IUFRO 7.01 Symposium: “Forest Fires and Air Pollution Issues”

Monday, September 11, 2006
Riverside Convention Center, Victoria Room

Abstracts

Meeting co-sponsored by the USDA Forest Service, Pacific Southwest Research Station; USDA Region 5 Air Quality Program; and the Joint Fire Science Program

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Program

8:00 - 8:10 *Organizational Remarks*

8:10 - 8:20 *Welcome from the Director of the USDA Forest Service, Pacific Southwest Research Station* – James Sedell

8:20 - 8:30 *Welcome from the National Leader of Atmospheric Sciences Research, USDA Forest Service Washington Office* – Allen Riebau

Session I "General Information & Wildland Fire Emissions" (Allan Legge, Chair)

8:30 – 8:45 *Global perspective on wildland and prescribed fires – history, present day and future outlook* (Johann G. Goldammer and Meinrat O. Andreae; Germany)

8:45 – 9:00 *Climatic and weather factors affecting fire occurrence and behavior* (Francis M. Fujioka, A. Malcolm Gill, Domingos X. Viegas, B. Mike Wotton and Shyh-Chin Chen; USA, Australia, Portugal and Canada)

9:00 - 9:15 *Effects of wildland fire on regional and global carbon stocks in a changing environment* (Allen Solomon and Sue Conard; USA)

9:15 - 9:30 *Characterizing sources of forest fire emissions* (Roger Ottmar, Ana Isabel Miranda, David Sandberg; USA and Portugal)

9:30 – 9:45 *Trace-gas emissions from burnings in tropical forest and savanna of Brazil* (Phillip Riggan; USA)

9:45 – 10:00 *Airborne remote sensing of wildland fires in California and Brazil* (Phillip Riggan; USA)

10:00 – 10:15 *Discussion*

10:15 – 10:45 Break

Session II "Effects of Wildland Fires on Ambient Air Quality" (Gerhard Mueller-Starck, Chair)

10:45 – 11:00 *Effects of forest fires on air quality and visibility in North America* (Douglas Fox, Roger Ames, Bret Schichtel, William Malm, and Allen Riebau; USA)

11:00 – 11:15 *Real-time smoke prediction systems* (Susan M. O'Neill, N Narasimhan. Larkin, Jeanne Hoadley, Graham Mills, Joseph K. Vaughan, and Roland Draxler; USA and Australia)

11:15– 11:30 *Estimating contributions of wildland and prescribed fires on diurnal patterns of ozone in Southern Sierra Nevada, California* (Haiganoush Preisler, Sharon Zhong, Annie Esperanza, and Julide Koracin; USA)

11:30 – 11:45 *The influence of grassfire on atmospheric environment* (Sharon Zhong, C. B. Clements, G. Aumann, P. Potter, S. Goodrick, and X. Bian; USA)

11:45 – 12:00 *Discussion*

12:00 – 13:15 Lunch Break

Session III "Regional Impacts of Wildland Fires" (Kevin Percy, Chair)

13:15 – 13:30 *Assessment of forest fires impact and emissions in the European Union based on the European Forest Fire Information System* (Paulo Barbosa, Ilaria Palumbo, Jan Kucera, Andrea Camia, Jesus San-Miguel, and Guido Schmuck; Italy)

13:30 – 13:45 *Forest fires and air quality issues in southern Europe* (Ana Isabel Miranda, Enrico Marchi, Millan Millan, and Marco Ferretti; Portugal, Italy, and Spain)

13:45 – 14:00 *Spatial and temporal trends in distribution of forest fires in central and eastern Europe* (Barbara Ubysz, Ryszard Szczygiel, and Tomasz Zawila-Niedzwiecki; Poland and Germany)

14:00 – 14:15 *The 2002 mega-fire event in central Russia: meteorology, optical properties of the atmosphere, air quality, and unexpected consequences* (Nataly Ye. Chubarova, Nickolay G. Prilepsky, Alexei N. Rublev, and Allen R. Riebau; Russia and USA)

14:15 – 14:30 *Remote sensing applications of wildfire and air quality effects in China* (John J. Qu, Allen Riebau, and Yongqiang Liu; USA)

14:30 – 14:45 *Smoke from wildfires and prescribed burning in Australia: health and environmental issues* (Tina Bell and Mark Adams; Australia)

14:45 – 15:00 *Discussion*

15:00 – 15:30 Break

Session IV “Ecological and Land Management Issues” (Martin Lorenz, Chair)

15:30 – 15:45 *Managing smoke from wildfires and prescribed burning in southern Australia* (Alan Wain, Graham Mills, Lachlan McCaw, and Tim Brown; Australia and USA)

15:45 – 16:00 *Effects of warmer climate on stress complexes in forests of western North America* (Don McKenzie, David Peterson, and Jeremy Littell; USA)

16:00 – 16:15 *Ecological changes in forests caused by fires in California and Baja California* (Richard A. Minnich; USA)

