

WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR AGRICULTURAL METEOROLOGY

CAGM Report No. 99

**FIRE IN FORESTS, RANGELANDS AND
AGRICULTURAL SYSTEM**

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Report of the Joint Rapporteurs on the Impact of Agrometeorological Advisories and
Information on Operational Aspects of Forestry Planning, with Emphasis on
Wildland Fire Ecology, Including the Use of Prescribed Fire in
Rangelands and Forests Preventing and Combating
Wildfires in Forests and Rangelands

WMO/TD No. 1313

Geneva, Switzerland

January 2006

ABSTRACT

The Commission for Agricultural Meteorology (CAgM) at its 12th Session held in Accra, Ghana, 18-26 February 1999, established the Joint Rapporteurs on the Impact of Agrometeorological Advisories and Information on Operational Aspects of Forestry Planning, with Emphasis on Wildland Fire Ecology, Including the Use of Prescribed Fire in Rangelands and Forests Preventing and Combating Wildfires in Forests and Rangelands. The terms of reference for the Joint Rapporteurs include the following:

- a) To survey and summarize the existing agrometeorological advisories and information managing forests and rangelands (wildlands) particularly with respect to fire and on the potential effects of changing climate;
- b) To describe, using case studies from Member countries, the impacts of such advisories and information;
- c) To suggest ways and means to improve further the quality of such agrometeorological advisories and information for applications in forestry;
- d) To submit mid-term information on the progress of activities of the joint rapporteurs and a final report to the president of the Commission not later than six months prior to the next session of the Commission.

This report was prepared by the joint rapporteurs, Mr Alan Riebau from the United States Department of Agriculture's Forest Service in Washington, D.C. and Douglas Fox from Colorado State University in the United States.

The report gives an overview of the data needs for fire advisories such as fire danger and fire behavior meteorology, fire weather forecasting, and fire and air quality/smoke management. The report summarizes the use of observation networks in fire meteorology and mesoscale meteorological modeling for fire meteorology and air quality and it reviews the World Health Organization Health Guidelines for Episodic Vegetation Fire Events. The report concludes by discussing the future challenges and needs in the field such as automated weather stations, mesoscale meteorological models and fire management, remote sensing of fire and smoke, and computer assisted training and education for agricultural meteorologists.

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FIRE IN FORESTS, RANGELANDS AND AGRICULTURAL SYSTEMS

I. INTRODUCTION

This report will survey and summarize existing information about fire as it is used for managing forests, rangelands and agricultural lands; as a source of local, regional and global air pollution, and; as an agent of climate change. It will reference case studies from Member countries. It will also suggest ways and means to further the quality of agro-meteorological advisories and information for wildland fire applications. We will use the term wildland fire to include both planned and unplanned fire in forests and rangelands. Agricultural fire is distinguished from wildland fire because it is used to directly support agricultural production.

Fires burn in vegetative fuels largely as a function of weather conditions. The WMO has addressed this issue over the years by developing tools to evaluate and predict the effects of weather and climate on fires and their potential (Reifsnyder and Albers 1994). This report, first published in 1978 in cooperation with UNEP, contains a discussion of the general principles of fire-danger and fire-weather forecasting and presents proposals for the development of a universal fire-danger-rating system. It also covers the establishment of fire-weather observing stations, the application of lightning-locating systems to forest-fire detection and the use of remote-sensing techniques to wildland fire management.

Historically this concern about fire danger has been driven by a concern about large fires, particularly those burning out of control and endangering human lives and property. The emphasis has been toward drought indices of various sorts and their potential to provide some warning dangerous conditions are developing. Two additional aspects of fire have attracted concern in the international community more recently. Fire's influence on and response to the changing global climate and, on a smaller scale, fire's effects on regional and local air quality have become international issues. Particularly as countries have sought to improve the public health, wildland and agricultural burning have attracted increasing attention as sources of concern and become the target of regulatory attention.

Wildfires and prescribed fires differ in many respects. Wildfires are unplanned and usually caused by lightning, human negligence or malice. Wildfires usually happen during extended dry periods when soil moisture levels are low and plants are severely stressed. Such poorly timed fires can result in reduced forage yields and other undesirable effects. In contrast, prescribed fires are managed, that is they are planned and conducted at an appropriate time, and in a safe manner, to meet specific management objectives. Typically, desirable plants are dormant, soil moisture is sufficient to support plant growth after the fire, and favorable environmental conditions ensure predictable fire behavior and simplify any control problems.

Prescribed fire is not a "magic bullet" that alone will erase past management failures or make up for improper management in the future. However, prescribed fire can yield many benefits if it is used with other sound management practices. We have learned though the past century that many forest ecosystems have evolved with fire as an integral agent of change. In fact, it has become apparent that excluding fire from such forests, leads to poor health, reduced productivity, and dramatically increased wildfire risks. In grasslands, prescribed fire can increase grass nutritive quality, palatability, availability, and yield, reduce hazardous fuels, suppress unwanted plants, and improve wildlife habitat. Grass quality, palatability, and availability are improved because the fire removes dead plant material and improves access to new growth. If soil moisture is adequate, grass yields increase because baring and darkening the soil surface allows it to warm more quickly and stimulate earlier growth, and because competing weeds are suppressed (Ortmann, et. al. 1998).

How a plant responds to fire depends on the height above ground of its growing points, a function of plant maturity and plant-growth characteristics. If growing points are above the soil surface, within reach of lethal temperatures, the plant likely will be damaged or killed. Perennial grasses that tolerate fire when dormant have growing points at or below the soil surface. Generally, a fire will raise the temperature of the upper centimeter or so of soil only momentarily.

Annual grasses and broadleaf plants are damaged when burned during active growth. Biennials also can be damaged during intense fires if their growing points are raised. Perennial plants differ in their responses to burning based on reproductive strategies and position of the growing points. Perennial grasses are damaged if stems are elongated. Timing of fires can be used to favor desirable grasses and suppress undesirable grasses. Plants that reproduce solely by seed, such as eastern redcedar (*Juniperus virginiana* L.), can be killed by fire if their growing points at the twig tips are exposed to lethal temperatures. In contrast, perennial plants that can reproduce vegetatively from subsurface buds are usually only top killed. These plants, such as smooth sumac (*Rhus glabra* L.), initiate new shoots after fire. Woody plants resist heat damage when their growing points are above the flames. Their bark also protects vascular tissue. The protective quality of bark depends on its thickness, composition, fissuring, and moisture content. These factors affect the bark's ability to absorb and transmit heat. Since bark is the only protection for vascular tissue, young, thin-barked saplings are not as heat resistant as older plants. In addition, moist bark absorbs, holds, and transmits heat more than dry bark.

Recent information suggests that on the global scale (Figures 1 and 2) biomass burning is much more extensive and widespread than previously thought. Biomass burning is dominated by burning forests, grasslands and agricultural lands following the harvest for land clearing and land conversion. Biomass burning occurs in the tropics (tropical rain forests and savanna grasslands), in the temperate zone, and in the boreal forest, and is a truly global phenomenon. Combustion products of biomass burning include carbon dioxide, carbon monoxide, methane, nonmethane hydrocarbons, nitric oxide, nitrous oxide and

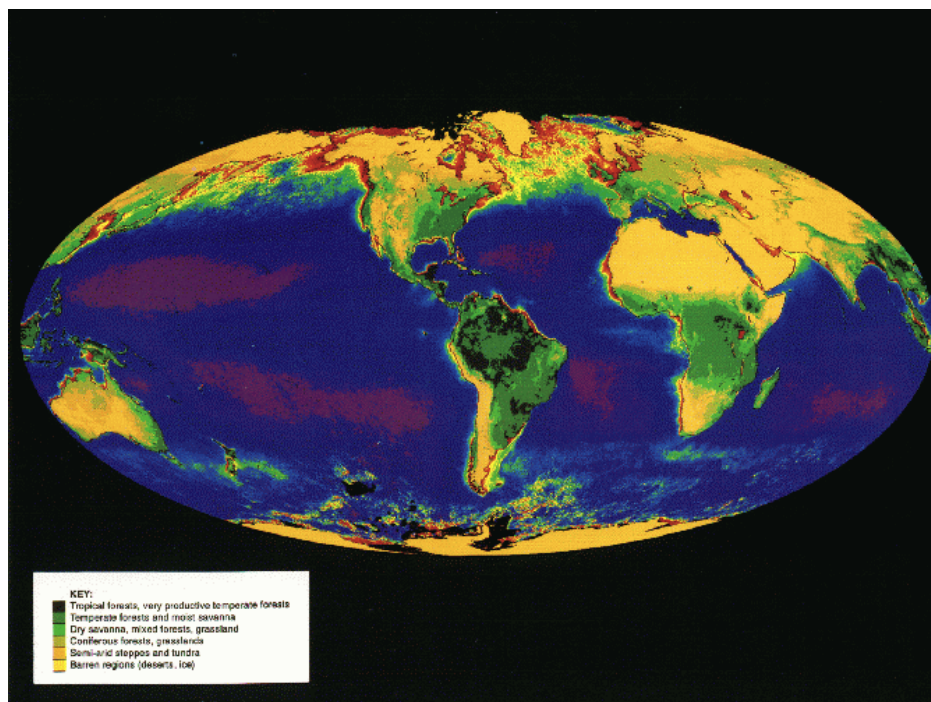


Figure 1. First image of the global biosphere (Source: NASA Goddard Space Flight Center)

atmospheric particulates. Carbon dioxide, methane, and nitrous oxide are important greenhouse gases that impact global climate. Carbon monoxide, methane, nonmethane hydrocarbons, and nitric oxide are chemically active gases that lead to the chemical production of ozone in the lower atmosphere or troposphere. Tropospheric ozone is a pollutant and harmful to living things, including humans. Recent measurements suggest that biomass burning may be a significant global source of methyl bromide. The bromine released from this compound leads to the chemical destruction of ozone in the upper atmosphere or stratosphere. Unlike tropospheric ozone, stratospheric ozone is very beneficial to living things, including humans, since it absorbs biologically lethal ultraviolet radiation emitted from the Sun. Particulates produced during biomass burning impact the radiation budget of the Earth and, hence, impact global climate. It is thought that as much as 90% of global biomass burning is human-initiated and that such burning is increasing with time. Hence, biomass burning may be an important driver for global atmospheric and climatic change.

