the air mass by bringing cooler air to valley bottoms and thus forming inversions. Local winds can be reinforced by the general wind field or destroyed by the general wind depending on the strength and direction of each. For example, a strong general wind field blowing in the opposite direction of a local wind would negate the local wind. Information about local wind fields can probably be obtained from meteorologists familiar with the local weather or from meteorological publications.

Large-scale or general surface wind patterns are those associated with fronts, troughs, and ridges. The effects of these weather systems on wind fields are usually easily determined by reading weather forecasts. Planning and executing burns can be enhanced by taking advantage of the classic wind changes associated with the weather systems.

Understanding surface wind characteristics, either from local wind or general wind, is important to smoke management. Smoke from the smouldering stage of a burn will be caught in the surface wind. The manager should plan this burn so the smouldering phase does not occur at the same time of the day as a predictable but unfavourable change in wind direction. To avoid sensitive areas, lengthy low-intensity burns may have to be accomplished during periods when no significant wind changes are expected. Local winds will transport smoke to various locations at different times of the day and night.

Another point to consider is that strong surface winds tend to bend plumes over, thereby not allowing maximum height development. In such

cases, the smoke produced from the convective and non-convective phases will be under the influence of surface wind patterns.

Upper winds

Upper winds are also important in smoke management. The upper wind field is not as prone to local effects as is the surface wind. Sudden changes in wind speed or direction (wind shear) as a result of terrain influences, stability changes, or frontal boundaries can profoundly affect fire behaviour and plume rise. Wind-shear layers can be as effective as stable layers in inhibiting or limiting plume rise.

Another concern with upper winds is that, although surface wind direction may be acceptable in keeping smoke from impacting a sensitive area, upper winds from a different direction may blow smoke over or through a sensitive area.

The smoke manager must fully understand the total wind pattern that is affecting the area during the burn as well as the wind that will be affecting the area around the burn during and after the burn. Initial success at keeping smoke away from sensitive areas will be overshadowed by a failure to recognize wind shifts which result in impacts on sensitive areas.

Dispersion

Dispersion refers to those processes within the atmosphere which mix and transport pollutants away from a source. The concentration of smoke experienced at down wind locations greatly depends upon weather conditions at the fire site and on the downwind smoke path.

Atmospheric dispersion mainly depends on three characteristics of the atmosphere: atmospheric stability, mixing height, and transport wind speed. Atmospheric stability is a measure of the tendency for vertical mixing to take place in the atmosphere. Mixing height is that height through which the mixing process is relatively complete. Transport wind speed is the average diluting wind speed within the smoke-laden layers of the atmosphere.

Stability

The effect of atmospheric stability on plume dispersion is not always fully appreciated or understood by prescribed burners. Stability affects the

mixing of smoke during the convective phase as well as during the non-convective phase of the burn.

Stable atmosphere

During the main convective phase in a stable atmosphere, smoke will at best rise to some altitude and remain there. More likely, the smoke will start settling to the lowest levels of the atmosphere, and high smoke concentrations will result. The smoke from the smouldering phase will remain near the surface and be moved around by the surface wind.

A poor time to burn is when a stable, high-pressure area is forming with an associated subsidence inversion. The subsiding air not only creates a more stable atmosphere but also one in which mixing volume decreases with time. It is often stated that supplying enough heat by burning can break through an inversion, thus eliminating the smoke as a problem. However, only under special circumstances does this occur, (i) if the inversion is already being destroyed naturally; (ii) if the burn is very close to the inversion; and (iii) if the fire is extremely large and hot. The third circumstance is contrary to good smoke management practices because a hot fire burning over a large area is likely to have significant levels of non-convective smoke which would not disperse well under stable conditions unless the fuels were flashy (fine) with little residual burning. Stable conditions are readily apparent to the observant manager. Indicators are cloudless nights with light winds; hazy conditions and reduced visibility; clouds with a flattened or layered appearance; and light winds.

Unstable atmosphere

An unstable atmosphere tends to have cumulus clouds with good vertical extent, good visibility, strong, gusty winds, and hot, clear days (without any low-level subsidence inversions). Unstable air masses tend to aid good mixing of smoke plumes with little, if any, long-term high volumes of smoke. The best overall mixing is not, however, necessarily associated with the most unstable atmosphere.

For most prescribed burning, a slightly unstable atmosphere tends to produce an optimum dispersion pattern, particularly when surface wind speeds are moderate.

Neutral atmosphere

A neutral atmosphere is one in which vertical mixing and plume rise are neither enhanced nor suppressed. The level at which a parcel of smoke reaches equilibrium with the surrounding air is the level at which it remains. Cloudy conditions with moderate wind speeds are indicators of neutral atmospheric conditions. Burning activity can generally be planned under neutral stability conditions as long as the wind direction is away from a sensitive area.

Relative humidity

Other than its relationship to fine fuel moisture and subsequent fire behaviour, the major impact of relative humidity is on visibility. As relative humidity increases, natural visibility may decrease due to increased water vapour in the air.

The significance of relative humidity to prescribed burning is that, as smoke particles are added to the atmosphere, they combine with the water vapour at these higher humidities to significantly reduce visibility. Smoke particles can also be the stimulus for fog or cloud formation, which reduces visibility. Reduced visibility can negatively affect airport operations and highways. To reduce the impact of smoke on visibility sensitive areas, prescriptions should be prepared with the lowest feasible relative humidity consistent with fire control. Frontal passage, time of day, and elevation will affect relative humidity.

Mixing height

Atmospheric mixing height is that height through which relatively vigorous mixing takes place. A mixing height exists only when the lower atmosphere is unstable or neutral. Above this height is a layer of stable air which acts to suppress vertical mixing. The result is as if a 'lid' were placed upon the atmosphere, above which smoke penetrates very slowly. The higher this 'lid'. the better the conditions for smoke management because a reasonably deep layer of vigorous mixing is needed to maintain low background concentrations in the lower atmosphere. Even if a prescribed fire emits low quantities of smoke, it may aggravate air quality problems when mixing height remains low.

During stable atmospheric regimes, there is no mixing height; that is, there is no height below which dispersion processes are rapid. Because high smoke concentrations are maintained for extended distances in such conditions, no burning should occur. Smouldering fires should be extinguished.

Visibility protection

Visibility protection is an important goal of smoke management. At high relative humidities, a small concentration of smoke can trigger fog formation. On roadways, high humidity combined with smoke has led to tragedy. Poor visibility of this nature is caused by condensation of atmospheric moisture on smoke particles, resulting in a greatly increased number of particles of the size range which block out light. This condensation process begins for certain types of airborne particles at relative humidities around 70 percent. As the humidity increases to nearly 100 percent, condensation is much more likely. For southern regions of the United States, highway visibility management has been addressed in a publication (13) which cites a method that can be used to calculate visibility distance based on total suspended particulate matter concentrations during dry weather.

Long duration fires

Long-duration fires typically burn under all types of meteorological conditions and can grow to fairly large sizes (400 to 6,000 hectares). Thus, the potential exists for these fires to produce a large volume of smoke. This smoke can affect smoke-sensitive areas, cause health-related problems to people with respiratory ailments, impair the ability to detect new fires, and saturate local air sheds. The prediction of future smoke episodes, though difficult, is needed to:

- develop contingency plans to limit smoke production if the need arises (for example, to contain a portion of the fire with a fire line to restrict further spread);
- establish and maintain close communications with local air quality groups regarding the status of such fires;
- monitor smoke plumes as appropriate to provide some advance warning of deteriorating air quality conditions; and
- inform the general public of the status of such fires, including smoke management contingencies, through the local press, radio, and television.

Benefits resulting from smoke management include:

- reducing the risk of accidents on highways and other sensitive areas;
- reducing the risk of liability suits;
- reducing the risk of a "regulatory approach" replacing voluntary approaches on a local level;
- improving public health and welfare;
- reducing intrusions in smoke sensitive areas;
- improving visibility; and
- reducing public complaints.