16:15 – 16:30 *Air pollution increases forest susceptibility to wildfires in southern California* (Nancy E. Grulke, Richard A. Minnich, Timothy Paine, Alex Dunn, and Deborah Chavez; USA)

16:30 – 16:45 *Wildfire effects on forest carbon and nutrient budgets and water quality in Sierran forests* (Dale W. Johnson, J.D. Murphy, W.W. Miller, and R.F. Walker; USA)

16:45 – 17:00 *Managing forests affected by air pollution, climate change and altered fire regimes near urban areas* (Michael Arbaugh, Trent Procter, and Annie Esperanza: USA)

17:00 – 17:15 *Discussion*

17:15 Adjourn

Session I “General Information & Wildland Fire Emissions” (Allan Legge, Chair)

Impacts of vegetation fire emissions on the environment, human health and security – a global perspective

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Air pollution generated by vegetation fires is a phenomenon which has influenced the global environment in prehistoric and historic time scales. Although historic evidence of the impacts of vegetation fire smoke on societies is rather scarce, there are indications that vegetation fire smoke has been a factor which influenced society significantly in the Middle Ages. In the recent decades increasing application of fire as a tool for land-use change has resulted in more frequent occurrence of extended fire and smoke episodes with consequences on human health and security. Some of these events have been associated with droughts that are attributed to inter-annual climate variability or possible consequences of regional climate change. In metropolitan or industrial areas the impacts of fire smoke may be coupled with the emission burden from fossil fuel burning and other technogenic sources, resulting in increasing vulnerability of humans. The paper reviews magnitude and role of pyrogenic gaseous and particle emissions on the composition and functioning of the global atmosphere, human health and security. A exemplary historic review of land-use fire smoke impacts on European society in the Middle Ages is followed by an analysis of contemporary pyrogenic air pollution episodes throughout the world. Special emphasis is given on radioactive emissions generated by fires burning in peatlands and on terrain contaminated by radionuclides. The transboundary effects of vegetation fire smoke pollution are a driving argument for developing international policies to address the underlying causes and avoidance of excessive fire application, sound fire and smoke management practices and protocols of cooperation wildland fire management at international level.

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Climatic and weather factors affecting fire occurrence and behavior

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Wildland fire occurrence and behavior are complex phenomena involving essentially fuel (vegetation), topography and weather. Fire managers around the world use a variety of systems to track and predict fire danger and fire behavior, at spatial scales that span from local to global extents, and temporal scales ranging from minutes to seasons. The nature of the fire management application determines the makeup of the planning tool, which usually incorporates one or more computer models. A new generation of fire planning tools to predict fire occurrence and fire behavior is emerging, taking advantage of advances in computing technology. A review of fire danger and fire behavior modeling systems from Australia, Europe, and North America is presented, including not only operational tools that have been in use for decades, but also newer models that profoundly enhance the spatial and temporal resolution of the resultant predictions. Linkages between these models and air quality models could very likely improve the mapping and prediction of air pollution due to wildland fires.

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Effects of wildland fire on regional and global carbon stocks in a changing environment

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Every year tens of millions of hectares are burned globally. Some are burned intentionally for land conversion, pasture renewal and other reasons, but most of the area burned is by wildfire. The estimates of burned area available in the literature vary widely, but satellite remote sensing data are increasing their accuracy. In some years and in some regions, the carbon emissions from wildfire can exceed those from all fossil fuel sources combined. Studies and modelling efforts published over the past several years indicate that, especially in the boreal zone and some tropical areas, changing climate is likely to increase the extent and frequency of wildfires. All of this is important information to consider in evaluating the regional and global effects of wildfire on carbon stocks and on atmospheric carbon compounds. However, the actual intensity of feedbacks between fire and climate will depend not only on changes in the area that is burned annually, but, perhaps more importantly, on how those fires burn, and on how the ecosystems respond and recover after the fires. Changes in burn severity can result in large differences in the amount of fuel consumed, and in the capacity of the ecosystem to recover carbon rapidly after a fire. Recent work also indicates that even surface fire may cause significant changes in soil respiration—these changes can either increase or decrease the net effects of fire on atmospheric carbon. Postfire recovery to a different vegetation type--which may occur in response to changing climate, invasive species, unusually high burn severities, or other factors--also has the potential to affect the amount of carbon storage on the landscape. Past and future vegetation and fire management activities also play a role in ecosystem condition and carbon storage, although the nature and magnitude of these impacts is a source of considerable debate. Improved understanding of the effects of changing fire regimes on all aspects of the carbon cycle is needed before we can fully predict the magnitude, or even the direction, of the effect of changing fire regimes on global carbon balance.