During the last week of July 1999, there were reportedly some 500 fires in the Indonesian Riau province alone where the air pollution standard index (PSI) hit 978, compared to a danger level of 301 and a normal range of 0-50. Schools were closed, sports activities were cancelled, traffic -- including air and sea traffic -- was disrupted, and people were advised to wear masks. If other areas of Sumatra are included, the number of fires is estimated to run into the thousands by the Indonesian government's Environmental Impact Office. It's the same story in Kalimantan province: the Indonesian State Minister for the Environment Panangian Siregar told the official Antara news agency that he himself counted at least 280 fires as he flew over West Kalimantan.

Of course, this is not just an environmental, but also an economic, problem. It affects air and maritime activity -- therefore trade, can potentially cause a loss of hundreds of millions of dollars in tourism revenues, besides being a menace to public health. Economists estimate that it cost Singapore somewhere between \$240 million and \$425 million in 1996, on a conservative estimate. Region-wide, the figure would easily run into the billions of dollars -- and that's just for one year (Lebel 1999).

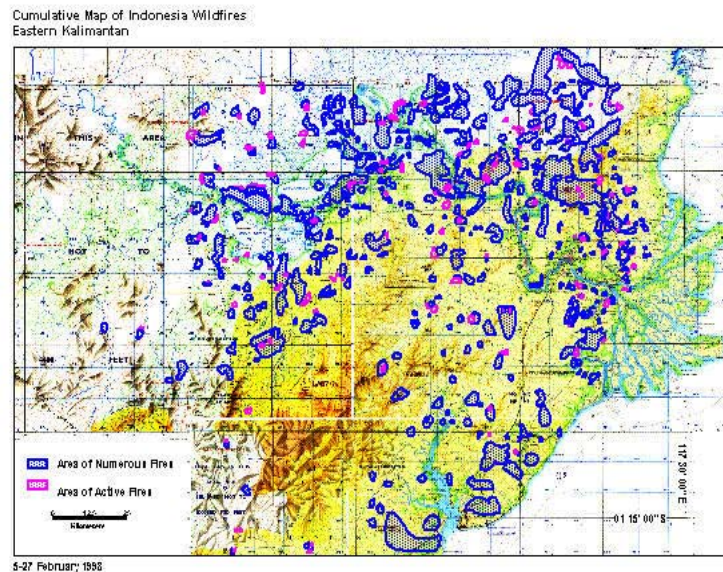
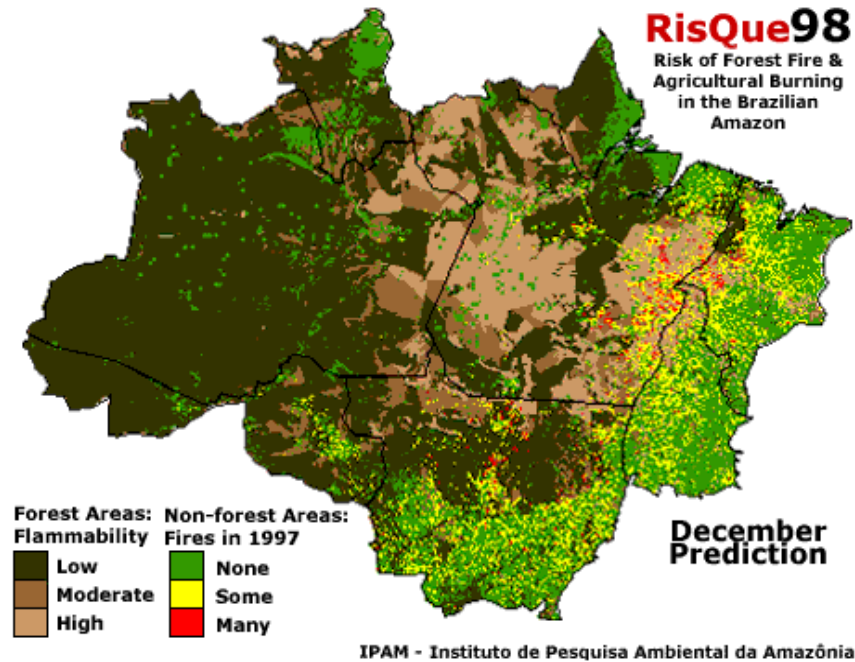


Figure 2. Indonesian cumulative fire map prepared by USDA Forest Service National Forest Systems Engineering



Monthly fire prediction maps are the final product of RisQue98. These maps rank the flammability of the region's remaining forests (shades of brown) and the risk of fire on non-forest lands (shades of yellow and red). Forest flammability is a function of both drought and logging. We assume that the soil was full of water in May 1997, and add to this soil water map the "Precipitation minus Evapotranspiration" data layer calculated through the date of the map. (Current rainfall data were used for May 1997 through September 1998. "Average" rainfall conditions were assumed for the months of October through December of 1998.) Based on field studies of forest flammability, we classify as "High" the flammability of forests that have depleted plant-available soil water in the upper 5 meters of soil. We classify as Moderate flammability those areas with less than one month's supply of soil water remaining. We assume the fire risk in non-forested areas is related to the amount of burning recorded by the NOAA satellite in 1997.

Figure 3. Fire in the Amazon, 1997. Source: The Institute of Environmental Research for Amazônia - IPAM, Federal University of Pará (UFPA).

Fire attracts the attention of three distinct scientific communities, forestry, climatology, and air pollution.

Fire is, of course, inexorably linked with the vegetation and ecosystems in which it operates. Forest ecosystems, especially in arid and semiarid environments, require fire for their stability, growth and health. So, foresters and ecologists interested in forest growth, forest health, ecosystem sustainability and species preservation and biological diversity all have interests in wildland fire. Specifically, forest ecologists are interested in fire as a tool for ecosystem development and as a mechanism of forest ecosystem management.

Second, fire strongly influences the global climate, especially the chemical climate. Fire is a significant global source of CO₂ as well as of carbon and other aerosol particles. Fire, particularly wildfire, can release overwhelming amounts of CO₂ into the atmosphere and thus must be considered in any attempts to manage global climate.

Thirdly, the air pollution that results from forest and agricultural fires can be a significant danger to public health and welfare. Recent fires in Southeast Asia, especially in Indonesia highlighted the regional and international nature of these concerns.

Fire's influence on forest productivity is among the primary concern of forestry agencies. For example, the Economic Commission for Europe (ECE) supports: the periodic collection and publication of fire statistics of the member states. Fire statistics are collected and evaluated by the UN-ECE Trade Division, Timber Section, Geneva. The statistics include all Western and Eastern European countries, countries of the former Soviet Union, the U.S.A. and Canada. The last data set covers the period 1995-97. The statistics can be obtained via: <http://www.unece.org/trade/timber/ff-stats.html>.

The ECE also hosts an FAO/ECE/ILO Team of Specialists on Forest Fire as a component of its Joint Committee on Forest Technology, Management and Training. The Team of Specialists on Forest Fire, created in the 1980s, provide a critical link in communication and cooperation between fire scientists, managers and policy makers. They produce the International Forest Fire News (IFFN) in support of the Global Fire Monitoring Center (GFMC); organize seminars; and promote synergistic collaboration between government, non-government institutions, and individuals, especially science and technology transfer. The scope of the work of the Fire Team includes the countries outside the ECE region because there is no similar institutional arrangement available in other FAO regions.

The International Forest Fire News (IFFN) has been published bi-annually since 1988. Currently the printed version of IFFN is subscribed by more than 1000 agencies, research laboratories and individuals all over the world. Starting with its 19th issue (August 1998) the IFFN are available on the website of the "Global Fire Monitoring Center" (<http://www.fire.uni.freiburg.de>). The website includes all past issues since 1990 which are organized in 64 country folders and several other special files.

The FAO/ECE/ILO Team of Specialists on Forest Fire conducted the following seminars between 1981 and 2000:

- Fire Suppression Technologies (Poland 1981)
- Fire Prevention (Spain 1986)
- The Socio-Economic Environment of Fire (Greece 1991)
- Forest, Fire, and Global Change (Russian Federation 1996)
- The First Baltic Conference on Forest Fires (Poland 1998)
- The Baltic Exercise on Fire Information and Resources Exchange - BALTEX FIRE 2000 (Finland 2000)

II. DATA NEEDS FOR FIRE ADVISORIES

As mentioned in the fire related literature referenced above, fire depends on the weather. Meteorological data are critical to forecasting the potential for fires to get started and for their behavior once started. A third area of meteorological data needed relates to predicting smoke trajectories and dispersion.