SMOKE MONITORING AND EVALUATION

As a first step, managers must develop and maintain an awareness of air quality monitoring techniques. This awareness will facilitate an evaluation of programme effectiveness and effective communication with local air quality personnel. Familiarity with air quality monitoring does not require having an elaborate array of monitoring instruments or hiring a monitoring contractor to evaluate burns. The following issues are important:

- understanding of air monitoring concepts and instrumentation;
- development of a smoke management/monitoring component in conjunction with the plan for prescribed burning; and
- development of a systematic and objective method to evaluate the effectiveness of smoke management efforts.

Ambient air quality monitoring for air pollution standards

From a regulatory perspective, air quality is judged against legally adopted national or state ambient standards or both. In most cases, a time-averaging term is specified, such as hourly, 8-hourly or an annual mean. It is fairly well accepted that in prescribed burning, particulate matter (visible smoke) is the pollutant with the highest potential for violating standards, specifically, the Secondary National Ambient Air Quality Standard (24-hour standard) for total suspended particulate (TSP). In an area subject to inversions, it is vital to know 'the details of an episode-control plan, the legal authority, the monitoring and surveillance systems.

Fire emissions inventory

Fire emission inventory and source monitoring is a difficult and expensive process, and every agency cannot be expected to have the resources to develop their own source monitoring programme. It is essential, however, to develop a database that answers the questions where, when, and how much fuel is burned.

Overview of smoke monitoring methods in use by air quality regulatory agencies

Particulate matter is a difficult substance to monitor; however, a number of monitoring instruments and methods have been developed and are being used today. The following sections describe a few of the air quality surveillance methods and monitors available and in use by air quality agencies for visibility and smoke monitoring.

High-volume (Hi-Vol) samplers

The high-volume sampler is the most widely used particulate matter monitor and is the standard reference method used by US EPA and states to monitor compliance with the National Ambient Air Quality Standard for TSP. The Hi-Vol is a large filter connected to a vacuum type motor/blower and a timer. Hi-Vols are used as a source monitoring device and have little utility in operational prescribed fire programmes. This is because a Hi-Vol is an "ambient" monitor and it presumes sampling a well-mixed air sample representative of a very large area surrounding the sample site. A Hi-Vol near a single source will be biased by that source and monitoring results will not be representative of the designated area.

When USEPA began deliberation of adopting a new particulate standard, new monitors were rapidly developed. These are known as dichotomous or size selective inlet samplers. In general, they operate like Hi-Vols except that the sampler inlets are designed to screen out particles larger than 10 µm.

Real-time particulate monitors

Air pollution agencies are required to continuously monitor particulate levels during air pollution episodes to protect public health. These methods include beta gauge monitors, TEOMs (Tappered Element Oscillating Microbalance) and nephelometers. Beta gauge monitors and TEOMs instruments measure particulate concentrations by detecting the reduction of beta rays as they pass through the sample or by change of oscillation frequency, respectively. Nephelometers measure the amount of light scattering associated with fine particles in the atmosphere that reduce visibility. They can be used as an indication of TSP concentrations if a nephelometer/Hi-Vol correlation can be established.

Visibility monitors

The teleradiometer is an instrument that measures light intensity or brightness over a given distance or path length, which may be 50 or 60 km or more. Nephelometers are also used as visibility monitors.

Although teleradiometers and nephelometers are used primarily by air resource management agencies, land management agencies are also beginning to use them. Land managers have generally used this equipment in research studies and not as an operational tool, but there is a trend in using visibility data to assess the impact of air pollution sources, such as new industrial facilities, on the visibility resource of Class I areas.

Overview of smoke monitoring methods in use by land managers

Visual estimates

This is the most common method in use. Some agencies use a test fire coupled with visual observations to ensure that the smoke plume does not affect a smoke-sensitive area. Although visual methods are subjective and limited, they are still very useful.

Photo documentation

Photo points are established adjacent to project locations. A permanent record of plume height, colour, and direction is obtained. This method has proven valuable in documenting responses to public complaints.

Aircraft plume tracking

Aircraft tracking is a relatively expensive method presently in limited use by researchers and some regulatory agencies. Aircraft are being used to identify violations of air quality/smoke management regulations and to verify forecasts.

Balloons

Fire managers have reported using small helium-filled balloons to determine mid-level wind direction to ensure that their smoke does not impact any smoke-sensitive areas.

Smoke dispersion prediction systems

Single fires, flat terrain

Under these conditions, smoke dispersion can be predicted using techniques that are described in the Southern Forestry Smoke Management Guidebook (13). The outputs of this system allow the manager to decide whether concentrations of TSP are above or below selected standards. Inputs include some information about the meteorological conditions (wind speed, direction, and cloud cover) at the burn site. This information is used to calculate potential smoke concentration downwind. The calculations are based on assumptions that the measured wind characterizes the path followed by the smoke. This assumption is rarely correct when the fire is located in or near mountain terrain or coastal locations.

Smoke screening process

This is a computerised data base that includes weather forecasts as well as locations of smoke-sensitive areas. Users input information such as location and magnitude of planned fires. They receive information about the potential of the fire or fires to cause visual impacts on any smoke sensitive areas. The automated system uses the Weather Service as well as local meteorological data and diffusion models which predict downwind concentrations.

Topographic air pollution analysis system (TAPAS)

TAPAS is a system of models for predicting the dispersion of air pollution over flat and mountainous terrain. Variables of topography, wind speed, and direction are used to model plume direction and dispersion to predict ground level concentrations of smoke. Because the system does not include any emission models, the manager will require some knowledge of relationships between fire and emissions. TAPAS currently operates on the Colorado State University computer system. Documentation and more information is available from the Rocky Mountain Experiment Station, Fort Collins, Colorado (14).

Selected smoke management glossary

This glossary is a compendium of terms used in the operation of smoke management programmes. Terms included are those used in the fields of meteorology, air pollution and forestry.

Aerosol

A colloidal system in which the dispersed phase is composed of either solid or liquid particles in which the dispersion medium is some gas, usually air.

Air contaminant

Dust, fume, gas, mist, odour, smoke, vapour, soot, pollen, carbon, acid or particulate matter or any combination thereof.

Air mass

A widespread body of air having approximately the same characteristics of temperature and moisture content throughout its horizontal extent. In addition, the vertical variations of temperature and moisture are approximately the same over its horizontal extent.

Air pollution

The general term alluding to the undesirable addition to the atmosphere of substances (gases, liquids, or solid particles) either that are foreign to the 'natural' atmosphere or are in quantities exceeding their natural concentrations.

Air pollution alert

A statement issued by an air quality regulatory agency due to high measured concentrations of pollutants. The alert remains in effect until monitoring shows a decrease in pollutant levels. Should conditions worsen, air pollution warnings and emergencies may be issued. At each stage (alert, warning and emergency) additional emission restrictions are put into effect so as to not exacerbate the situation. Essentially, at the emergency level all industrial activities and vehicle usage stop. (Below in the text).

Air pollution potential

The relative ability of the atmosphere to dilute and transport pollutants. A high potential per unit of pollution results from low dilution rates and little transport by the wind.

Air quality

The composition of air with respect to quantities of pollution therein; used most frequently in connection with "standards' of maximum acceptable pollutant concentrations. Use instead of ‘air pollution’ when referring to programmes.

Air quality maintenance area (AQMA)

An area that has been identified by an air quality regulatory agency to have the potential for exceeding any federal or state ambient air quality standard due to projected growth and development.

Air quality model

Mathematical or quantitative representation or simulation of air quality processes; e.g. emission models, receptor models or air quality dispersion models.

Air stagnation advisory (ASA)

A statement issued by a national weather service forecast office when atmospheric conditions are stable enough such that the potential exists for air pollutants to accumulate in a given area. The statement is initially issued when conditions are expected to last for at least 36 hours. (Above the text).

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

DRAFT WILDFIRE SMOKE EMERGENCY ACTION PLAN IMPLEMENTATION GUIDELINE (15)

Forward

According to information received by the World Health Organization (WHO), the air pollution caused by the 1997-98 forest fires in Indonesia, Brazil, and Mexico have resulted in serious health problems. The fine particles found in wood smoke is particularly dangerous to vulnerable groups of the population, like people which chronic respiratory problems, infants and the elderly. In September 1997 only, the number of smoke-related hospital admissions in Sarawak, Malaysia, alone was more than 26,000.