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Characterizing sources of emissions from wildland fires

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Smoke emissions from wildland fire can be harmful to human health and welfare, impair visibility, and contribute to greenhouse gas emissions. To estimate potential impacts of wildland fire smoke, the generation of emissions needs to be characterized. This requires explicit knowledge of the size of the area burned, characteristics and condition of the fuels, amount of fuel consumed in each combustion phase, and emission factors for specific pollutants. Although errors and uncertainties arise in the process of estimating emissions, the largest errors are related to the characteristics and condition of the fuels and fuel consumption. We present an overview of two software tools that enable land managers, regulators, and scientists to create and catalogue fuelbeds and predict fuel consumption and emissions by combustion phase during wildland fires. The Fuel Characteristic Classification System (FCCS) offers a set of fuelbeds, representing the United States, that were compiled from published and unpublished literature, fuels photo series, fuels data sets, and expert opinion. The system enables modification and enhancement of these fuelbeds to represent a particular scale of interest. The FCCS reports assigned and calculated fuel characteristics for each existing fuelbed stratum including the canopy, shrubs, nonwoody, woody, litter/lichen/moss, and duff. Consume 3.0 software imports the FCCS fuelbed characteristics and along with fuel condition and weather information, calculates the amount of fuel consumption and emissions by combustion stage for all fuelbed components. The empirically-based fuel consumption models were derived for forest and shrublands in the western, southeastern and boreal regions of the United States. The FCCS and Consume are being used in a regional and national fire emissions inventory. Although the FCCS and Consume 3.0 were built for the United States, the conceptual framework is applicable worldwide.

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Trace-gas emissions from burnings in tropical forest and savanna of Brazil

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Wildland and agricultural fires may now be contributing to global climate change depending on their extent and the strength of their emissions. Best available estimates have considerable uncertainty but do show that biomass combustion is likely a globally important source of atmospheric aerosols, methane, hydrocarbons, carbon monoxide, carbon dioxide, methyl bromide, and nitrous oxide. They also show that burning in tropical savanna and forest are likely the greatest sources of global fire emissions.

The importance of fire emissions is not well established at present, partly due to large uncertainties in the extent and frequency of burning, the ecosystem impacts, and the strength of emissions. It is clear that fire is nearly ubiquitous during the dry season in tropical regions such as central Brazil. A comprehensive assessment is needed, not only to understand the potential course of climate change, but to devise strategies for managing trace gas emissions.

In 1990 the USDA Forest Service and the Brazilian Federal Institute of the Environment and Renewable Natural Resources (IBAMA) established a cooperative program on *Fire and Environmental Change in Tropical Ecosystems* with a goal of assessing the potential impacts of fire and fire emissions on climate, ecosystem productivity, and human health. The assessment of fire impacts on the atmosphere, including estimates of greenhouse gas emissions from burning in Cerrado (tropical savanna) and tropical forest, involved in situ intensive aircraft-based measurements of trace gases in active fire plumes during campaigns in 1992, 1994, and 1995.

In this chapter we will analyze results from the collection of 82 trace gas samples from active fire plumes and a total of 135 samples from plumes or dispersed smoke in central Brazil, in an area from 2.5º to 17.8º S latitude and 46º to 49.8º W longitude. This constitutes one of the most extensive data sets of tropical fire emissions yet collected. Quadratic regression models have been very successful in accounting for variance in the concentrations of methane and primary hydrocarbons. Models accounted for more than 95 percent of the variance in the dependent variable even though plumes originated from a wide range of fire situations in savanna, slashed forest, moist pasture, and agricultural fields.

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Airborne remote sensing of wildland fires

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Wildland fires create an environment in which inattention to the surroundings or ignorance of immediate possibilities can be fatal or extremely expensive. Especially with complex or uncertain fire behavior, rapid and critical changes in weather, and obscuring terrain and smoke, good fire intelligence is at a premium for fire fighters and the public that depends on them. Fire intelligence and an ability to understand or predict fire behavior are needed for deployment of resources and decision making during tactical fire suppression; for fire-fighter safety; to mitigate fire effects in the environment; and to design, justify, and evaluate strategies for fire management including the use of landscape-scale fuel treatments.

Airborne remote sensing at infrared wavelengths has the potential to accurately quantify large-fire properties and behavior, including energy release or intensity, residence time, fuel consumption rate, rate of spread, and soil heating. Remote sensing at a high temporal rate can track fire-line outbreaks and acceleration and the location and rates of spotting ahead of a fire front. Together with GPS-based asset tracking, remote sensing could improve fire-fighter safety by showing the spatial relation of fire fighters and equipment to the fire, and especially to regions of high fire intensity or activity.

Yet infrared imagers and imaging spectrometers that are now used for operational fire management and earth remote sensing typically are saturated by—and incapable of measuring—the very bright infrared light that radiates from large wildland fires. Thus they provide a limited or even distorted view of fire activity.

The Forest Service Pacific Southwest Research Station and its partners have addressed this problem by developing and applying infrared imaging systems for the first quantitative, high-resolution measurements of wildland fires.