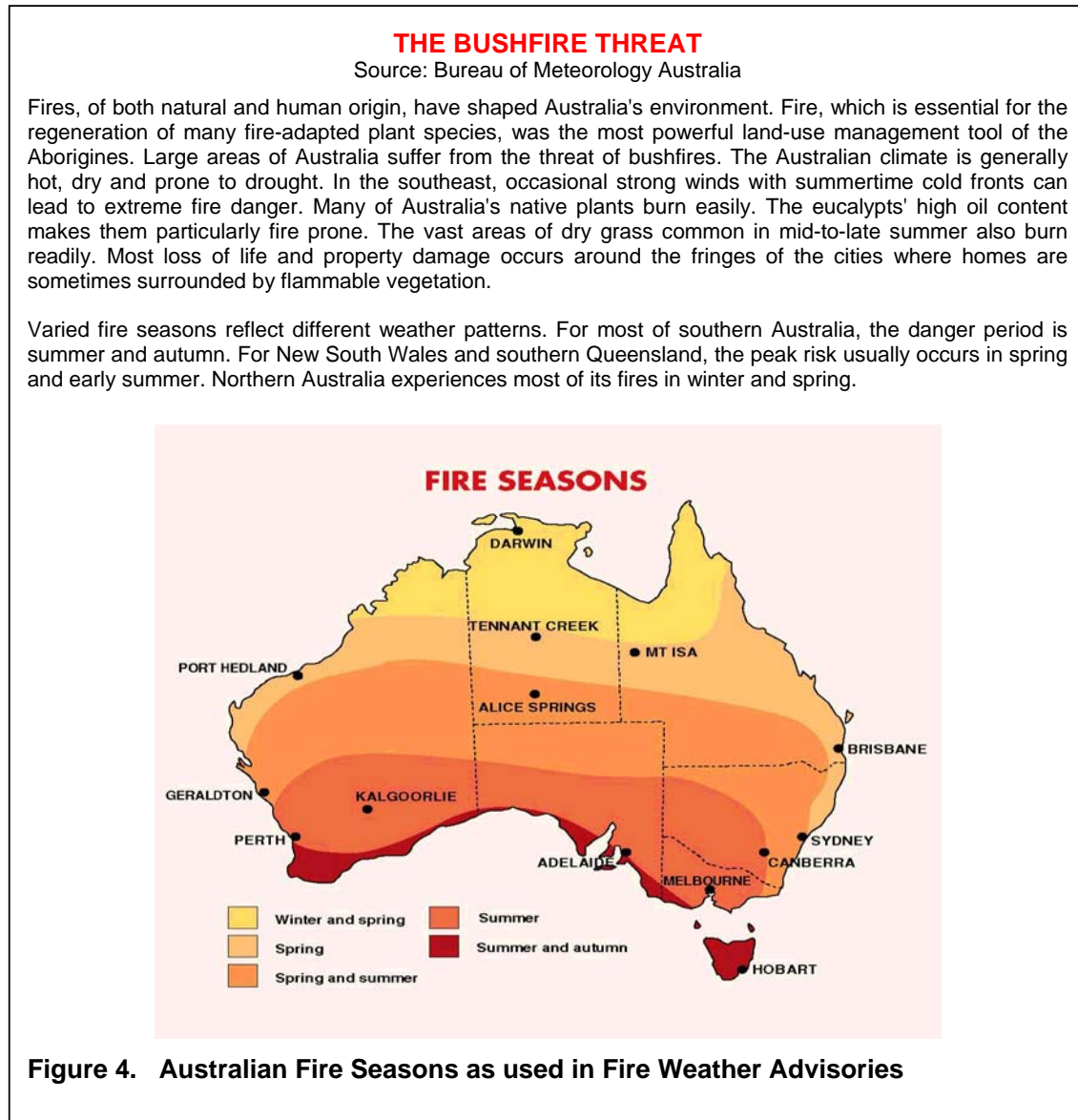
II. A Fire Danger Meteorology

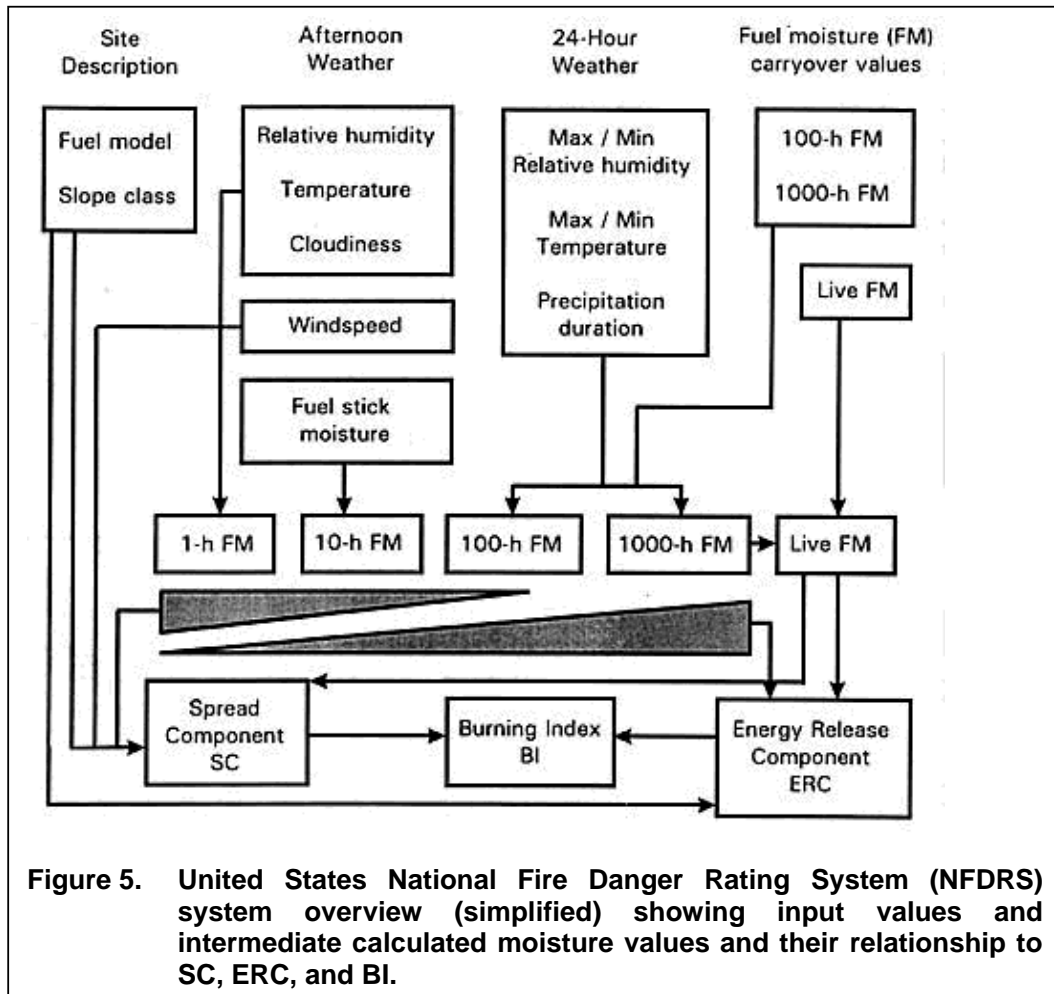
The potential for fire to get started is generally referred to fire danger. Fire danger is generally assessed through the moisture content of the fuels involved in the fire. Basically, the concept is that fire occurs when sufficient energy, in the form of a "fire brand" is brought into contact with fuels. These fuels will sustain fire when their moisture content is below a critical threshold, called the 'moisture of extinction' namely the moisture content that will extinguish the fire. As fuels are heated, for example, by being near an existing fire, the heating vaporizes any existing moisture in the fuel until it falls below the moisture of extinction when the fuel begins to burn.

In some climates there is a clear seasonal pattern to forest fires. The Australian approach to bush fire danger is illustrative of such a climate driven pattern, as shown in Figure 4.

Weather fires are seasonal or not, the primary meteorological data needed to assess fire potential are those data that can help to establish the moisture content of the fuels. Fire Danger rating systems have been constructed on the assumption that fuels are best characterized by their physical size. The US system for example, is based on 1, 10, 100, and 1000-hour time lag fuels. These, so called “number” hour fuels, are defined as sizes of fuels that will take the length of time in question, 1, 10 etc. hours to approach the moisture of extinction. A full review of fire modeling can be found in Andrews and Queen (2001).

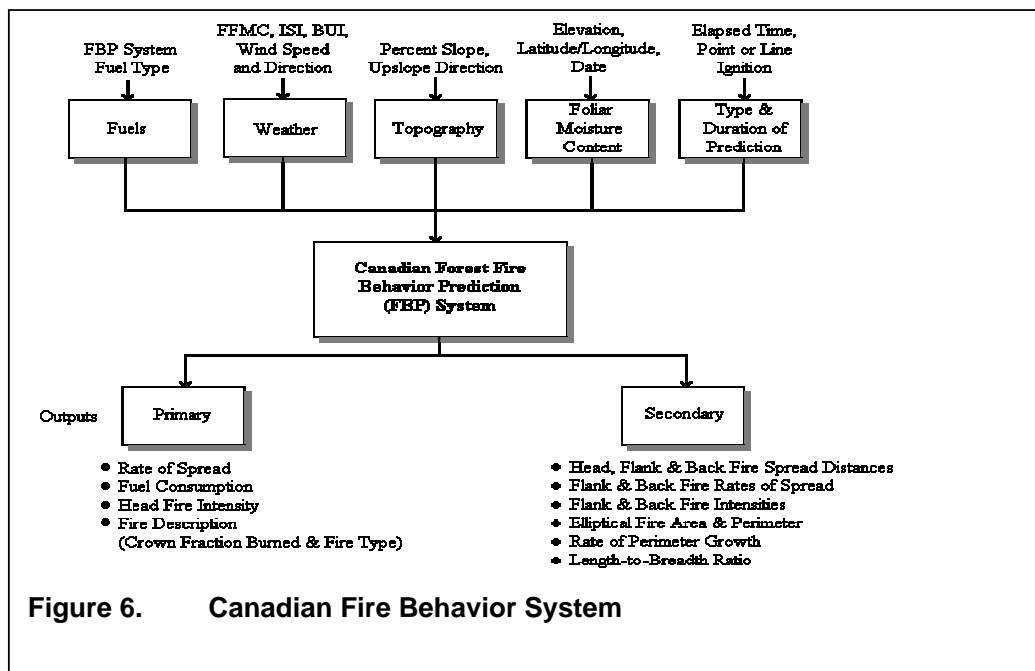
Perhaps the most concise way to illustrate the meteorological data needed for fire danger considerations is by showing the wiring diagram, Figure 5 for the US National Fire Danger Rating System (Andrews and Bradshaw 1992). This figure illustrates the current and historical data needed for calculating the various parameters involved in fire danger rating. Certainly details between fire danger calculation procedures will vary but the general need for meteorological data is likely to be similar. In general, the data are needed for the most critical period of time that is toward mid-day, 2 pm local time is used in the US National Fire Danger Rating System.