Global annual deaths from air pollution are estimated at more than 2.7 million, with 900,000 in cities and 1.8 million in rural settings.

Wildfires are a significant source of smoke and air pollution throughout the world and are projected to become much larger; potentially exposing large segments of the public to high concentrations of fine particulate matter. Increased exposure to aldehydes and carbon monoxide is also of concern. The issue of public exposure to smoke and air pollution agency's lack of readiness to respond to those situations is a major concern

Since 1992, new attention has been focused on emerging epidemiological studies that suggest that exposure to particulate matter may be a much greater public health threat than previously known. These studies, coupled with the disastrous wildfires of 1996, 1997 and 1998, have again brought the need for wildfire emergency action planning into the spotlight.

Purpose

This document was prepared to provide air quality agencies, federal land managers and others with the most current information on the health effects of wildfire smoke and measures that air quality agencies, federal land managers and communities can take to prepare for wildfire smoke emergencies. Public advisory statements suitable for use by the media are also provided.

Health effects of wildfire smoke

Smoke from wildfires and prescribed burning can pose health hazards to downwind communities. Smoke is a complex mixture of particles and gases which includes respiratory irritants such as air toxics (including aldehydes), nitrogen dioxide, particulate matter (PM) and cardiovascular toxins such as carbon monoxide (CO). Particulate matter less than 10 microns in diameter (PM_{10}) and particulate matter less than 2.5 microns in size ($PM_{2.5}$) have been linked in numerous epidemiological studies with increased respiratory illness, decreased lung function, increased emergency room visits and hospital admissions and even increased daily mortality. While these events are more likely to occur at high PM_{10} and $PM_{2.5}$ levels, they have been observed over a broad range of concentrations with no obvious threshold. About 85 per cent of wildfire smoke PM_{10} particulate matter is within the $PM_{2.5}$ fraction.

Symptoms which can result from population exposure to wildfire smoke include irritation of the eyes, nose and throat, nasal congestion, headache, cough, chest tightness, wheezing or whistling in the chest, excess phlegm production, difficulty in breathing, chest pain and nausea. While symptoms of eye and upper respiratory tract irritation will occur in many people exposed to wildfire smoke, serious symptoms are more likely to occur in people with pre-existing lung conditions (i.e., asthma, chronic bronchitis and emphysema) and heart disease (such as angina). Other potentially vulnerable persons include those over age 65 and very young children.

Issuance of public health alerts

Issuance of public health alerts on wildfire smoke should be based on an assessment of the potential public health risks and the likelihood of continued exposure. Alert levels need to be based on real-time monitoring for PM_{10} or $PM_{2.5}$ which can serve as an easily measurable indicator for other smoke constituents. Real-time monitoring is necessary because sometimes, exposure conditions associated with wildfires are changing rapidly.

With this background, we recommend that concerned communities be properly prepared to respond to wildfire smoke emergencies and that the alert levels noted below serve as action points for public health protection.

Preparing for wildfire smoke emergencies

Air regulatory agencies are encouraged to write to community leaders to advise them of the potential for wildfire smoke public health emergencies and to ask them to assess the likelihood of such an event in their community. Those communities judged to be at risk of wildfire smoke emergencies should be prepared to protect public health through coordination with their air pollution and public health agencies, the land management agencies and others. The following actions are suggested:

1. Adopt a Memorandum of Understanding (MOU) establishing mechanisms for monitoring wildfire smoke concentrations in affected communities, communicating between air agencies and wildfire incident commanders and distributing public health - air quality information to the public. A draft MOU outlining suggested responsibilities of each of the parties is available.

2. Air monitoring instruments must be available for rapid deployment into affected communities. To ensure that equipment is available, a monitoring programme plan must be adopted and funded.

3. Actions that should be taken by community public health officials include the following:

- Each community should develop a list of contacts and phone numbers of local health officials, hospitals, clinics, relief agencies, air quality regulatory and wildfire suppression agencies. Trained medical personnel available to assist in a wildfire smoke emergency should also be listed.

- Each community should develop a coordinating committee to establish wildfire smoke emergency procedures. Representatives of the above agencies need to be involved as should members of the local medical community. The committee should develop a communications network through which fire and air pollution information can be quickly passed via phone, radio or other means. Special consideration should be made for notification of individuals with pre-existing respiratory or cardiac health conditions and those individuals over the age of 65 years. Persons that are disabled or may not be easily moved within the general population need to be identified. These lists need to be maintained and kept current.

- Guidelines should be developed to ensure that such individuals (especially those with asthma and heart disease) have access to emergency medications and/or an ample supply of their regular medications. It may be advisable for each community to carry out smoke alert drills to assist in development of a plan and ensure rapid response if needed.

- Each community should identify one or more facilities such as nursing homes or schools that are equipped with climate control and HEPA air filter exchange systems, should they be needed as temporary shelters for smoke-affected individuals.

- Study should be conducted to evaluate the effectiveness of disposable face masks for reducing exposure to wildfire smoke.

Wildfire smoke emergency action plans

Actions taken to protect public health during wildfire smoke events need to be based on:

- An assessment of current particulate matter concentrations based on actual, on site air monitoring data. Portable nephelometers providing hourly estimates of fine particulate matter concentrations are recommended. Filter-based portable samplers may also be helpful. Under extreme conditions, or in the event that monitoring equipment is not available, estimates of smoke concentrations may need to be based on visibility observations. Table 4 provides a rough measure of smoke concentrations based on visual observations.

- A forecast of likely future smoke conditions based on weather, wildfire behaviour and suppression forecasts. This information is needed to judge how much longer smoke is expected to remain in the area.

- The severity of smoke-exposure symptoms on community residents.

Proposed advisory stages

Each of the following action plans suggests that individuals remain indoors to reduce their exposure to smoke. In poorly sealed, drafty homes with a high air exchange rate, this recommendation may offer little protection from smoke exposure.

Stage 1, Alert: PM_{10} concentrations of greater than 100 µg/m^3 or $PM_{2.5}$ concentrations of 85 µg/m^3, 4 hr average

Action: All individuals with pre-existing lung or heart disease should try to remain indoors with door and windows closed and should avoid excessive exertion and exposure to tobacco smoke and other respiratory irritants. People who need to take regular medications should make sure that they have at least a 5 day supply available. Individuals with chronic medical conditions should contact their physicians for guidance, regardless of the occurrence of symptoms. All others should contact a health care provider in the presence of any of the following symptoms: headache, repeated coughing, chest tightness or pain, wheezing in the chest, excessive phlegm production, difficulty in breathing and nausea. All individuals should avoid vigorous outdoor activity.

Stage 2, Warning. PM_{10} concentrations of greater than 150 µg/m^3 or $PM_{2.5}$ concentrations of 130 µg/m^3, 4 hour average

Action: All of the Stage 1 warnings also apply to Stage 2. In addition, individuals with chronic respiratory and cardiac conditions should be advised to evacuate to smoke-free environment, providing this can be done safely. Such an environment could be either away from the community or at a "clean" site within the community, such as a Red Cross shelter or a school especially equipped with tight-fitting windows and doors and with adequate indoor air-filtration equipment. All other individuals should try to remain indoors with doors and windows closed, and avoid excessive exertion and exposure to cigarette smoke and other respiratory irritants.

Stage 3, Emergency: Heavy smoke conditions with PM_{10} concentrations exceeding 400 µg/m^3 or $PM_{2.5}$ concentrations exceeding 340 µg/m^3, 1 hour average.

Action: Healthy individuals who choose to remain in the community should be advised to remain indoors, keep doors and windows closed, reduce activity, cut down on smoking and conserve energy. Persons that are uncomfortable should be advised to move out of the area or to a pre-designated "clean air" facility. Those individuals with respiratory and/or cardiac problems, the elderly, infirm persons and young children should also be relocated to the "clean air" facility following careful screening by health care providers. Special consideration should be given to keeping family units together. Relocated persons should return as soon as smoke conditions allow.

Re-entry

Action: After the wildfire has been contained, an "all-clear" declaration has been issued based on a forecast of smoke clearance, and public health alerts have been cancelled, affected persons can return to the area.

Public advisories

The public advisories in Appendices 1-3 are intended for use by radio and television stations to advise the public about the health effects of the smoke and the actions they should take to protect their health.