In this chapter we will discuss the basis for quantifying large-fire properties by remote sensing and provide examples from fires in California mixed-conifer forest, northern coniferous forest, chaparral of Mediterranean-type climates in southern California, and savanna and tropical forest of Brazil.

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Session II "Effects of Wildland Fires on Ambient Air Quality" (Gerhard Mueller-Starck, Chair)

Effects of forest fires on visibility and air quality in North America

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The United States' Clean Air Act establishes the goal of preventing future and remedying existing visibility impairment in 156 Class I areas (national parks, wilderness areas and wildlife refuges). A key element in implementing this goal is the Regional Haze Regulation (RHR). RHR is based on relating impaired visibility, using metrics of extinction (inverse mega-meters and/or "deciviews"), to concentration of particulate matter smaller than 2.5 micrometers in diameter, PM2.5. PM2.5 itself is also subject to national ambient air quality standards. Forest, rangeland and agricultural fires, both natural and human caused emit both primary and secondary (formed in the atmosphere from gaseous organic carbon emissions) PM2.5. This paper will review the RHR and what we know about relationships between fire emissions, their fate in the atmosphere and their contribution to regional haze and PM2.5.

Specifically, we will present results from the Interagency Monitoring of PROtected Visual Environments (IMPROVE) network of 175 sites throughout the US collecting aerosol samples every third day. We will use the IMPROVE data to display the ratio of organic carbon to elemental carbon which may suggest the relative magnitude of industrial and transportation sources and fire and biogenic source contributions at different locations. We will review source apportionment modeling approaches based on relationships between temporal and spatial fire emission inventories and atmospheric back trajectories. Finally we will review on-going efforts to identify fire tracers capable of uniquely identifying different types of fire contributions to regional air quality.

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Real-time smoke prediction systems

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Smoke from fire is a local, regional and often international issue that is growing in complexity as competition for airshed increases globally. The impacts from large wildfires are well known to cause air quality impacts that are detectable on continental scales and beyond, even crossing oceans. Yet planned burns – in both wildlands and agricultural fields - are being increasingly regulated based on air quality concerns, causing a point of potential friction between land managers, farmers, and air regulators. In the US, land management agencies are increasing their use of prescribed fire in order to counteract a history of fire suppression that has left many forests ripe for catastrophic wildfires. Meanwhile wheat stubble burning and grassland burning are part of the typical practices of many farming communities. Many of these burning activities occur at rural/urban interfaces and can impact sensitive populations such as children, asthmatics and the elderly. In order to maximize the ability of land managers and farmers to utilize planned burning activities for ecological and crop productivity reasons while at the same time avoiding adverse air quality impacts, tools for predicting the impacts of these activities in a cumulative sense from multiple sources are needed

Four tools that meet these needs are currently operational in the US and Australia. They link together existing fuels data, emissions models, and meteorological, dispersion and trajectory models to produce a prediction of smoke concentrations from prescribed fires, wildfires, or agricultural fires across a region. The BlueSky system is operational for regional domains across the US and obtains prescribed burn information and wildfire information from databases compiled by various agencies. The ClearSky agricultural smoke prediction system is operational in the States of Idaho and Washington and burn location information are input via a secure website by regulators in those states. The NOAA-HYSPLIT smoke prediction system is initialized with satellite fire detections and is operational across North America. Finally, the Australian smoke prediction system is operational for Australian wildfires. While there was an initial development focus for each of these systems, each system has found a user base well beyond it's initial demonstration. For example, BlueSky was initially designed to aid land managers in go/no-go burn decisions but is now being used by wildfire incident command teams to inform the public and plan burnouts, and by air quality regulators to determine fire impacts on local air quality. Evaluation of these systems is difficult because all systems suffer from the compounding of uncertainty associated with each step of the modeling process, from the choice of the meteorology and dispersion models, to the fuels, consumption & emission estimations. However, despite the uncertainty associated with each prediction, the systems are proving useful to a clientele of land managers and air quality regulators as a point of interagency understanding from which to negotiate the conflicting needs of ecological fire use and minimal air quality health impacts.

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Estimating contributions of wildland and prescribed fires on diurnal patterns of ozone in southern Sierra Nevada, California

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Concerns about smoke from wildland and prescribed fires have been increasing during the past decade. There is a growing awareness that smoke from fires can expose individuals and populations to hazardous air pollutants. The San Joaquin Valley of California and the Sierra Nevada has been recognized as one the most polluted areas in the United States and is upwind of the federally managed lands in the southern part of the Sierra Nevada Mountains. Because wildland fires produce the precursors of ozone and particulate matter formation, the effect of fires on air quality in the southern Sierra Nevada is a serious air quality management issue.

In this paper we will describe a statistical model for estimating effects of fires on diurnal ozone levels in the presence of other causes of ozone fluctuations, including temperature, wind speed and wind direction. Predicted PM2.5 values from the BlueSky Smoke Modeling Framework will be used as a surrogate for the amount of pollution reaching a given site from specific fire events.

