FIRE WEATHER RESEARCH:

A BURNING AGENDA FOR NOAA

A REPORT FROM THE NOAA SCIENCE ADVISORY BOARD

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I. EXECUTIVE SUMMARY

Hazardous wildfires occur in all parts of our nation and have long been feared for their catastrophic destruction, causing loss of life, destruction of property and critical infrastructure, and widespread environmental damage. In the United States, human population densities in wildfire-prone areas are increasing. In particular, the area of intersection between population and wildland, called the “wildland urban interface” (WUI) has been increasing, with 2000 Census data showing that 100 million people now live in WUI areas. Consequently, the vulnerability of communities to incursion of wildland fire, both in human and economic terms, is escalating.

There are numerous examples in recent years of exceptional fires that caused death and destruction at remarkable levels. For example, in 2007, over one million people were evacuated in Southern California fires, giving rise to scenes usually associated with hurricane evacuations. Wildfire-suppression costs are estimated at $3B a year, with additional costs for damage to property, infrastructure, health (particularly from air quality issues), and natural resources. Insurance claims from wildland fires are averaging $1 billion a year this decade, with claims from 2007 alone totaling $4 billion. Local and regional weather play significant roles in the initiation of wildland fire and on the behavior of the fire once it has started. Much of the historical research on fires has focused on surface conditions but there is increasing recognition that the three-dimensional atmosphere also plays a key role. While the specific effects of climate change on wildfire occurrence, extent, and severity are likely to vary in different regions of the country, there is growing scientific evidence that climate change will increase the number and size of wildfires.

Following a December 2006 presentation to the National Oceanic and Atmospheric Administration (NOAA) Science Advisory Board (SAB), the SAB established a Fire Weather Research Working Group (FWRWG) and charged it with conducting a review of NOAA’s operationally-oriented fire weather research activities. Specifically, the FWRWG was chartered to (1) ensure NOAA’s fire weather research priorities meet the needs of the federal wildland management agencies, and (2) explore opportunities to leverage current NOAA internal and external collaborative fire weather research efforts to ensure improvements to NOAA’s fire weather products and services are implemented in a timely manner. In order to represent a broad user community, FWRWG members were academics, researchers, and operational users of, and private-sector contributors to, NOAA’s fire weather information.

The FWRWG has heard nothing but praise for the services provided by forecasters in Weather Forecast Offices and Incident Meteorologists (IMETs), who are deployed to incident command posts and regional centers. NOAA’s IMETs and other forecasters from Weather Forecast Offices have done a remarkable job with utilizing their knowledge of meso- and miso-scale meteorology to provide very fine scale forecasts used by decision-makers at fire scenes. However, having seen what services NOAA can provide, fire managers from the federal wildland management agencies are consistently asking for more services.

The recommendations in this report are consistent with those from other groups (Western Governors' Association, National Association of State Foresters) and complementary to the findings and recommendations in a recent study by the Office of the Federal Coordinator for Meteorology of fire weather user information needs.

While all the recommendations are important, some are clearly of greater significance than others and so merit a higher priority as NOAA considers its next steps in this important area. These key recommendations are that NOAA should …

> **2.1 … Assimilate output from all available local observation sources, including data from surface-data networks, ground-based radars and profilers, UASs, and satellite sensors, when generating gridded nowcasting and forecasting products, and fire-danger maps.**

> **2.2 … Explore the use of remote sensing methods, including ground-based radar, HALE UAS, and satellite (including high frequency fire detections and characterization from GOES), for sustained, continuous monitoring and forecasting of the tropospheric misoscale weather, surface conditions, and fire growth during ongoing wildland fires.**

> **3.1 … Increase research and development of integrated fire weather modeling systems, for normal-to-exceptional fire weather conditions (extreme fire weather conditions may require special consideration), leveraging research expertise and capabilities where possible from other federal agencies, universities, and the private sector. The long range goals for this larger research community include accurate simulation of fire in complex terrain and, ultimately, the wildland-urban interface; NOAA's weather prediction capabilities are central to attaining these goals.**

> **5.1** …**Use data assimilation systems described in Recommendation 2.1 to generate high resolution fire danger maps.**

> **8.1 … Develop a standardized "intelligent assistant" or decision-support tool for the WFO forecaster replying to requests for spot forecasts from first respondents and for deployed IMETs providing weather support to Incident Commanders.**

> **12.1 … Explore emerging communication formats and low-bandwidth technologies with the goal of allowing fire managers to access site data and to initiate and receive both spot weather forecasts and extended nowcasts; emphasis should be placed on maximizing the capabilities of currently-available low-bandwidth wireless devices such as Blackberries, iPhones, PDAs, and cellular modem-equipped laptops.**

14.1 … Ensure availability of live weather data via the current FX-Net and subsequently the AWIPS II thin client to facilitate IMET support at fires.