APPENDIX 1

DRAFT WILDFIRE SMOKE PUBLIC HEALTH ADVISORY
STAGE 1: ALERT
PM_{10} > 100 µg/m^3 or $PM_{2.5}$ > 85 µg/m^3, 4 HR AVERAGE

FOR IMMEDIATE RELEASE:

SMOKE FROM FOREST FIRES IN THE AREA HAVE REACHED LEVELS THAT MAY AFFECT YOUR HEALTH. AIR POLLUTION MONITORING INFORMATION FROM (LOCATION) INDICATES THAT SMOKE LEVELS DURING THE PAST 4 HOURS HAVE REACHED A STAGE I ALERT LEVEL. FIRE FIGHTERS EXPECT SMOKE LEVELS IN THE AREA TO REMAIN HIGH DURING THE NEXT HOURS.

ALL PERSONS WITH LUNG OR HEART DISEASES SUCH AS ASTHMA, BRONCHITIS OR ANGINA SHOULD STAY INDOORS WITH YOUR DOORS AND WINDOWS CLOSED. AVOID EXERTION AND EXPOSURE TO TOBACCO SMOKE. BE SURE YOU HAVE AT LEAST A 5 DAY SUPPLY OF YOUR MEDICATION.

SPORTS PRACTICES SHOULD BE CANCELLED. EVERYONE SHOULD AVOID VIGOROUS OUTDOOR ACTIVITY.

IF YOU HAVE REPEATED COUGHING, HEADACHES, CHEST TIGHTNESS OR PAIN, WHEEZING OR WHISTLING IN YOUR CHEST, DIFFICULTY BREATHING OR NAUSEA, CONTACT YOUR HEALTH CARE PROVIDER.

FOR MORE INFORMATION, CONTACT THE ____________________________
(AGENCY NAME)

AT__________________________ (PHONE NUMBER).

ISSUED AT: _________________ TIME _____________ DATE ____________

APPENDIX 2

DRAFT WILDFIRE SMOKE PUBLIC HEALTH ADVISORY
STAGE 2: WARNING
PM_{10} > 150 µg/m^3 or $PM_{2.5}$ > 1 3 0 µg/m^3, 4 HR AVERAGE

FOR IMMEDIATE RELEASE:

SMOKE FROM FOREST FIRES IN THE AREA HAVE REACHED LEVELS THAT MAY AFFECT YOUR HEALTH. AIR POLLUTION MONITORING INFORMATION FROM (LOCATION) INDICATES THAT SMOKE LEVELS DURING THE PAST 4 HOURS HAVE REACHED THE LEVEL 2 WARNING LEVEL. FIRE FIGHTERS EXPECT SMOKE LEVELS IN THE AREA TO REMAIN HIGH DURING THE NEXT HOURS.

ALL PERSONS WITH LUNG OR HEART DISEASES SUCH AS ASTHMA, BRONCHITIS OR ANGINA SHOULD EVACUATE TO A SMOKE-FREE AREA, PROVIDED YOU CAN DO SO SAFELY. IF YOU CHOOSE NOT TO LEAVE THE AREA, YOU SHOULD TEMPORARILY MOVE TO ___________________________ (NAME OF FACILITY) LOCATED AT ___ __________________(ADDRESS) WHERE THE AIR IS SMOKE-FREE. HEALTH CARE PROVIDERS ARE THERE TO HELP YOU.

ALL OTHERS SHOULD STAY INDOORS WITH YOUR DOORS AND WINDOWS CLOSED. AVOID EXERTION AND EXPOSURE TO TOBACCO SMOKE. IF YOU HAVE REPEATED COUGHING, HEADACHES, CHEST TIGHTNESS OR PAIN, WHEEZING OR WHISTLING IN YOUR CHEST, DIFFICULTY BREATHING OR NAUSEA, CONTACT YOUR HEALTH CARE PROVIDER.

SPORTS PRACTICES SHOULD BE CANCELLED. EVERYONE SHOULD AVOID VIGOROUS OUTDOOR ACTIVITY.

FOR MORE INFORMATION, CONTACT THE ____________________________
(AGENCY NAME)
AT ______________________ (PHONE NUMBER).

OUR NEXT UPDATE ON SMOKE CONDITIONS WILL BE IN ______________ MINUTES.

ISSUED AT: __________________ TIME ____________ DATE ___________

APPENDIX 3

DRAFT WILDFIRE SMOKE PUBLIC HEALTH ADVISORY
STAGE 3: EMERGENCY
PM_{10} > 400 µg/m^3 or $PM_{2.5}$> 340 µg/m^3, 1 HR AVERAGE

FOR IMMEDIATE RELEASE:

SMOKE FROM FOREST FIRES IN THE AREA HAVE REACHED LEVELS THAT WILL AFFECT YOUR HEALTH. AIR POLLUTION MONITORING INFORMATION FROM ____________________. (LOCATION) INDICATES THAT SMOKE LEVELS DURING THE PAST HOUR HAVE REACHED THE STAGE 3 EMERGENCY LEVEL. FIRE FIGHTERS EXPECT SMOKE LEVELS IN THE AREA TO REMAIN HIGH DURING THE NEXT HOURS.

PERSONS WITH LUNG OR HEART DISEASES SUCH AS ASTHMA, BRONCHITIS OR ANGINA SHOULD STAY INDOORS WITH YOUR DOORS AND WINDOWS CLOSED. IF YOU MUST GO OUTSIDE, AVOID EXERTION. SPORT SHOULD BE CANCELLED. PERSONS EXPERIENCING SHORTNESS OF BREATH, COUGH, CHEST PAIN, NAUSEA OR ANGINA SHOULD CONTACT THEIR HEALTH CARE PROVIDER.

PERSONS BEING AFFECTED BY THE SMOKE SHOULD IMMEDIATELY MOVE TO __________________ (NAME OF FACILITY) LOCATED AT (ADDRESS)____ WHERE THE AIR IS SMOKE-FREE. HEALTH CARE PROVIDERS ARE THERE TO HELP YOU. YOU WILL BE ABLE TO RETURN HOME AS SOON AS THE SMOKE CONDITIONS ALLOW.

FOR MORE INFORMATION, CONTACT THE ____________________________
(AGENCY NAME)
AT ______________________ (PHONE NUMBER).

OUR NEXT SMOKE UPDATE WILL BE IN ______________________ MINUTES

ISSUED AT: ________________ TIME ____________ DATE ____________

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Table 1
Components, key elements and examples of a wildland fire prevention programme

Components	Key elements	Examples
Engineering	Separating heat sources from fuels; reducing or eliminating fuels when heat sources must remain; and shielding fuels from heat sources to prevent contact.	Creating and maintaining fuel breaks; clearance around structures and power lines; design and installation of spark arresters; and the development of fire codes and regulations.
Education	Informing the public of wildland fire prevention practices; changing attitudes and behaviour; and creating an awareness of fire prevention.	School and civic group programmes; person-to-person contacts; parades, exhibits and displays; posters and billboards; and public service contacts on radio or TV.
Enforcement	Compliance with local, state and federal fire codes and regulations; fire cause determination; and law enforcement action.	Inspection for compliance with fire safety laws and regulations; investigation of fire cause; red flag patrolling and closure of areas; and law enforcement and court action.

Table 2
Guidelines for width of fire line

Fuel type	Width of cleared area (m)	Width in mineral soil (m)
Grass	0.61 to 0.92	0.61 to 0.92
Medium brush	1.22 to 1.83	1.83 to 2.44
Heavy brush	2.75	0.31 to 0.61
Very heavy brush or logging slash	3.66	0.92
Timber	6.1	0.92

Table 3
Emission factors for particulate matter as a function of fire behaviour

		Ton[1]
Grass	Flaming dominates	7.5
Understory vegetation/litter	Flaming w/light smouldering[2]	12.5
	Flaming w/moderate smouldering[3]	15
	Flaming w/moderate smouldering[4]	37.5
Broadcast slash	Flaming dominates 10	
	Flaming w/smouldering component	20
Piled and windowed slash	Flaming dominated	12.5
	Flaming w/moderate smouldering	25
Slash	Flaming w/heavy smouldering[5]	7.5
Brush fuels	Flaming dominates	12.5
	Flaming w/moderate smouldering	25
All fuels	Burning where smouldering dominates	75

1 g/kg of fuel burned on dry weight basis.
2 backing fires or heading fires in light fuels without duff involvement.
3 heading fires in litter fuels with heavy loading.
4 fires in litter fuels with substantial duff consumption.
5 soil free and very dry.
6 heavy mineral soil component and/or high fuel moisture.