Using the statistical model we will study the skill of the BlueSky variable in characterizing the variations in diurnal ozone levels and, consequently, in predicting impacts of particular fires events on ozone. At locations where PM2.5 values are measured, we will also study the accuracy of the BlueSky output in predicting amounts of particulate matters at various distances from a specific pollution source.

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The influence of grassfire on atmospheric environment

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Grass fires, although not as intense as forest fires, present a major threat to life and property in regions of drought in the Great Plains of the United States. Recently in the spring of 2006, major wildland grass fires at the Texas and Oklahoma border burned nearly 5 million acres and destroyed over 400 homes, resulting in a lost of 11 lives and an estimated 10,000 head of livestock, marking it the worst fire season to date for Texas and Oklahoma. In addition to posing direct threat to properties and lives, fire plumes also pose a health threat by dramatically increasing concentrations of particulates, carbon dioxide, and other pollutants.

Understanding fire behavior and its impact on the surrounding environment has been hindered by the lack of observational data within and immediately downwind of the fire perimeter. To fill this gap, a field experiment was conducted in February 2006 near Galveston, Texas. Fluxes of heat, moisture as well as carbon dioxide produced by a prescribed burn of a 155 acre tall-grass prairie were documented quantitatively using a 42-m tower instrumented at multiple levels with fast response sensors in the middle of the prairie, and a tethered balloon sounding system immediately downwind of the fire. The measurements revealed significant increases of temperature (up to 20 ^{o}C), heat flux (greater than 1000 W m^{-2}), and CO_2 (larger than 2000 ppmv) within the smoke plumes as well as strong up and downdrafts (up to 5 m s^{-1}) induced by the fire. Furthermore, the observations revealed an increase in water vapor mixing ratio of more than 2 g kg^{-1} or nearly 30% over the ambient air, which is in good agreement with theoretical estimate of the amount of water vapor release expected as a combustion byproduct from a grass fire. These observations provide direct evidence that natural fuel load grass fire plumes may modify the dynamic environment of the lower atmosphere through not only heat release and intense mixing, but large addition of water vapor. The data from this experiment are being used to validate dynamic and numerical models used to predict fire behavior and smoke plumes.

Session III "Regional Impacts of Wildland Fires"
(Kevin Percy, Chair)

Assessment of forest fires impact and emissions in the European Union based on the European Forest Fire Information System

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This chapter presents an analysis on the number of forest fires and burned area distribution as retrieved by the European Forest Fire Information System (EFFIS) database. Furthermore, for the 5 European Union (EU) countries that have the largest contribution in terms of burned area, 98% of the total burned area in the EU occurs in Portugal, Spain, France, Italy and Greece, estimates of atmospheric emissions of CO2 and other trace gases are shown. These estimates were done for a number of years for which burned area maps have been retrieved using remote sensing imagery, and then combined with fuel load and burning efficiency figures, to estimate the quantity of burned biomass. Emission factors were further used to estimate trace gas and aerosol emissions produced by vegetation fires. Fuel load was estimated based on values found in the literature and from existing land cover maps of Europe. Average burning efficiency and emission factors were retrieved from the literature. The results obtained show the spatial and temporal trend of forest fire emissions for the 5 countries since year 2000.

Forest fires and air quality issues in southern Europe

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Each summer, southern Europe is affected by forest fires, which are responsible for the emission to the atmosphere of large quantities of pollutants and for several air pollution episodes that have been measured by the air quality monitoring networks and felt by the population. The main purpose of this paper is to analyze the impact of forest fires on the air quality of specific regions of southern Europe. Two main approaches were used that are based on modeling work and on the cross-analysis of measured air quality values and forest fires characteristics.

Concerning the cross-analysis, data from the summer of 2003, which was critical in terms of burned area, was studied aiming to identify air pollution episodes clearly related to the occurrence of forest fires. It was possible to identify and quantify several particulate and photochemical air pollution episodes caused or enhanced by smoke from forest fires.

A case study was selected and a mesoscale air quality modeling system, specifically adapted to forest fires, was applied to simulate the impact of fires on the air quality. Emissions from forest fires were estimated based on the burned vegetation and the fire characteristics. Also emissions from the aircrafts used to fight forest fires were calculated. These emissions were compared to total ones from national European inventories. Meteorology was simulated by the modeling system for the fire duration and emissions were inputted to the model. Modeling results were compared to measured air concentration values from the monitoring networks showing a skill that can be considered as reasonable taking into account all the uncertainties inherent to this kind of simulation. A comparison between air pollutants concentration values estimated without forest fire emissions and with those emissions allowed to verify their contribution to air quality deterioration and to the exceeding of the European air quality directives thresholds.