II.B Fire Behavior Meteorology

Fire behavior calculations are in principle much the same as fire danger calculations however there is a greater need for local wind field data. Fires respond to the local wind and especially toward its interaction with local terrain and the vegetation canopy itself. As well, to predict fire behavior it is necessary to predict the weather, especially the wind speed & direction, temperature, humidity and precipitation. The Canadian Fire Behavior model, Figure 6, illustrates an example of forest fire behavior prediction schemes.



II.C Fire Weather Forecasting

Fire weather forecasting involves predicting all of these meteorological conditions and is a specialized branch of general weather forecasting. An excellent example of the types of data needed and utilized for fire weather forecasting can be found at the US Weather Service, Boise Idaho office at <http://www.boi.noaa.gov/fwx.htm>. This office is co-located with the US National Interagency Fire Center, the prime leader in coordinating wildland fire fighting throughout the US. Their site describes an assortment of tools that can be useful for fire weather forecasting. Illustrative of the information used for fire weather forecasting is this loop of satellite and model products prepared by the Boise Fire Weather office for a daily briefing of national fire fighting leaders. This can be found at http://www.wrh.noaa.gov/boise/fire_wx_brief.htm

Perhaps the dominant forecasting element for forest fire is drought. There are a number of drought indices available for the forecaster's use. In the United States, these are all summarized with the Drought Monitor depicted in Figure 7.

U.S. Drought Monitor

April 16, 2002
Valid 8 a.m. EDT

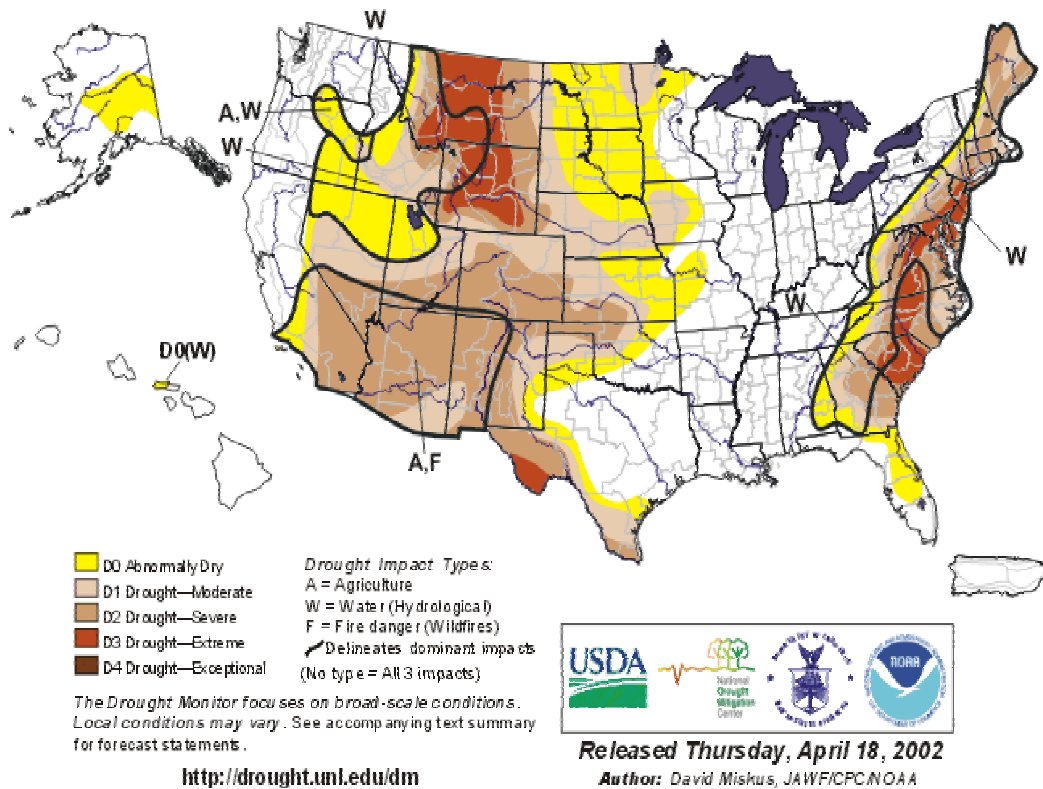


Figure 7. The Drought Monitor is a comprehensive index developed from considering the six different parameters, including the Palmer Drought Index, soil moisture, streamflow, precipitation, and satellite NDVI.

Fire weather forecasters also utilize the Haines Index which is a lower atmosphere stability index computed from the morning (12Z) soundings from RAOB stations across North America. The index is composed of a stability term and a moisture term. The stability term is derived from the temperature difference at two atmosphere levels. The moisture term is derived from the dew point depression at a single atmosphere level. This index is correlated with large fire growth on initiating and existing fires where surface winds do not dominate fire behavior. The Haines Index ranges from 2 to 6 for indicating increasing potential for large fire growth. Figure 8 shows a map of the Index for the United States.

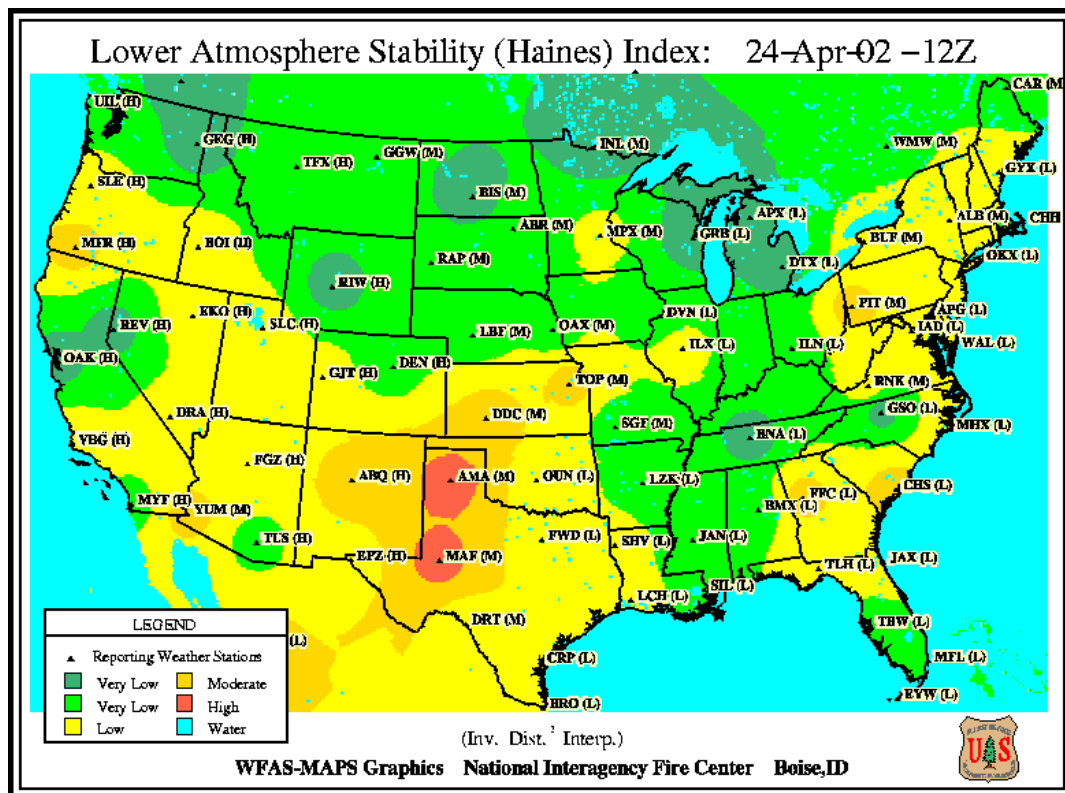


Figure 8. Lower Atmospheric Stability Index, the Haines Index, for the United States.