Table 4
Approximate relationship between wildfire smoke concentrations and visibility conditions

PM_{10} particulate matter ($\mu g/m^3$)	**Visibility (km)**
100	6.0
200	3.0
400	1.5
600	1.0
800	0.7

Figure 1
Stages of combustion

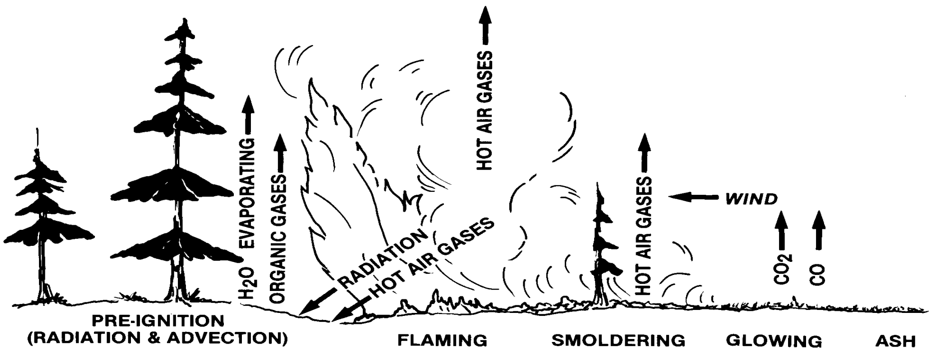


Figure 2
Why a fire spread

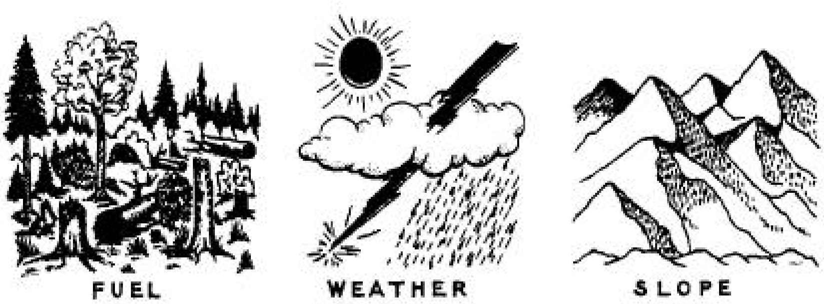
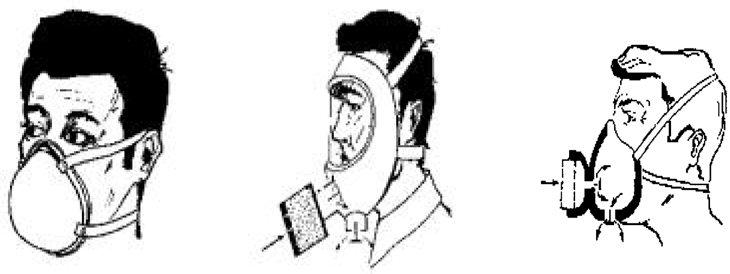


Figure 3
The fire triangle

Figure 4
Respirator Design



Mask **Full face mask** **Half-face mask**

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

PUBLIC INFORMATION AND MITIGATION MEASURES FOR A HAZE EPISODE: THE SINGAPORE EXPERIENCE

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INTRODUCTION

During the 1997 regional smoke haze episode, the authorities in Singapore were inundated daily with enquiries from members of the public and the mass media on various haze-related issues. The environmental health questions posed included the state of air pollution, what the authorities were doing about the problem, what were the health and other effects, and what mitigation measures could be taken. The tremendous pressure for coordinated flow of timely information to the public enabled a more organised management system to emerge, and practical advice on mitigation measures such as the use of air cleaners and masks gave confidence to the public that the authorities were in control of the situation. Although the Singapore experience applies to an urban context and cannot be directly extrapolated to other countries, some of the lessons learnt could be useful. We present herein the country-level activities that can be undertaken in relation to information provision and mitigation measures during a haze emergency.

INFORMATION TO THE PUBLIC

Information on ambient air quality

Among the basic requirements in protecting the public health during a haze emergency is the provision of a reasonably reliable air quality monitoring and management system. Information on ambient air quality is of prime importance as it is the basis of preventive and protective actions that need to be taken by the population to minimise damage to health. An air quality monitoring programme should be put in place as a primary activity to protect the public against air pollution episodes such as vegetation fires. In general, the air quality monitoring programme could have the following objectives:

- to assess the nature and magnitude of air pollution problems;
- to monitor trends in the ambient air quality so as to enable policy decisions to be made to prevent air pollution episodes; and
- to assess the effectiveness of pollution control measures implemented to improve ambient air quality

The establishment of a well-managed air quality monitoring infrastructure and programme would be the first step in building a health information system for the public against a serious air pollution event such as vegetation fire pollution.

In Singapore, ambient air quality is monitored by an island-wide network of 15 stations. These stations are linked via the public telephone network to a central control station situated within the headquarters of the Ministry of the Environment. The main air pollutants monitored in Singapore are sulphur dioxide, nitrogen dioxide, carbon monoxide, ozone and particulate matter less than 10 µm in aerodynamic diameter (PM_{10}). The monitoring of $PM_{2.5}$ has also been initiated at two separate stations in Singapore. Other environmental parameters such as humidity, temperature, wind speed and direction are measured at selected stations as well. The monitoring in Singapore uses the United States Environmental Protection Agency (USEPA)'s reference methods (1).

Once the air quality monitoring and management system is in place, authorities must decide on the air quality standards and goals to be set for the population. The standards and goals set by other countries or international agencies which have carried out credible research on air quality and health impact could be adopted. For example, the 24-hour Pollutant Standards Index (PSI) developed by the USEPA is useful as it is accepted internationally and is based on extensive evidence of the health effects among the population due to various air pollutant components.

In Singapore, the long-term goals of the World Health Organisation (WHO) and the primary air quality standards of the USEPA are used as the guidelines to assess the ambient air quality. The levels for some gaseous and particulate pollutants are given in Table 1 and 2. Singapore has also adopted the PSI method of reporting the daily pollutant measurements. Basically, the index is obtained by converting the pollutant concentration for five major air pollutants, ie, sulphur dioxide, particulate matter (PM_{10}), nitrogen dioxide, ozone and carbon monoxide, into a simple integer scale of 0 to 500. The highest value for any one of these five readings will be the PSI level for the day. The PSI reading is released to the public every day at 4.00 pm. The air quality is classified as "good" for PSI levels of 0-50; "moderate", 51-100; "unhealthy", 101-200; "very unhealthy", 201-300; and "hazardous", above 300 (1).

It should be noted that in the event of emergency due to vegetation fire, the health alert advisory given for pollution levels experienced over the last 24 hours as indicated by the PSI level may not be adequate to help the population react fast and modify their activities. It is important that pollution indices should not be overemphasized, and pollutant-specific information should also be reported. This is particularly important for PM_{10}, as current research as well as WHO air quality guidelines generally do not support the concept of a threshold or no-adverse effect level for particulate exposure (2-5). Index readings slightly below "unhealthy" levels, when based on PM_{10} measurements, may provide a false sense of security. There is consistent evidence of short-term health impact of the haze below the USEPA PM_{10} standard of 150 $\mu g/m^3$ from various studies (6-11). Modifications may need to be made by the government to the air quality reporting system to ensure more timely information on the pollution levels during vegetation fire and other serious pollution emergency. Information on the pollution levels should be made through the broadcasting media together with appropriate health advisories.

Information on national action

A comprehensive haze action plan (HAP) should be developed to ensure a full preparedness of the population to the health impact of vegetation fire pollution, particularly the more vulnerable sections of the population such as the asthmatics, the elderly and children. The HAP must be widely publicized through the media before the occurrence of any vegetation fire pollution episode. This will enable the public to be familiar with tasks to be taken and modification to activities to be made at various air quality levels to reduce the health effects of the pollution. Based on the HAP, government departments should draw up operating procedures to be adopted in the event of a vegetation fire pollution emergency. This will ensure that the population would know the changes made to public services and facilities in accordance with the prevailing vegetation fire pollution emergency situation.