Also, the effect of the accumulated pollutants, which could be raising the cloud condensation level of the air masses, leading to fewer summer storms and triggering a series of concatenated feedback effects that could result in a very rapid desertification in the area, was analyzed with a special focus on the possible consequences of precipitation losses on the vegetation, including increased forest fires.

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Spatial and temporal trends in distribution of forest fires in Central and Eastern Europe

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Forest in Central and Eastern Europe-CEE (Austria, Belorussia, Czechia, Estonia, Germany, Hungary, Latvia, Lithuania, Poland, Slovakia and Ukraine) covers 56 285 000 ha, which is about 5% of European total forested area. Forest cover in CEE makes 30% of land use and is much lower than European average of 46%.

Almost 50% of the forest under study is formed by coniferous species and only 30% by deciduous ones. Forest younger than 60 years old grows on 57% of that area. These factors, together with climate conditions cause that on the main part of CEE middle forest fire risk is noted. Only some areas of Germany and Poland were classified to the highest fire risk degree (in 3 grade scale).

Between 1991 and 2001 some 387 680 fires burning 757 000 ha were noted in CEE which is 37% of the total number and 13% of the total burnt area of European fires. The most hazardous situation is observed in Poland where over 60% of fires and burns happen.

Forest Research Institute in Warsaw has prepared a method of emission calculation based on the Polish experience. As the type of forest and environmental condition in the described area are similar, some calculations on emissions from neighbour countries, based on FAO's forest fire statistics were elaborated. The study presents the information on CO, CO_2, NO_x, hydrocarbonaceous, as well as on the solid and liquid particles emissions.

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The 2002 mega-fire event in central Russia: meteorology, optical properties of the atmosphere, air quality, and unexpected consequences

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The Zvenigorod Moscow State University Biological Station Sanctuary is composed mainly of sub-boreal forest is located about 70 km west of Moscow, Russia. In 1999, a long-term study began on the effects of climate variability, solar radiation, air pollution, and their synergistic impacts on forests. As part of this study, automated weather stations, measurements of total solar radiation and ultraviolet radiation, atmospheric aerosol loadings, and forest plant phenology were begun both at Zvenigorod and in Moscow itself. In 2002, a major drought occurred in Central Russia which resulted in unprecedented wildland fires. Smoke emissions from these fires resulted in perhaps the most significant exposures of fire smoke to a major population area in recorded history. Due to instrumentation and field studies being conducted as part of the on-going study, the magnitude of the smoke intrusion, information on climatic factors exacerbating the event, and effects on forest plants were recorded. Unprecedented reductions in solar radiation were observed. Additionally, decreases in solar radiation from smoke coincided with changes in forest herbaceous plant development, flowering, and seeding.

Remote sensing applications of wildfire and air quality effects in China

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Wildland fire is one of major natural hazards in China. Fire information is a fundamental and yet challenging prerequisite for understanding natural fire regimes. Remote Sensing (RS) is important tools for monitoring both a global and a regional fire hazard and air quality emissions. In addition, satellites can provide nearly global coverage of the Earth with spatial resolutions and repetition rates that vary from one platform to another. Satellite RS has emerged as a useful technique for fire detection. With the unique features of global coverage, high-resolution, and continuous operation, RS is able to obtain detailed information of fire occurrence, extent, structure, and temporal variation, together with the related fuel properties. Satellite instruments such as the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) have been applied to field experiments and routine monitoring of wildfires and air quality emissions. Among these instruments, AVHRR is the most suitable for this study because of its combined advantages of long-period daily data over two decades and moderate spatial resolution of 1 km. MODIS has more spectral bands and higher spatial resolution comparing with AVHRR. Fire hazard potential estimation from satellites is extremely useful for large scale and remote areas. Scientists of National Satellite Meteorology Center (NSMC), Chinese Meteorology Administration (CMA) have monitored wildland fire and air quality emissions using multi satellite measurements for years. MODIS applications of fire monitoring have been done by the Chinese Academy of Forestry Sciences. Landsat applications of land cover also been taken by the Geography Institute, Chinese Academy of Sciences. Land cover has been used to determine fuel type and loading and to estimate fire emissions. This paper will review satellite remote sensing applications of the of air quality effects from wildland fire burning in the China.

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Smoke from wildfires and prescribed burning in Australia: health and environmental issues

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Much of Australia is seasonally hot and dry and as a consequence is an extremely fire-prone country. Biomass burning ranges from annual savanna fires in the north to devastating forest fires in the south. In addition, prescribed burning (the controlled application of fire) is being used more frequently as a means of reducing fuel loads, for maintenance of plant and animal biodiversity and in forestry practices. Despite this, there are few Australian studies investigating the production or composition of smoke from biomass burning in comparison to the Northern Hemisphere. There is also a relatively small body of literature relating the effect of wildfire smoke on vegetation (in Australia and elsewhere). The bulk of these publications are concerned with the effect of smoke on germination of seed with little information available on the direct effects of smoke from biomass burning on the physiology and biochemistry of plants. This paper will firstly outline the knowledge of emissions and effects of smoke from prescribed and wildfire in Australia on human health and the environment.