II.D Fire and Air Quality --- Smoke Management

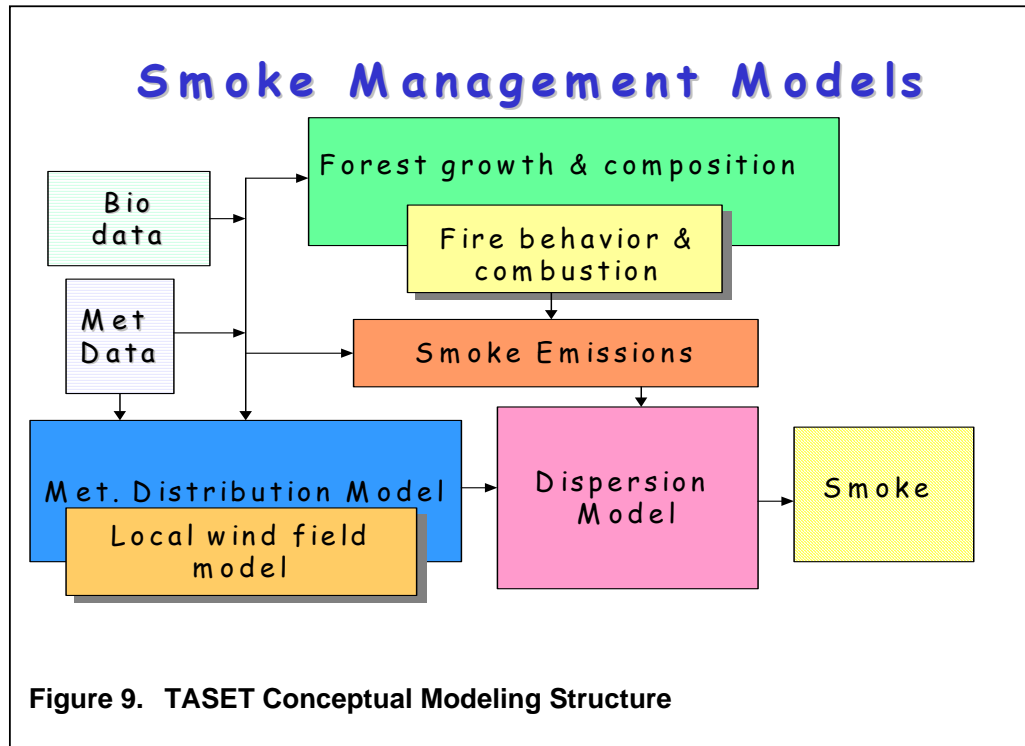
As mentioned above, a current relevant topic is providing meteorological data to help identify the potential for and actual occurrence of smoke from forest burning. A detailed review of the tasks required was recently undertaken by the Technically Advance Smoke Evaluation Tools (TASET) project and is available over the web at <http://www.cira.colostate.edu/smoke>.

The TASET project was funded to review existing smoke management tools and prioritize research and development needs in the United States. The project developed a broad view of smoke management that looked beyond smoke dispersion techniques (Figure 9). Of the nine specific recommendations made by the project, emphasis was given on emission inventory development, use of mesoscale meteorology models in fire management, and observation techniques for smoke concentrations.

The current state of the science associated with smoke modeling involves coupling a mesoscale wind field model with either a eulerian or lagrangian dispersion model. There are two basic types of wind field models, diagnostic and prognostic. Diagnostic models are based on the interpretation of observations while prognostic models are forecasting tools based on utilizing our understanding of atmospheric processes to simulate the evolution of meteorological patterns from an initial measured state. An excellent example of the application of diagnostic modeling is illustrated by the VENT project. This project provides a climatological wind and dispersion index, a so-called ventilation index, for the United States.

Some examples of mesoscale models are MM5, WRF and RAMS. The state of science currently is that many facilities around the world have the capacity and capability to run these mesoscale prediction schemes operationally.

The wind models are generally coupled with one or another form of dispersion model. Such models as Cal Puff, REMSAD and CMAQ are examples of tools that can be utilized for this purpose.



III. USE OF OBSERVATION NETWORKS IN FIRE METEOROLOGY

The RAWS network provides fire weather data to United States federal agencies involved in forest and range fire management. Each day during the fire season (April – October), early-afternoon (13:00 LDT) weather observations are collected from each RAWS site in the US for use in developing fire danger variables. The number of RAWS stations has increased significantly over the years. Figure 10 illustrates the location of the over 1300 RAWS sites in the United States. There are also numerous portable RAWS that are generally deployed for wild fires and during prescribed burns.

RAWS fire weather observations are sent from each site via satellite communications to the National Interagency Fire Center in Boise and selected sites are also directly input to the Weather Information Management System, a computer based analysis system. The data are combined with site fuel type and topographic parameters and processed through algorithms to generate fire danger index product maps to forecast fire potential. Forecasts are also made for next day weather, dead fuel moisture, greenness, drought, the atmospheric stability Haines index, and lightning ignition efficiency.

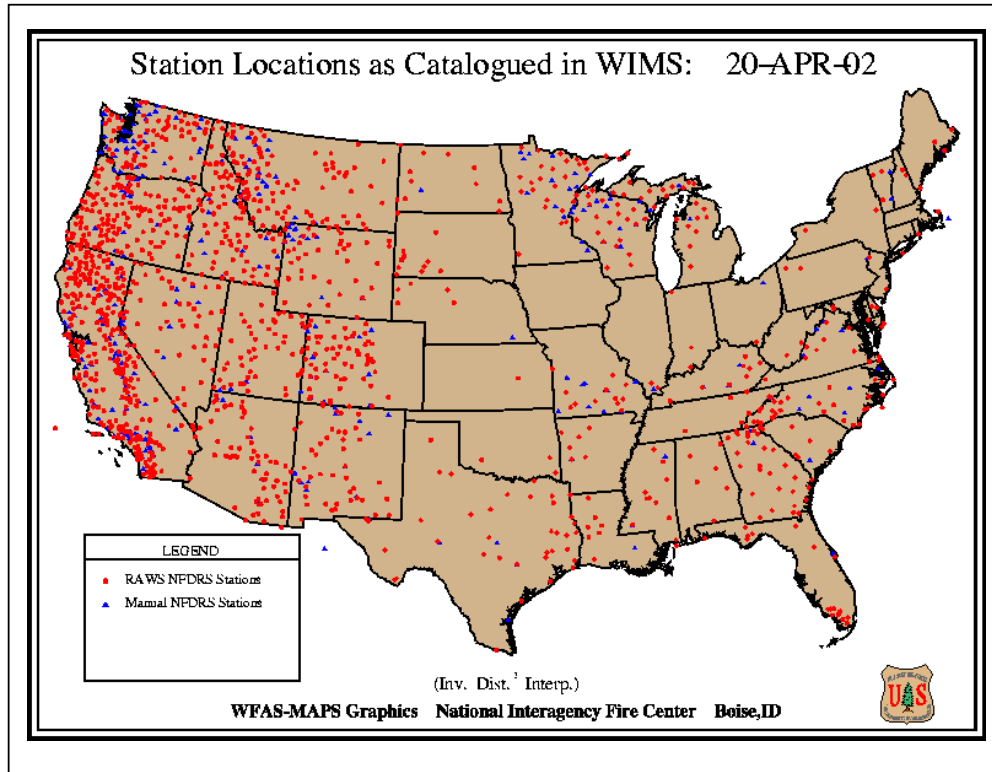


Figure 10. Location of the over 1300 RAWS in the United States of America.

The RAWS sensor suite and data collection procedures are as follows:

- Rain gauge/precipitation – tipping bucket, continuous cumulative 0.01 inch; some may be heated;
- Wind speed – mph, 10 min mean just prior to data transmission;
- Peak wind speed (gust) – max mph from previous hour prior to data transmission;
- Wind direction – degrees, 10 min mean prior to data transmission;
- Direction of peak gust – degrees;
- Air temperature – °F, instantaneous at time of data transmission;
- Fuel temp. (optional) - °F, instantaneous;
- Relative humidity – percent, 10 min mean prior to data transmission;
- Battery voltage – volts, instantaneous;
- Barometric pressure (optional) – inches of Hg, instantaneous;
- Fuel moisture (optional) – grams H₂O in a 100 g pine dowel, instantaneous;
- Solar radiation – watts/m², instantaneous;
- Coordinated universal time – WWV clocks required;
- Data collection Platform (DCP) (Vaisala/Handar, FTS, or Campbell Sc.)
<http://www.fs.fed.us/raws/>

Two recent studies (Brown et al. 2001; Marsha, 2001) and a third (Brown et al. 2002) have explored statistical approaches for analyzing RAWS data to develop a methodology for optimizing inter-regional RAWS deployments. Brown et al. (2002) performed a quality control on historical data improving metadata files for almost 250 RAWS sites in California. Such improved data will be used in support of fire danger rating analyses and RAWS climatological characteristics across the state. Marsha (2001) constructed a correlation matrix for the parameters air temperature (AT) and humidity (RH) and a wind dispersion statistic for most of the RAWS sites in the FS Pacific Northwest Region. The matrix is defined as:

$$[(90^{\text{th}} \text{ percentile peak WS}) - (\text{median peak WS})] / (\text{median peak WS})$$

The rationale for this work was to reduce station redundancy without sacrificing quality these parameters were chosen because these elements have profound effects upon on fire danger indices and fire behavior. Stations with highly correlated AT and RH were removed from the matrix until all correlations fell below a pre-set threshold. Results indicated that some stations could be removed from the network. For wind speed sensitivity, a rating (0,1, or 2) was then calculated using both the 90th percentile peak WS and the dispersion statistic. Zero was considered “inadequate”, 1 was “adequate”, and 2 was “good” (Marsha 2001). This procedure was followed before running correlations for temperature and humidity so that only those stations with an adequate or good wind sensitivity rating were included in the correlation matrices.

Brown et al. (2001) identified four primary categories for RAWS data: fire danger, fire behavior, fire use, and other. Fire danger is of course, using the data to calculate daily fire danger indices and operations. Fire behavior means either the behavior during a fire event or the modeled behavior for planning purposes. Fire use refers to management practices such as prescribed burning. These three categories/applications are the force behind the RAWS network, its establishment, its continued operation and maintenance and the need to upgrade. The last category (other) refers to all applications that do not fit into the first three groupings including developing historical climatological analyses for a variety of purposes, for monitoring soil erosion, environmental restoration and risk assessment, budget analysis, forest health, ground water, watershed, and hydrologic assessments, weather impacts on wildlife, soils studies, and ecosystem model parameterization.

Decision making (short and long term) for fire management is an additional fire related use supported by RAWS data. For short term planning RAWS data supports: tactical planning during a fire, prescribed burning go/no go decisions, staffing levels and duty hours, fire behavior modeling, pre-positioning of resources, and providing weather information to incident commanders and fire crews. For long term planning RAWS data supports: budget preparation, fire resource needs, planning for fire prevention and pre-suppression, restoration of forest and range, seasonal droughts, modeling, seasonal fire danger analysis, and long term climate analysis.