In Singapore, there is a multi-agency Haze Task Force, chaired and coordinated by the Ministry of the Environment, which is responsible for the national HAP. The aim of the national HAP is to ensure full preparedness to ameliorate the impact of haze on the health and well-being of the general public, in particular, the more vulnerable sections of the population such as the young and elderly. The HAP is publicised widely through the media and is posted on the internet at http://www4.gov.sg/env/pi/psi/index.html. Under the HAP, detailed tasks have been formulated for activation at different pollution levels. A summary of the HAP is given in Table 3. The Ministry of Health has also lined up contingency measures to deal with forest fire pollution emergency in line with the PSI levels. Some of the actions include:

a) 24-hour PSI level between 51 and 200:

- *All necessary facilities will be made adequately available to cope with the anticipated increase in demand for services. Additional relevant facilities at polyclinics and Accident & Emergency Departments will be identified and activated.*

- *Suppliers of respirator masks will be alerted to ensure adequate stocks are made available at retail pharmacies, hospitals and polyclinics.*

- *Toll-free call-in lines will be provided to provide heath-related enquiries to supplement the Ministry of the Environment's Haze Hotline.*

b) 24-hour PSI level between 201 and 400:

- *Additional staff will be deployed to government polyclinics and Accident & Emergency Departments of public hospitals if attendances reach an identified critical level. Polyclinic operating hours will be extended if the need arises.*

- *Respirator masks will be issued to field health workers.*

- *Hospitals will be alerted of impending worsening conditions, and elective admissions and surgery may be cancelled.*

Information on health effects and cautionary statements

It is imperative that the authorities monitor the population's health during a vegetation fire pollution emergency to detect any worsening of the impact at different pollution levels. Data on haze-related illnesses from primary health care providers, hospitals, and mortality registries should be reported periodically. Health data during non-haze periods (normal levels of pollution) should also be monitored to provide the baseline information. In the longer term, the information gathered would enable the authorities to refine their national action plan.

Special emphasis should be placed on explaining the health effects of susceptible populations such as the asthmatics, elderly and children at different pollution levels. This will help to ensure that there are adequate preparations to deal with the expected increase in the susceptible population's demand for medical services during vegetation fire pollution episodes.

Concern about frequently asked questions such as the safety of food and potable water exposed to smoke haze for indefinite periods should be addressed by authorities through the media. Based on available medical literature, there is no conclusive evidence to indicate that adverse health effects result from the consumption of exposed food or water.

In Singapore, a national sentinel health surveillance system will undertake close monitoring of the following haze-related conditions:

i) Attendance at government polyclinics for conjunctivitis, acute upper respiratory tract infection (including influenza), allergic rhinitis, acute bronchitis, asthma (acute and chronic), eczema (including contact dermatitis), exacerbation of chronic obstructive pulmonary diseases, exacerbation of ischaemic heart disease (IHD);

ii) Attendances for the following haze-related conditions at public hospitals and Accident & Emergency Departments: IHD, pneumonia, asthma, bronchitis, emphysema, acute conjunctivitis;

iii) Admissions into public hospitals for the following conditions: IHD, pneumonia, asthma, bronchitis, emphysema and exacerbation of obstructive lung diseases; and

iv) Mortality from IHD, pneumonia, asthma, bronchitis, emphysema and other chronic obstructive pulmonary diseases.

A summary of the known general health effects and cautionary statements at different levels of air pollution is given in the HAP in Table 2.

MITIGATION MEASURES

Remaining indoors

For non air-conditioned homes or buildings, only limited protection from fine particulate air pollution is gained by remaining indoors. Recent research has indicated that the impact of outdoor particles on indoor levels is determined mainly by the rate of ventilation, and that the impact of outdoor particles can easily be calculated for any air exchange rate (12). In typical North American homes, outdoor air accounts for 75% and 65% of fine and coarse particles, respectively. The geometric mean air exchange rates are 0.45-0.55 air changes per hour, but vary by season and specific geographical location (13). In general, air-conditioned homes typically have lower air exchange rates than homes that use open windows for ventilation. In one

study, air-conditioned homes had air exchange rates of 0.8/hr, while non air-conditioned homes had rates of 1.2/hr, implying indoor fractions of outdoor $PM_{2.5}$ of 67 and 75%, respectively. One method of reducing particle exposure would be to decrease air exchange rates, by weatherizing in cold seasons and by installing air conditioners for hot seasons to reduce the use of open windows (13). The infiltration of outdoor particles into commercial buildings is likely to be highly variable as it is dependent upon the air exchange rate and specific characteristics of the ventilation system, including the efficiency of air filters.

To enhance the protection offered by remaining indoors, individuals/building managers should take actions to reduce the infiltration of outdoor air. Air conditioners, especially those with efficient filters, will substantially reduce indoor particle levels. To the extent possible, effective filters should be installed and maintained in existing air conditioning systems and individuals should seek environments protected by such systems.

Personal lifestyle modifications

In addition to remaining indoors, the authorities should also advise members of the public on other exposure mitigation measures involving personal lifestyle modifications such as the reduction of physical activity and restriction of cigarette smoking.

Use of air cleaners

Portable air cleaners are effective at reducing indoor particle levels, provided the specific cleaner is adequately matched to the indoor environment in which it is placed. Unfortunately, economics will limit the distribution of such devices throughout the population. As with air conditioners, the increased use of air cleaners by a large segment of the population may have a significant impact on energy consumption.

Air cleaners can be used as a mitigation measure against pollution due to forest fires and information on their effectiveness should be publicized. Portable air cleaners are compact, stand-alone appliances designed to lower the particulate levels of an enclosed space. Air cleaners are able to reduce the level of fine particles in a typical living room or bedroom to an acceptable level when there is an intense haze; for example when the PSI reading exceeds 200. Air cleaners are classified by their clean air delivery rate (CADR) which describes the volume of air which the specific cleaner

can filter. By matching a device's CADR to the specific space in which it is placed, effective air cleaning can be achieved. Recommendations should be made on the use of air cleaners, particularly to households with members who are vulnerable to the effects of deterioration in air quality. Evaluation could be conducted on models of air cleaners available in the market (or a certification programme could be established) and appropriate recommendations be made to the public to assist them in purchasing the model suitable for their homes or offices.

In Singapore, the Ministry of the Environment has carried out evaluation tests on air cleaners and given appropriate practical advice to schools, building owners and the general public on the installation of air cleaners in buildings. Press statements have been made advising the public to consider fitting their homes and offices with air filters to minimise the impact of the vegetation fire pollution. Results of evaluation tests are released to the media together with information on the CADR given by overseas testing agencies. A list of portable air cleaners available in the market that passed the evaluation test have been made available to the public. For buildings with central air conditioning systems, special devices are recommended to be added to the air handling unit to keep the particulate levels to acceptable levels. These devices include electrostatic precipitators, high-efficiency media filters and medium-efficiency media filters. Schools, child-care centres, old folk homes, hospitals and hospices are also urged to install these air filters to minimise risks to susceptible individuals and children.

Use of masks

While dust masks are relatively inexpensive and may be distributed to a large segment of the population, their effectiveness for general population use must be questioned. Despite this reservation, it is likely that the benefits (even partial) of wearing dust masks will outweigh the physiological and economic costs. Accordingly, in the absence of other mitigation techniques, the use of dust masks is warranted. Education of the population regarding specific mask types to purchase, how to wear them and when to replace them will increase their effectiveness, as will the development of new masks designed for general population use.

The public should be advised on the use of masks, particularly when they are involved in outdoor activities during periods of air pollution. Advice should also be given to the public on the relative utility of masks in keeping out particulates from the smoke haze. These include the proper use and selection of appropriate masks from among those available in the market.