A large proportion of the vegetation of Australia is composed of forests dominated by native species of *Eucalyptus* and *Acacia* while large expanses of plantations are dominated by single species of *Eucalyptus*. The production of volatile organic compounds (VOCs) by such vegetation is estimated to be up to 60% of total VOC emissions. For example, the characteristic blue haze in the Dandenong Ranges in Victoria and the Blue Mountains in New South Wales is associated with emissions of VOCs from eucalpyts. In the second part of this paper, we will outline an emerging research area in which we explore the links among the production of VOCs via the terpene biosynthesis pathway of native Australian species, combustion processes of fuels and the composition of smoke from burning such biomass.

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Session IV “Ecological and Land Management Issues”
(Martin Lorenz, Chair)

Managing smoke from wildfires and prescribed burning in southern Australia

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Biomass burning, whether resulting from wildfire, fuel reduction or silvicultural operations often stimulates community concerns about hazards from fine particulates and chemical compounds contained in smoke. Recognition of the need for a response to these concerns has led to the development of a smoke management research program within the Bushfire Cooperative Research Centre, in conjunction with fire and land management agencies and the Australian Bureau of Meteorology. This program aims to assist land management planning by predicting where smoke from scheduled burns would be transported, thus providing the opportunity to avoid burning in situations where there is potential for adverse community impact. The primary tool provided is a dispersion model forecast, currently based upon HYSPLIT, and using input from Bureau's operational mesoscale NWP models. Decision tools are applied in a similar manner for prescribed burning and wildfires, and have been used by agencies to provide community advice and to avoid smoke hazards during aircraft operations.

In Australia the responsibility for management of forests and other public lands rests largely with state governments, and multiple government agencies may be involved in burning operations. Management practices and community perceptions also differ from region to region according to social and environmental factors. This paper will describe the strategies used by several land management agencies to minimize community impact of smoke from prescribed burns, with particular emphasis on the way in which the dispersion model forecasts are integrated into their decision support systems. Included are details of HYSPLIT's configuration, several examples of its use in prescribed and wildfire events, and the research direction being pursued to improve both the quality of the dispersion forecasts and to enhance the use of these forecasts in agency planning.

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Effects of a warmer climate on stress complexes in forests of western North America

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A warmer climate in western North America will first affect those forests that are most susceptible to soil moisture stress. Increased water deficit will accelerate the normal stress complex experienced in forests, which typically involves some combination of multi-year drought, insects, and fire. Symptoms of prolonged drought and insects are currently manifested in extensive dieback of pine species in the pinyon-juniper forest of the American Southwest, an area where only a few tree species can survive. Less severe dieback has occurred in mixed conifer forests of the Sierra Nevada, an area also subjected to air pollution stress. Bark beetles are proliferating and killing millions of hectares of dry forest in the northern interior of western North America, setting up the prospect of large and intense fires. Recent analyses of area burned by fire in the 11 large Western states of the conterminous United States indicate that fire area will be at least twice as high in the warmer climate predicted by general circulation models. Such a large increase in disturbance superimposed on forests with increased stress from drought and insects may have significant effects on growth, regeneration, and long-term distribution and abundance of forest species.

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Ecological changes in forests caused by fires in California and Baja California.

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In California forests, fire regimes—the pattern of burning on the landscape—accommodate the long-term dynamics and spatial distribution of cumulative growth (fuel) and water demand in plant assemblages at scales of decades to centuries. The assessment of fire regime properties (size, intensity, interval, removal of biomass) is assessed empirically using georeferenced time-series aerial photographs and geographic information systems. The landscape approach permits probabilistic studies on variance and "means" of fire properties that correlate with landscape variables such as topography, climate, and primary productivity. While the earliest aerial photographs (1930s) do not permit site-specific assessment of temporal properties, the study of large areas constrained for vegetation permits assessment of modal fire properties for individual plant assemblages (space substituted for time). A more effective approach is to compare plant assemblages under different land management systems: fire suppression in California and no fire control in Baja California, Mexico. Transnational differences in fire regime properties of individual assemblages permit hypothesis testing concerning baseline (pre-suppression) status of ecosystems, and long-term changes in fire properties due to suppression. These changes include fuel build-up states beyond the natural variability, the non-randomization of large fires to high weather risk states, increase in fire size and severity, destabilization of forests to other vegetation states, and enhanced sensitivity of forests to climatic perturbations and pollution. Suppression has greatest influence on productive systems that respond rapidly to changes in fire properties, in particular forests with surface fire regimes (mixed-conifer forest, *Pseudotsuga macrocarpa*). Productive stand-replacement assemblages with serotinous tree species (*Pinus coulteri*, *P. attenuata*, *Cupressus forbesii*) exhibit plastic response to changes in fire regime. There is little evidence of change in unproductive pinyon-juniper and subalpine forest where fire intervals are longer than the suppression period. Catastrophic drought and forest mortality in 2002-03 illustrate the critical role of fire history in landscape scale evapotranspiration demand.