IV. THE USE OF MESOSCALE METEOROLOGICAL MODELING FOR FIRE METEOROLOGY AND AIR QUALITY

IV.A Mesoscale Meteorological Modeling

Since the development of the European Centre for Medium Range Forecasting in Reading, England, in the early 1980's weather services worldwide have increasingly used Mesoscale and other sub-global scale models and analyses in their forecasting. The spatial resolution of these forecast models has steadily been reducing because of regularly

expanding computing capacity. Currently it is possible to simulate the meteorology of large regions with PC based computers. Accompanying the expansion of computing power has been the development of community models. Such community models as MM5 allow access to mesoscale forecasting models that have had a long heritage of development. They are maintained as state of the science capabilities and can be obtained at no cost from the developers. For example, MM5 is available from NCAR who also provides a regular training schedule and other support for it. The access to and availability of these models has vastly expanded the abilities of meteorologists from around the world.

The U.S. Forest Service Research and Development, recognizing the importance of weather intelligence for fuels reduction, to aid fire planning, fire operations and smoke management, last year initiated four regional fire weather and smoke modeling centers, the Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS). These centers will offer critical research knowledge and weather and smoke modeling support to Forest Service, States and other partners. A new national regional haze regulatory program to support Section 169A of the Clean Air Act, has been developing for the past several years. It is built around protecting visibility in 156 Class I areas in the United States by reducing human-caused visibility degradation. Eighty-eight of these Class I areas are Forest Service managed wilderness and the remaining are National Parks and F&W Wilderness. In October 2001, EPA released its proposed regulatory program. The program is complex, but basically it will require that States implement regulations to reduce emissions from identified air pollution sources in their State. Regulatory programs will be based on visibility monitoring conducted by the IMPROVE program (an interagency measurement program supported by EPA, Federal Land Managers and States) and data analysis and modeling to identify the emission sources and amounts of emission reductions required. To implement the Clean Air Act and new Regional Haze Rule, regulatory agencies require that the Forest Service become more active in smoke modeling and real-time emission tracking to better understand the impact of prescribed fire and wildfire on air quality and visibility. In addition, the National Fire Policy and Cohesive Strategy require improved understanding of smoke impacts that often limit our use of fire.

During wildfire events thousands of people can be affected by harmful smoke concentrations for long periods of time, but citizens tolerate very little smoke from prescribed burning. An automated, real-time, web-based smoke modeling system will address concerns from air regulators, smoke managers, and fire operations and planning. The functioning system will eliminate the burden on users for copious inputs, provide immediate feedback on accuracy, show cumulative effects of smoke from prescribed agriculture and forest burning across land ownerships, and create an efficient emission tracking system.

The National Fire Plan also calls for the enhancement of firefighting capacity and preparedness through research and development of fire weather and fire behavior models. Fire planners need better predictive models of fire behavior and fire hazard to increase the efficiency, effectiveness and safety of fire operations high resolution weather models coupled to fire behavior models will provide substantially greater detail of anticipated fire spread. This will allow better planning for the safety of firefighters and the public, and for more efficient and effective allocation of fire suppression resources.

To date five regional consortia, located in Athens, Georgia; East Lansing, Michigan; Riverside, California; Ft. Collins, Colorado, and Seattle, Washington have been developed. The FCAMMS have all developed high speed computing capabilities to support product delivery and on-going research. Three of the FCAMMS have brought super-computer level processing in FS R&D through the purchase of high-speed "Beowulf" PC clusters. The Pacific Northwest FCAMMS, has completed sensitivity analyses on fuel structure, fuel condition, ignition pattern, consumption, and emissions for use in an advance smoke modeling system called "BlueSky." At the Missoula Fire laboratory, initial feasibility discussions have begun to link high-resolution meteorological modeling products to fire behavior models. The Southern High Resolution Modeling Center FCAMMS has begun

initial development of model performance testing and delineation of its modeling domains. The Riverside Fire Laboratory FCAMMS has begun direct support activities to fire managers in Southern California and Hawaii, while developing cooperative links with Geographic Coordination Centers in all parts of the state. The East Lansing, Michigan FCAMMS has developed strategies for linking high resolution model outputs to fire weather indices and has begun implementation of nested modeling domains on its Beowulf PC cluster.

FCAMMS will be developing:

1. An automated, real-time smoke modeling framework that tracks daily emissions and shows cumulative impacts of smoke from wildland and agricultural prescribed fires;
2. Internet rapid-access system to mapped predictions of cumulative smoke, location of planned and accomplished burns, hourly concentration estimates at any point, and high-resolution (temporal and terrain) meteorology simulations;
3. Improved understanding of the role of numerical smoke models in fire planning and operations, management, and regulations, and;
4. Linkage of high-resolution meteorology simulations to fire behavior.

IV.B Fundamental Fire Behavior Applications

Such models are also increasingly recognized as important for fire behavior. Scientists at the National Center for Atmospheric Research (NCAR) in the United States have recently tied mesoscale model output with models directly linked to the advancing fire front in their on-going research to better understand fire. Using this coupled fire model, the scientists were able to examine a variety of wind speeds and observe, at resolutions as fine as 20 meters, how a fire's development can alter the circulation around it (Clark, et al. 1996).

Among their findings:

- 1) A fire's pattern of growth depends not only on large-scale winds but on the balance between those winds and a fire's heat output. If the winds relative to an advancing fire line are weak, and the heating is particularly strong, a fire can force its own circulations, possibly resulting in unstable, "blow-up" fire conditions. (It was a sudden blow-up that killed 14 firefighters near Glenwood Springs, Colo., in 1994.) On the other hand, strong winds relative to the fire line, though literally fanning the flames, tend to produce a more stable regime in which the fire is less likely to create its own circulation pattern. Thus, the fire's spread may be more predictable.
- 2) Air temperatures near a fire are lower than one might normally think. In the first several minutes of a new fire, the model shows surface temperatures soaring, which creates a chimney-like plume of rising air. Shortly thereafter, the atmosphere establishes a balance between the updraft (blowing at near-hurricane speeds as high as 30 meters per second) and the heat provided by the fire. In the model, the updraft strengthens and pulls in surrounding cooler air as a fire's heat output increases. This keeps air temperatures near the fire in the range of 60 to 100 degrees Celsius (C), even as the fire itself burns at more than 800 degrees C.
- 3) The model helps to explain a commonly observed trait of wind-driven fires that the growth of fingers of flame, spaced about a kilometer apart, form the main fire line. Previous researchers had proposed that the fingering was due to variations in either the fire's fuel or the local geography. However, the coupled model suggests that, when winds are weak, a fire line several kilometers or more in length is inherently unstable and very likely to break up into fingers.

V. RECENT UNITED NATIONS REPORTS AND ADVISORIES REGARDING FOREST FIRES

Because of problems arising from vegetation fires and smoke impacts on human health and the environment, other groups within the World Meteorological Organization (WMO) and the World Health Organization (WHO) have collaborated on a series of activities to address these problems. These included workshops by each organization June 1998 in Singapore and Kuala Lumpur “Regional Workshop on Transboundary Smoke and Haze in Southeast Asia” and “WHO Bi-Regional workshop on Health Impacts of Haze-related Air Pollution”

Recommendations from these workshops have resulted in recently published WHO Health Guidelines for Episodic Vegetation Fire Events.

V. A World Health Organization Health Guidelines For Episodic Vegetation Fire Events.

The WHO Health Guidelines for Episodic Vegetation Fire Events (WHO/UNEP/WMO, 1999b) represent a comprehensive review of the subject. The Guidelines are intended to:

- To develop the necessary capacity, not only at regional and national levels but also at the local level, and to give WHO's support to local planning efforts in health, environment and sustainable development;
- To strengthen the basis for inter-sector action in sustainable development policy and planning, by providing the necessary evidence and guidance;
- To determine best practices and disseminate such knowledge worldwide, so that all may benefit and learn from them;
- To strengthen the linkages between health, environment and development;
- To provide ongoing support in the development and implementation of the Regional and National Haze Action Plans, as parts of Environmental Action Plans to be integrated into national sustainable development planning efforts; and
- To ensure that the health components of Agenda 21 of the United Nations Programme of Action, following the Earth Summit in Rio de Janeiro, are adequately addressed so that health gains trigger economies to grow and, subsequently, poverty to decrease.

The best practices components of these guidelines represent an excellent current statement of the capabilities needed for meteorological advisory activities associated with fires. The relevant technical components of these Guidelines are repeated below from the summary.

Emission, transport of air pollutants and exposure

The Health Guidelines have compiled the information on major fire events in the world and their health and economic effects. Wildfires (uncontrolled fires) are common in all vegetation zones. They are mostly caused by negligence and are often associated with escaped land-use fires. Biomass burning is a major contributor of toxic gaseous and particle air pollutants and occurs throughout the world. The nature of biomass burning is such that the combustion is not complete, and as a result a large number of pollutants are emitted. Among the air pollutants emitted from biomass fires are widespread pollutants such as

particulate matter, oxides of nitrogen, sulphur dioxide, and carbon monoxide. But unlike some anthropogenic sources, emissions are poorly quantified (Goldammer 1999).

After the emission, during transport, the air pollutants undergo transformation processes, which result in physico-chemical changes of the pollutants.

According to the Health Guidelines, comprehensive approaches to be standardized for use in dealing with potential risks to public health of emissions from vegetation fires should include:

- Characterization of the magnitude and composition of the emissions and their transformations during transport;
- Quantification of resulting concentrations of ambient air pollutants in populated areas;
- Evaluation of likely exposure scenarios for affected populations (both indoors and outdoors);

Assessment of consequent health risks posed by such human exposures. It is pointed out in the Health Guidelines that with respect to the exposure to smoke plumes from biomass burning and corresponding health effects, particles receive the most attention of all air pollutants that have potentially detrimental health effects. Very small airborne particles (aerodynamic diameters below 2.5 μm) are considered the most significant pollutants. These particles have a very high probability of deposition in deeper parts of the human respiratory tract, where they may lead to a range of health impacts by virtue of their physical, chemical, toxicological or carcinogenic nature (Ward 1999).