Basically, there are two categories of masks: surgical/similar masks and respirator masks. The public should be advised that surgical/similar masks are not too useful in preventing the inhalation of fine particles from vegetation fires. These masks generally cannot filter out particles less than 10 μm in size. Respirators, on the other hand, are special masks designed for the protection of workers exposed to occupational health hazards. Typically these respirators can filter out 95% or more of fine particles produced during forest fire episodes.

While respirators may be useful, they are uncomfortable and increase the effort of breathing. Respirators may have a role for those with chronic cardiorespiratory illness, but they should be used on the recommendation of attending doctors. According to some assessments, over an eight-hour period of use, a respirator of 95% efficiency can offer satisfactory filtration without undue breathing resistance to an average healthy adult. At higher efficiencies, breathing resistance increases and the user will experience more discomfort.

In Singapore, the general public has been advised that the use of masks is unnecessary when the air quality remains in the good to moderate region. During intense haze (eg, PSI over 200), the public should avoid outdoor activity rather than put on a mask and stay outdoors for prolonged periods. However, for those who could not avoid going outdoors, the use of respirators would provide some relief. In the case of

those with cardiopulmonary illness who need to use masks on the recommendation of their doctors, they should choose the right respirators, ie, those designed for fine particle removal.

Outdoor precautionary measures

Precautionary measures should be taken to safeguard the health and safety of workers who must continue to perform outdoor work. Appropriate respirators, if necessary, should be provided by employers to ensure workers are well-protected.

In Singapore, the Ministry of Manpower advises employers to ensure that appropriate precautionary measures are taken to safeguard the health and safety of their workers, especially those who have to work during the haze. Employers should provide suitable respirators to workers who need to use them for outdoor work as part of the safety and health requirements for the protection of the health of their workers. At PSI level <200, it is not necessary for normal healthy workers to use respirators when working outdoors. Outdoor workers are advised to use respirators when the PSI levels exceed 200 and they must use respirators when the PSI levels exceed 300.

Workers with existing heart or respiratory ailments are more susceptible to the effects of the haze. When the PSI levels exceed 100, outdoor workers with existing heart or respiratory ailments are advised to consult their doctors on their fitness to work outdoors and to use respirators. If they experience difficulty working outdoors, employers should deploy them to indoor work. At higher PSI levels (>200), they should be deployed to do indoor work which is not physically strenuous. When the PSI levels exceed 300, outdoor work should not be carried out unless workers are adequately protected (eg, with suitable respirators). Those who have difficulty with using respirators and working outdoors should be deployed to do indoor work. In addition, outdoor work which involves strenuous physical activity should be minimised. For safety reasons, when the PSI levels exceed 300, outdoor work with a risk of falling from heights should not be allowed (unless precautions have been taken to reduce this risk). When the PSI levels exceed 400, no outdoor work should be allowed except for emergency and essential services.

CONCLUSION

The coordinated flow of information to the public and practical advice on mitigation measures such as the use of air cleaners and masks is crucial in the management of a smoke haze emergency. In Singapore, the main emphasis in the 1997 smoke haze episode has been on strengthening and fine-tuning the provision of timely information on the severity of air pollution and appropriate health advisories for members of the public.

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Table 1
USEPA primary air quality standards

Parameter	Averaging Time	Concentration (µg/m³)	Method
Gaseous pollutants			
Sulphur dioxide	Annual mean 24 hour	80 365	Pararos-aniline pulsed fluorescence
Carbon monoxide	8 hours 1 hour	10,000 40,000	Non- dispersive infrared spectrometry
Nitrogen dioxide	Annual mean	100	Chemiluminescence
Ozone	1 hour	120	Ultraviolet photometry
Particulate pollutants			
Respirable suspended particles	Annual mean 24 hours	50 150	High volume Sampling
Lead	3 months	1.5	Atomic absorption Spectroscopy

Table 2
World Health Organization long-term goals (14-16)

Parameter	Averaging Time	Concentration (µg/m³)
Gaseous pollutants		
Sulphur dioxide	Annual mean 24 hours	50 125
Carbon monoxide	8 hours 1 hour	10,000 30,000
Nitrogen dioxide	Annual mean 1 hour	40 200
Ozone	8 hours	120
Particulate pollutants		
TSP	24 hours	120
Respirable	24 hours	70
Lead	1 year	0.5

Table 3
National haze action plan (Singapore) (17)

Index value	PSI descriptor	General health effects	Cautionary statements	Detailed tasks
Up to 50	Good	None	None required	Provide hourly PSI updates to the media. Provide PSI updates to other ministries and agencies so that they can get ready to implement their Standard Operating Procedures (SOPs). Liaise with industries with fuel-burning equipment on the need to cut down emissions. Liaise with major vehicle fleet owners on measures to minimise emissions
51 to 100	Moderate	Few or none for the general population	None required	Same as above

Note: PSI = Pollutant Standards Index; NHTF = National Haze Task Force

Table 3
National haze action plan (Singapore) (cont'd)

Index value	PSI descriptor	General health effects	Cautionary statements	Detailed tasks
101 to 200	Unhealthy	Mild aggravation of symptoms among susceptible people with irritation symptoms in the healthy population	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity. General population should reduce vigorous outdoor activity.	Provide hourly PSI updates and health advisories to the media. Provide PSI updates to the other ministries and agencies. Liaise with industries with fuel-burning equipment on the need to cut down emissions. Liaise with major vehicle fleet owners on measures to minimise emissions Activate Haze Info-line (1800-7319222) to provide information and to answer queries from the public. When 24-hour PSI stays above 100 for more than 48 hours, NHTF to meet as often as required to co-ordinate implementation of the SOPs of individual ministries and agencies. NHTF to hold press briefings

Note: PSI = Pollutant Standards Index; NHTF = National Haze Task Force

Table 3
National haze action plan (Singapore) (cont'd)

Index value	PSI descriptor	General health effects	Cautionary statements	Detailed tasks
201 to 300	Very Unhealthy	Significant aggravation of symptoms and decreased tolerance in persons with heart or lung disease; widespread symptoms in healthy population	Elderly persons with existing heart or lung disease should stay indoors and reduce physical activity. General population should avoid vigorous outdoor activity	Provide hourly PSI updates and health advisories to the media. Provide PSI updates to the other ministries and agencies. Activate Haze Info-line (1800-7319222) to provide information and to answer queries from the public . When 24-hour PSI stays above 100 for more than 48 hours, NHTF to meet as often as required to co-ordinate implementation of the SOPs of individual ministries and agencies. NHTF to hold press briefings

Note: PSI = Pollutant Standards Index; NHTF = National Haze Task Force

Table 3
National haze action plan (Singapore) (cont'd)

Index value	PSI descriptor	General health effects	Cautionary statements	Detailed tasks
301 to 400	Hazardous	Early onset of certain diseases in addition to symptoms and decreased exercise tolerance in healthy persons	Elderly, children and persons with existing diseases should stay indoors and avoid physical exertion. General population should avoid unnecessary outdoor activity	Provide hourly PSI updates and health advisories to the media. Provide PSI updates to the other ministries and agencies. Inform industries with fuel burning equipment and major vehicle fleet owners to cut down emissions. Advise motorists through media to reduce use of private motor vehicles. When 24-hour PSI>250, NHTF to meet to reaffirm measures with regard to advising industries, schools and construction sites on outdoor work, closure of schools, stoppage of outdoor functions and sports activities. Provide regular updates on the haze situation to the public. NHTF to hold press briefings

Note: PSI = Pollutant Standards Index; NHTF = National Haze Task Force

Table 3
National haze action plan (Singapore) (cont'd)

Index value	PSI descriptor	General health effects	Cautionary statements	Detailed tasks
Over 400	Hazardous	PSI levels above 400 may be life-threatening to ill and elderly persons. Healthy people may experience adverse symptoms that affect normal activity	All persons should remain indoors, keeping windows and doors closed, and minimise physical exertion	Provide hourly PSI updates and health advisories to the media. Provide PSI updates to the other ministries and agencies. NHTF to convene urgent meeting to decide: 1. closure of schools. 2. closure of childcare centres. 3. closure of sports facilities and stoppage of sports activities. 4. stoppage of outdoor work by industries, construction sites, etc., and/or the use of respirators by workers doing outdoor work When 24-hour PSI>350, NHTF to deliberate on the need to declare a haze emergency if PSI exceeds 400. Proclaim a haze emergency if the government so decides. Regular public announcements to be made. NHTF to hold press briefings

Note: PSI = Pollutant Standards Index; NHTF = National Haze Task Force

The index value refers to the 24-hour Pollutant Standards Index (PSI) value and not to the 3-hour PSI value. Only the 24-hour PSI value is correlated to the health effects outlined.

Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998.
Background papers

APPLICATION OF APPROPRIATE SHORT-TERM AIR QUALITY GUIDELINES

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INTRODUCTION

The primary purpose of ambient air quality guidelines is the protection of public health. Guidelines provide exposure levels considered appropriate and acceptable for the safeguarding of health. The pollutant levels recommended are values below which exposure, for lifetime or for a given period of time, does not constitute a significant health risk. The guidelines are usually health consideration based on the latest state of scientific knowledge, although ecological concerns may be included. Local authorities need to take other factors into account when making risk assessment and risk management decisions, including prevailing exposure levels, technical feasibility, source control measures, abatement strategies, as well as social, economic, and cultural conditions (1).

DUAL ROLE OF SHORT-TERM AIR QUALITY GUIDELINES AS RISK MANAGEMENT TOOL

During short-term air quality deterioration such as a forest-fire air pollution episode, air quality guidelines alone is inadequate and ineffective. There is a need for immediate actions to mitigate untoward health impacts to the public. In this situation, guidelines should also serve as a tool for public information and recommended actions. It should link air quality or exposure levels with public precautionary measures and health risk communication

activity. Different levels of exposure, health effects (e.g. mild, moderate, severe) and action to be taken should be established for practical purpose of field operations, with consideration of non-health factors referred to earlier.

For the linkage between air quality with public information and recommended actions, two examples of air quality management guidelines proposed and adopted in Europe and the US demonstrate this approach.

First, "air pollution alert system" is a guide for action when peak exposures to urban winter- or summer-type smog occurs in a number of countries in Europe (2). In general, when effects are expected to be mild, no action other than announcement of the expected alert and its public health significance seems necessary. When effects are expected to be moderate, some public advice about exposure or dose reduction for sensitive individuals could be considered. When severe health effects are expected, additional measures could be recommended on a voluntary basis, and emergency short-term measures such as closing of schools or limiting of traffic could be considered.

The US Environmental Protection Agency (EPA) and several agencies developed an urban air quality composite index, called pollutant standards index (PSI), based on the integrated ambient measures of five major criteria pollutants (3). The EPA and local officials use the PSI as a public information tool to advise the public about the general health effects associated with different pollution levels, and to describe whatever precautionary steps may need to be taken if air pollution levels rise into the unhealthful range (Table 1). PSI levels above 100 may trigger health advisories by State or local officials. The 200 level is likely to trigger an "Alert" stage, in which some activities such as incinerator use or open burning might be restricted. A level of 300 on the PSI will trigger a "Warning", which is likely to prohibit the use of incinerators, severely curtail power plant operations, cut back operations at specified manufacturing facilities, and require the public to limit driving by using car pools and public transportation. A PSI level of 400 or above would constitute an "Emergency", and would require a cessation of most industrial and commercial activities, plus a prohibition of almost all private use of motor vehicles. In terms of particulate matter equal to or smaller than 10 μm (PM_{10}), the EPA is required to issue a public alert when the levels on a 24-hour average reach 350 $\mu g/m^3$, a public warning when the levels reach 420 $\mu g/m^3$, and a declaration of public emergency at the level of 500 $\mu g/m^3$.

Another example from the US comes from the recent guidelines of the wildfire emergency action plan of the Western States Air Resources Council (4, 5). Details are as follows.

Stage 1, Alert: PM_{10} concentrations of greater than 100 $\mu g/m^3$ or $PM_{2.5}$ concentrations of 85 $\mu g/m^3$, 4-hour average

Action: All individuals with pre-existing lung or heart disease should try to remain indoors with door and windows closed, and avoid excessive exertion and exposure to tobacco smoke and other respiratory irritants. People who need to take regular medications should make sure that they have at least a 5-day supply available. Individuals with chronic medical conditions should contact their physicians for guidance, regardless of the occurrence of symptoms. All others should contact a health care provider in the presence of any of the following symptoms: headache, repeated coughing, chest tightness or pain, wheezing in the chest, excessive phlegm production, difficulty in breathing and nausea. All individuals should avoid vigorous outdoor activity.

Stage 2, Warning: PM_{10} concentrations of greater than 150 $\mu g/m^3$ or $PM_{2.5}$ concentrations of 130 $\mu g/m^3$, 4-hour average

Action: All of the stage 1 warnings also apply to stage 2. In addition, individuals with chronic respiratory and cardiac conditions should be advised to evacuate to smoke-free environment, providing this can be done safely. Such an environment could be either away from the community or at a “clean” site within the community, such as a Red Cross shelter or a school specially equipped with tight-fitting windows and doors and with adequate indoor air-filtration equipment. All other individuals should try to remain indoors with doors and windows closed and avoid excessive exertion and exposure to cigarette smoke and other respiratory irritants.

Stage 3, Emergency: Heavy smoke conditions, PM_{10} concentrations exceeding 400 μg/m^3 or $PM_{2.5}$ concentrations exceeding 340 μg/m^3, 1-hour average

Action: Healthy individuals who choose to remain in the community should be advised to remain indoors, keep doors and windows closed, reduced activity, cut down on smoking and conserve energy. Persons who feel uncomfortable should be advised to move out of the area or to a pre-designated "clean air" facility. Those individuals with respiratory and/or cardiac problems, the elderly, infirm persons and young children should also be relocated to the "clean air" facility following careful screening by health care providers. Special consideration should be given to keeping family units together. Return of relocated persons should occur as soon as the smoke conditions allow.

Re-entry

Action: After the wildfire has been contained, an "all-clear" declaration has been issued based on a forecast of smoke clearance, and public health alerts have been cancelled, affected persons can return to the community.

APPLICABILITY OF WHO AIR QUALITY GUIDELINES

Smoke from forest fires consists mainly of fine particles in the respirable range which is conducive to long-range and transboundary transport (6), resulting in widespread short-term increase in particulate matter levels all over the affected areas.

Special consideration should be given to particulate matter when making appropriate short-term air quality guidelines. New scientific data on the epidemiological assessment of exposure to particles do not support the establishment of a level below which no effects would be expected (7,8). Instead of the usual threshold levels or guideline values, local authorities are now guided by exposure-effect information of major health impacts from short- and long-term exposure to various levels of particles.

However, for practical purpose, short-term forest fires air quality guidelines can be developed using the same general approach as the WHO's guidelines (1) in combination with risk management explained above. There may be questions regarding the averaging time and the appropriate unit that

better represent air quality or exposure levels. The averaging time used and reported in the guidelines should be 24-hour average, which conforms to the available evidence of short-term effects using daily exposure in time-series studies. As fine particulate matter is the main culprit, the concentrations or actual levels of particles should be used in the guidelines to directly reflect their relationship with health effects, instead of a composite index which requires additional numerical calculation and may cause differences between two computation schemes.

In practice, three levels of PM_{10} relating to the corresponding health effects, (mild, moderate and severe) and the corresponding preventive or mitigating activities (alert, warning and emergency, respectively) may be established. Available information on the dose-response relationship of particles will form the basis of demarcating these intervals based on scientific judgement.

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Table 1
General health effects and precautionary steps associated with levels of PSI (3)

Index value	Descriptor	General health effects	Cautionary statement
Up to <50	Good	None	None
50 to 100	Moderate	Few or none for the general population	None
100 to <200	Unhealthful	Mild aggravation of symptoms among susceptible people, with irritation symptoms in the healthy population	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity. General population should avoid vigorous outdoor activity.
200 to 300	Very Unhealthful	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease; widespread symptoms in the healthy population.	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity. General population should avoid vigorous outdoor activity.
Over 300	Hazardous	Early onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons. At PSI levels above 400, premature death of ill and elderly persons may result. Healthy people experience adverse symptoms that affects normal activity	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. At PSI above 400, general population should avoid outdoor activity. Everyone should remain indoors, keep windows and doors closed and minimize physical exertion.