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Air pollution increases forest susceptibility to wildfires in southern California

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Many factors increase susceptibility of forests to wildfire in California. Among them are increases in human population, changes in land use, increased fire starts, fire suppression, and frequent droughts. These factors have been exacerbating forest susceptibility to wildfires over the last century in southern California. Here we report on the significant role that air pollution has on increasing forest susceptibility to wildfires. Air pollution, specifically ozone and wet and dry deposition of nitrogenous compounds from fossil fuel combustion, has significantly increased since industrialization of the region after WWII. Ozone and elevated nitrogen deposition cause specific changes in forest tree carbon, nitrogen, and water balance that enhance individual tree susceptibility to drought, bark beetle attack, and combined, and these changes contribute to whole ecosystem susceptibility to wildfire. For example, elevated O_3 and N deposition increase leaf turnover rates, N content of leaf litter, and decrease decomposability of litter. Uncharacteristically deep litter layers develop in mixed conifer forests affected by air pollutants. Elevated O_3 and N deposition decrease the proportion of whole tree biomass in foliage and roots, the latter effect increasing tree susceptibility to drought and beetle attack. Because both foliar and root mass is compromised, overwinter carbohydrates are stored in the bole, perhaps contributing to increased beetle fecundity. Elevated O_3 increases drought stress by significantly reducing plant control of water loss. The resulting increase in canopy transpiration, combined with [O_3 + N deposition]-induced decreases in root mass significantly increase tree susceptibility to drought stress, and when additionally combined with increased bole carbohydrates, contribute to success of bark beetle attack. Phenomenological and experimental evidence is presented to support the role of these factors contributing to the susceptibility of forests to wildfire in southern California.

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Wildfire effects on forest carbon and nutrient budgets and water quality in Sierran forests

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A wildfire burned through previously-established research plots allowing comparisons of pre- and post-fire nutrient pools and fluxes. the fire resulted in the loss of 30.9 Mg ha^{-1} or 20% of total ecosystem C and 491 kg ha^{-1} or 15% of total ecosystem N. Vegetation was the most significant portion of the total ecosystem C loss (72%), mostly in the form of tree boles (77% of total vegetation). Loss of O horizon plus large woody debris accounted for 33% of total ecosystem C loss. The fire had no significant on soil C content. Vegetation loss accounted for 52% of ecosystem N loss, again mostly in the form of boles (60%). O horizon plus large woody debris losses accounted for 29% of total ecosystem N loss, and soil N loss accounted for 19% of total ecosystem N loss. Soil N contents summed over the entire profile did not differ significantly before and after the fire, even though there was a statistically significant decrease in N concentrations the A horizons. The fire caused short-term increases in ammonium and nitrate in both soil solution and surface runoff, but total leaching rates over the first three years post fire were small (< 30 kg ha^{-1}) relative to combustion losses. We conclude that the most lasting effects of the fire on the terrestrial ecosystem were direct effects on volatile losses, and previous research has shown that such losses can be easily made up for by post-fire N fixation if N-fixing vegetation invades the site.

Managing air pollution impacted forests in California

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Fuels treatments (prescribed fire and mechanical removal) proposed for National Forest lands in California are intended to reduce fuel accumulation and wildfire frequency and severity, as well as to protect property located in the wildland-urban interphase. However, prescribed fires produce gases and aerosols that affect local and regional air quality that is already impacted by urban and agricultural air pollution. The problem is complicated by air pollution from urban sources predisposing forests and other ecosystems to catastrophic fires. High Ambient ozone (O_3) and elevated levels of nitrogen (N) deposition weaken and predispose trees to bark beetle attacks, increase foliar senescence and fuel build-up, and increase water stress during drought periods. If fuels treatments are not aggressively conducted in air polluted forests, then wildland fires may become more frequent and severe causing worse public health and welfare affects or catastrophic mortality may occur. However, because of the air pollution research, fire research and fuels management are largely separate areas, there is little understanding about how to manage changes in forest ecosystems impacted by air pollution that may be creating increased fire hazards in forests near urban areas. Better understanding of air pollution and smoke interactions, multiple pollutant deposition effects on forest development, and interactions between air pollution, drought and insects is needed in order to manage air pollution impacted forests, protect public health and allow for socially & ecologically acceptable use of fire as a management tool. This could be accomplished by innovative wide-scale monitoring efforts (field and remotely sensed), and development of models predicting spatial and temporal distribution of air pollution and smoke resulting from forest fires, and incorporation of air pollution effects into forest mensuration models used to predict stand development. In addition, management efforts will be carried out in a very complex regulatory environment that requires consideration in developing successful strategies and identifying supporting research needs.

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