Ground-based monitoring

In view of the multidisciplinary approach of the Health Guidelines, harmonization of the various approaches is considered a very important issue. Ground-based air quality monitoring and remote sensing through satellite imagery are necessary to assess air pollutant concentrations of smoke caused by vegetation fires. The Health Guidelines give several recommendations with respect to monitoring.

Ground-based air quality monitoring should aim to provide information for public health warning and decision making on protective measures, for dispersion model inputs, verification and development, and for human health studies that evaluate effects of smoke. Air quality monitoring should be conducted on a regular basis in major urban and other populated areas likely to be impacted by biomass burning. In addition, stations should be located in rural areas, for background concentration information. Existing networks should be reviewed and the best sites for monitoring smoke and haze episodes identified. Establishment of additional monitoring stations in areas not covered by the existing networks should be considered. The location of the sites should be determined in accordance with existing guidelines. A ground-based network of air samplers is necessary to measure the concentration of aerosols for sizes under 2.5 μm in diameter (Grant 1999; Ward 1999).

In measured compounds efforts should be made to separate the contribution of biomass burning from that of other sources. Monitoring of aerosol mass, visibility, meteorological parameters, optical depth and solar radiation are of highest priority. At selected sites, targeted chemical quantities such as carbon monoxide, ozone, nitrogen oxides, sulphur dioxide, carbon dioxide, ultraviolet radiation, aldehydes and other trace pollutants should be measured.

Formulation of uniform protocols for sampling, including temporal resolution and reporting procedures, should be established. The establishment of quality assurance/quality

control procedures is essential for obtaining reliable and reproducible results. National and regional databases should be established for use of data before, during and after smoke/haze episodes. These data can be used, for instance, in epidemiological studies, planning for future events and for transport modelling studies. The exchange of validated measurement data should be promoted. The different air pollution indices that are used in regional smoke and haze alerts should be harmonized.

To maximize the usefulness of data collected by different networks, participation should be encouraged in international activities such as the Global Atmosphere Watch programme of the World Meteorological Organization or the Air Management Information System of the World Health Organization.

Satellite data

The Health Guidelines summarize the existing knowledge on satellite imagery and future developments in the field of remote sensing. Satellite data are available for monitoring fires and smoke aerosol, e.g., at the National Aeronautics and Space Administration (NASA) or the National Oceanic and Atmospheric Administration (NOAA) of the United States. Satellite imagery provides information on the dryness of the vegetation, location and size of major fires and smoke plumes, energy released by fires, and air pollutants in the smoke plumes. Additional satellite sensors delivering better data on vegetation fires will be available within the next 1-2 years. With respect to accessibility and evaluation of these data, it is recommended that a centre of excellence in fire and smoke monitoring be established. The centre should be familiar with the technology and software for analyzing satellite data. Its responsibilities would be to oversee the regional estimates of fire emissions and to validate the smoke and emission analyses of satellite data. The centre should develop new strategies for fire and smoke detection and advise the international bodies and agencies of its needs. It would also integrate ground-based, aircraft and satellite information. It would work with the regional centres in disseminating information and new technology to the regional centres, as well as co-ordinate the training of technicians to handle new satellite data and software.

It would also be important to establish an indicator for grading the severity of on-going fires. Such an indicator could combine satellite data on the number of active fires per unit area, size of the areas burning, energy released by the fires, the extent the smoke palls and the concentration of pollutants in them. Also recommended is the development of a space fire monitoring system, comprising fire detection satellites and real-time portable receiving hardware, to provide diurnal information on the location of active fires, smoke, and trace gases emitted from the fires. If possible, the information generated by this system should be provided directly from the satellite to local users in near real-time, in a simple and inexpensive manner.

On a regional level there is a need for fire activity centres. These centres would receive the regional satellite data using their own receiving stations, and integrate them both with meteorological information and with ground and aircraft monitoring efforts. The centres would use the data to monitor the development of the fires and smoke and predict the spread of the smoke. The centres are needed since the characteristics and amount of vegetation burning change from region to region, and since direct reception of the satellite data is essential for real time operation. As there are already WMO centres or representatives with satellite and meteorological capability, they are natural candidates for the location of the regional fire activity centres.

With respect to data availability, it is recommended that NASA and NOAA of the United States (Figure 11) and other appropriate agencies be approached to continue placing relevant data such as aerosol and vegetation indexes on the Web.

There is a need to develop software packages and instruction material for using satellite data to warn of smoke impacts and to analyze smoke concentrations. Where extensive and intense fire episodes cause severe health problems the reliability of the fire emission estimates should be ensured by continuous validation, using ground based in situ and remote measurements. Such validation will enhance the use of satellite data as input to the simulation model. Once developed, the software packages would also support the determination of environmental hazards for human health.

Atmospheric transport models

With respect to the evaluation of ground-based monitoring data and satellite imagery for the purpose of early warning, the Health Guidelines recommend the use of dispersion and trajectory modeling. The distribution and concentrations of fire emissions must be calculated from atmospheric transport models. A description of the spatial and temporal distribution of fire emissions should consider the situation before, during, and after the episode. Defined goals are to be achieved in each of those three stages of the event. It is recommended that the agency capable of carrying out the complete suite of tasks associated with climate monitoring and modeling be identified in each area (Garstang 1999; Tapper and Hess 1999).

It is also informative to discuss the findings and recommendations from the Workshops that were held in June 1998.

Among the lessons learned from the major fire episode in Indonesia in 1997 and 1998 were the following:

- Weather, climate, and smoke and haze do not recognize national boundaries. The fires last year were exacerbated by the El Niño related drought in the region which provided favorable conditions for large scale fire.
- Meteorological Services played a critical role in the response and management of the regional and national smoke and haze problem. They contributed in valuable ways through: (1) traditional activities related to meteorological monitoring and forecasting; (2) through monitoring and surveillance functions, including hot spot identification using satellite imageries, haze trajectory modeling, compiling monthly and seasonal climate prediction information, and activities related to air quality monitoring; and (3) through effective and prompt dissemination of information to environmental and other agencies, engaged in fire and smoke and haze response and management, and the general public through Internet activities and press releases.
- While the fires of 1997/98 were severe, they were not the first. Records in the region have shown that there have been at least 9 episodes of widespread smoke and haze episodes in the region since the 1970s, and that they occurred most frequently during El Niño periods. Looking at this trend, it is very possible that such fires and widespread smoke and haze episodes will occur again, as present land use plans in the region call for continued large scale land conversion. Thus there is a pressing need for the region to maintain its vigilance, and to further develop and implement haze-related action plans.

Recommendations:

- A. Enhance the regional capabilities to provide needed meteorological support in the form of improved predictions of ENSO and climate variability, and daily smoke trajectory and dispersion forecasts from Atmospheric Transport Models (ATMs), through:

- Further developing regional climate prediction capabilities to interpret and locally enhance predictions from global forecasts, and provide more frequently global climate predictions and improved climate products;
- Development of flexible, situation-dependent, measurement programs which allow for the provision of enhanced meteorological measurements (expanded frequency and spatial coverage) during periods of severe smoke and haze, and expanded use of satellite-derived meteorological products;
- Installing trajectory / dispersion modeling capabilities at local meteorological services, and utilization of local area modeling (LAM) capabilities in the region: and
- Improving model performance through case studies, model evaluation exercises, and by conducting dry run exercises and possible tracer experiments.

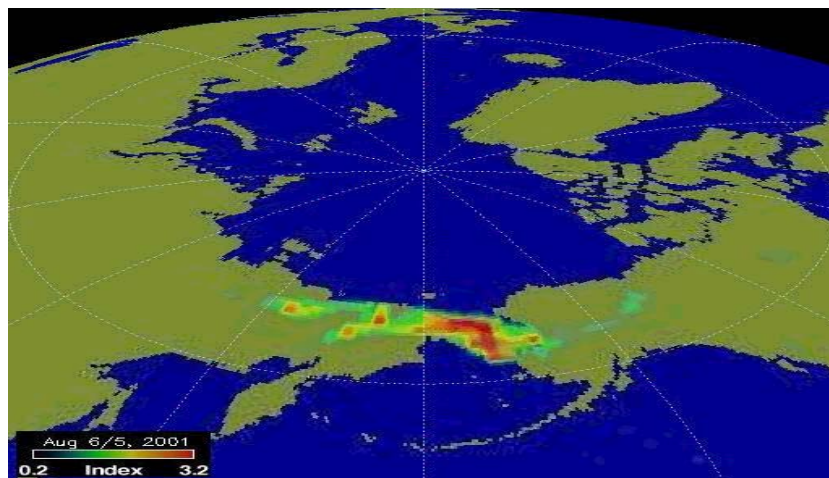


Figure 11. NASA Total Ozone Monitor (TOMS) image of smoke being transported over the Bering Strait on 6/5 August 2001 (source: NASA Goddard Space Flight Center)

- B.** Improve the ability to characterize fire activity and track the movement of smoke and haze by strengthening present satellite-usage capabilities by:
- Improving the operational aspects through provisions for back-up hot spot analysis capabilities, harmonization of fire counts by use of a single detection algorithm, through real time transmission of high resolution data on fires derived from NOAA satellites, and efforts to verify fire counts and burn-area information, through ground-truthing activities;
 - Expanded efforts to estimate aerosol and trace gas emissions from fires by combining fire counts with burn-area, along with a better characterization of source characteristics from diverse ecosystems and land-use systems; and
 - Promotion of the development of the next generation of satellites. This includes the need for a new NOAA channel-3 detector optimized for fire studies, dedicated fire satellites to monitor fires more precisely, and the use of space-borne radar for area burned determination and vegetation dryness assessment, and the use of LIDAR systems to measure the vertical distribution of trace gases and aerosols.

- C.** Strengthen regional monitoring efforts to assess the effects of smoke and haze on human health, to evaluate ecosystem impacts, to help validate atmospheric transport models, and characterize emission sources, by:
- Enhancement of existing monitoring networks to measure smoke and haze related quantities including aerosol mass (PM_{2.5}, PM₁₀), visibility, optical depth, and meteorological parameters; and at selected sites, targeted chemical quantities including aldehydes, aerosol composition, and UV-B, and other trace pollutants (CO, O₃, NO_x, SO₂, VOCs, CO₂). Two levels of observing stations are envisioned, a base level comprising fewer measurement parameters but with a high level of consistency across the network, and a second level with a more comprehensive measurement suite;
 - Establishment of additional and population-based monitoring stations at areas not presently covered by existing networks (e.g. Kalimantan);
 - Promotion of the scientific exchange of the validated measurement data, and the harmonization and regional coordination of the air pollution indices (API) used in regional smoke and haze alerts, and
 - Formulation of uniform protocols for sampling, including temporal resolution and reporting procedures, and expand efforts directed at QA/QC, building upon the WMO/GAW program components.
- D.** Improve the management of smoke and haze (and other transboundary) pollution events through enhanced efforts directed at improved information exchange and coordination, including:
- Enhancement of the current system for dissemination of data, products and other relevant information through the use of GTS for meteorological data and gridded model outputs, and the Intranet and/or Internet systems for non-standard products;
 - Efforts to increase the exchange of critical information including meteorological data (especially rainfall), air quality data (including air pollution indices), and trajectory and plume forecasts. A critical element is to promote harmonization of data and output products to support effective real-time decision-making;
 - Further coordinate emergency response responsibilities and activities between national and regional meteorological services, with primary responsibility for the provision of information and forecasts to reside with ASMC, but with the option of seeking further input from other RSMCs, and with provisions for bi-lateral arrangements;
 - Improvements in existing mechanisms to regularly review the operational coordination between the NMHSs and activities related to the Regional Haze Action Plan, and recommend changes and/or improvements to the plans; and
 - Fostering linkages between the meteorological services and other national, regional, and international organizations and scientific programs, such as (ICBP/IGAC), with common interests.

VI. FUTURE CHALLENGES AND NEEDS

Fire issues will gain in importance, especially if global weather patterns change. Drought and food scarcity will be exacerbated by fires as remove landscape cover, threaten resources, and harm humans. New technologies are being deployed in developed nations and are increasing affordable in less developed nations. Fire management is a discipline unto itself and in developed nations has become the responsibility of land management and natural resources agencies (e.g., USDOJ Bureau of Land Management in the United States, Conservation and Land Management (CALM) in Western Australia). In many areas of the world there is a growing recognition and concern that smoke from open burning is a serious air pollution management problem and public health risk. Additionally, considerable intellectual and financial resources are being expended to use satellites to detect fires, map burned areas, and track smoke plumes by the European Union and the United States among many others.

What, then, is the role of the agricultural meteorologist in fire? Certainly the information needs of agricultural meteorology and fire meteorology are convergent in many respects. As forest fires are seen as contributors to the global greenhouse gas emissions so agricultural burning for waste removal is seen as a contributor. When agricultural burns, especially for forage improvement in rangelands, adjoin forests these burns become potential starting points for forest fires. Finally seasonal forecasts for fire severity are closely related to traditional agrometeorology forecasts for such issues as drought. It is clear that agrometeorology and fire meteorology, although not the same, are so closely linked that forethought now may pay great benefits as new technologies are implemented for fire management. This is especially true as fire and air pollution issues draw a tighten circle around open burning as practice.

A new discipline, or a redefining of disciplines, may emerge from these issues: *Fire Agrometeorology*. Fire agrometeorology would then be the practice of applying meteorological knowledge and information to the stewardship of fire-managed sustainable agricultural systems.

VI. A Automated Weather Stations

Automated weather stations are useful for classical agrometeorological pursuits, and are very useful for fire management. A primary example of of automated weather stations for fire weather is the United States Remote Automatic Weather Station (RAWS) network. RAWS meets needs for fire that are perhaps different than those of agricultural meteorology pursuits in that they are primarily located in areas far from people (not only rural but isolated) and they have ability to report information in real time or near real time. It would be a vast oversimplification to state that agricultural meteorology differs in needs for remote location information or timely retrieval of data. However, different approaches to automation of weather station can often be used (e.g., US Oklahoma Mesonet). The challenge for the future will be for agriculture and fire management officials to come to agreement and compromises to develop national systems that can seamlessly serve both interests. In some developing countries, such as those of Central Asia, automated networks have been cost prohibitive. If a partnership between fire managers and agricultural interests on automated weather stations can be reached in Central Asia, for example, the development cost may shared between the military, disaster preparedness, water management, and agricultural interests to reach on common set of goals.

VI. B Mesoscale Meteorological Models and Fire Management

Models such as the MM5 have proven themselves useful in a broad array of meteorology issues. In the United States they are now being used in smoke management and are contemplated for routine use as input sources for fire behavior models. The use of

mesoscale models is certainly not limited to the USA and examples of application of this technology to fire management can be found in Australia, Asia, Russia, Europe, and others. Climate prediction models, such as the Global Circulation Models (GCMs) common to the global change literature, also hold great promise in fire management. In future, traditional fire management and agrometeorological interests may also converge on the use of weather and climate modeling, finding that information for one use is the basis for other uses. Although in past years the computer resources for mesoscale modeling were prohibitive for developing countries, it is now possible to use such models on clusters of personal computers linked to achieve new super-computer processing power but which cost less than US \$100,000. Modeling using such systems at high spatial resolutions (e.g., 4KM grids over an area the size of Spain or larger) is possible. Thus in many countries where the intellectual estate exists to run such modeling systems, computer resources may soon become a non-issues from a financial standpoint. The challenge will soon become not if mesocale modeling of meteorology can be done on routine basis for fire and agriculture, but rather how can developing nations foster a collaborative approach to its application.

Such studies and models will ultimately allow fire to be better managed in all systems, but they will require the agrometeorological community to become closely linked to research activities supported by fire management.

VI.C Remote Sensing of Fires and Smoke

High-resolution satellite data such as Landsat Thematic Mapper, SPOT and ERS-SAR combined with low-resolution satellite images such as NOAA-AVHRR offer new possibilities to monitor forest fires. They have a number of advantages over conventional means of observation: Using satellite images, it is possible to view vast expanses of land (thousands to tens of thousands of km² on one image). This can be performed regularly for the same area and recorded in different wavelengths, thus providing information on the state of forest resources. Satellite data can be acquired without encountering administrative restrictions (FAO, 1999). Aircraft based measurements using radiometers have been used in many areas, with extensive work being done in Brazil and the United States by the USDA Forest Service. The United States agencies of NASA and NOAA, along with the European Space Agency are international resources for remote sensing data and products related to fire. An outstanding example of international cooperation using remote sensing for natural resource management is the program of Global Observation of Forest Cover (GOFC). Global Observation of Forest Cover (GOFC) is a coordinated international effort working to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget. Originally developed as a pilot project by the Committee on Earth Observation Satellites (CEOS) as part of their Integrated Global Observing Strategy, GOFC is now a panel of the Global Terrestrial Observing System (GTOS).

GOFC is working to accomplish its objectives by:

- Providing a forum for users of satellite data to discuss their needs and for producers to respond through improvements to their programs;
- Providing regional and global datasets containing information on:
 - Location of different forest types;
 - Major changes in forest cover;
 - Biological functioning of forests (this will help quantify the contribution forests make as absorbers and emitters of greenhouse gases).

- Promoting globally consistent data processing and interpretation methods;
- Promoting international networks for data access, data sharing, and international collaboration;
- Stimulating the production of improved products.

Potential users of GOFC products include global change researchers, international agencies, national governments, non-governmental organizations, and international treaties and conventions (such as the Framework Convention on Climate Change). One of the most important challenges facing GOFC is to develop methods and implement systems that provide both research and operational information on a regular sustained basis (source: <http://www.gofc.org/gofc/overview/overview.html>)

For agrometeorology as it address fire issues, remote sensing will become increasing valuable. New satellites, improved spectral representation and spatial resolution below a 1km² will all help the fire business by improved detection of fires and their effects. Ground based remote sensing networks, such as the NASA AERONET (Holben, et. al., 1998) can also supply information of a non-traditional but useful nature to agrometeorologists and fire managers. There is no one answer for the WMO CAgM as it approaches the issue of fire in agricultural systems. However, several needs are clear: better data dissemination in developing nations, higher spatial and temporal resolutions to address fires on small scales (e.g., 100's of acres and 2 or 3 hour periods), increasing integration of satellite and ground based measurement programs, and more training programs.

VI. D Computer Assisted Training and Education for Agricultural Meteorologists

It has been said so often that computers will advance all areas of education that it is becoming a montra without meaning. As a pedagogical tool, the internet is an outstanding opportunity to make level the playing field for the rich and poor nations alike. Small inexpensive computers, such as the new Pocket PCs, will open up the world to even the remotest village. For fire agrometeorology the world information web offers information sources for day to use and research. It also offers a forum on techniques and technology.

The CAgM has developed successful in development of roving seminars for data management and remote sensing, both of which are highly dependent on computers as a learning tool. The next step for CAgM might be to develop a roving seminar of fire agrometrology. This seminar might include topics on climate change, fire ecology of agricultural systems, open burning practices management of agricultural wastes, fire behavior, and smoke management. Such a roving seminar could be developed and implemented with aid from the forest fire management community. It would fit into the existing structure of the business of CAgM and could be implemented as soon as a course of study was developed.

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