15.1 … Continue, in collaboration with USGS, to develop thresholds of rainfall rates and totals for public warnings of impending debris flows.

18.1 … Increase its focus on fire weather support in the next update of its Strategic Plan, making fire weather a higher priority, and seeking additional authorization and funding as needed.

18. 2 … Designate a research laboratory (one with an operational counterpart within the NWS, along the lines of the NSSL/SPC and AOML-HRD/NHC tandems) to lead its fire weather-related research and development efforts and provide it with appropriate budget and authority.

18.3 … Work with the federal fire agencies and other members of the National Wildfire Coordinating Group to establish a fire weather test bed, select a location for it and determine a strategy to leverage funding to build and staff it.

II. ACKNOWLEDGEMENTS

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III. INTRODUCTION

III.A Background

III. A.1 Fire Weather – a brief primer

Figure 1. Wildland fires occur in many ecosystems: forest fire (shown here), brush fire, vegetation fire, grass fire, peat fire, bushfire (in Australasia), or hill fire. *Photo credit: Al Henkel*

Wildland fire is a fundamental natural process in forest, brush, and grassland ecosystems. Wildfire is an unplanned, unwanted wildland fire. Ignitions can be from natural causes (lightning) or human activities (shorting of power lines, arson, and human carelessness). Prescribed fire (also called prescribed burning, controlled burning) and wildland fire use are natural resource management tools to meet specific management objectives (National Wildfire Coordinating Group, Glossary of Wildland Fire Terminology—see also detailed definitions in Appendix F). These objectives may include hazardous fuel reduction, wildlife management, range management, and/or ecosystem restoration and maintenance.

Figure 2. Prescribed burns have been strategically implemented around the Okefenokee Swamp on 3,100 acres. *Photo Credit: Jen Kolb.*

Fire management policy in the nation's forests and other wildlands changed many times through the course of the 20th century, ranging from no intervention, to vigorous intervention in all wildfires, to various combinations of the two. Several major wildfires in the 1980s and early 1990s, such as the great Yellowstone fires of 1988, showed that the management plans of that era – basically, minimal intervention in naturally ignited fires; intervention in anthropogenic fires -- sometimes resulted in uncontrollable fires when fires inevitably occurred during weather favorable to burning. Further, these events showed that many assumptions about fire behavior that had been adopted in developing models of fire spread (also called fire growth) were invalid or badly flawed, or too limiting to represent certain types of fire behavior. Combined with the understanding that many wildland species are fire-adapted and so can tolerate or even require the occasional, typically low-intensity fire, wildland managers now conduct each year more prescribed fires or decide (under benign weather conditions) to let non-threatening naturally-started fires burn (wildland fire use). Researchers are accordingly developing more physically-based fire models to support decision making by wildland fire managers.

While some regions of the nation are prone to wildfires year round, in many areas there is a distinct "fire season" (in addition to prescribed burning). Much of California, and especially the southernmost five counties, and the perennially dry Southwestern U.S.A. are susceptible to wildfires at any time of the year, though more so during their dry seasons. In other parts of the nation, wildfire is clearly associated with a dry season, often late summer and fall, after vegetation has matured and dried but before winter rains and snow arrive. Regional droughts can exacerbate burning conditions, while wet periods can greatly reduce or eliminate the threat of wildfire altogether. Given that in some regions of the nation, the wet and dry seasons are modulated by the El Niño-La Niña phenomenon, seasonal and interannual correlations between climate and fire activity can be seen to some degree in the historical record. The annual progression of fire season across the nation allows fire managers to shift their resources among the highest threat areas through the course of the year.

Wildland fire is a multifaceted interdisciplinary phenomenon, aspects of which lie within the purview of many federal agencies in the execution of their responsibilities. Fire is the exclusive concern of no one agency, so effective national wildland fire management requires high levels of interagency cooperation and collaboration.

Fire in nature, wild or prescribed, is driven by interactions between three environmental components: fuels, topography, and weather – the classic fire behavior triangle. Fuels provide the energy source for fire. Fuel availability depends on fuel arrangement, moisture content, and, once a fire is started, on the fire itself. Topography can influence fire indirectly, by solar exposure and mediating wind patterns, or directly - fires burning upslope spread faster than fires burning on flat land.

Of these three elements, weather is the most variable and least predictable. Weather is the state of the atmosphere and is quantitatively described by properties such as temperature, humidity, stability, pressure, wind speed and direction, clouds and precipitation. The interaction of these weather elements control many aspects of fire behavior such as its onset, spread, and intensity. For example, atmospheric moisture directly affects fuel flammability, and, by its relationship to other weather factors, has indirect effects on other aspects of fire behavior. Wind may carry away moisture-laden air and hasten the drying of fuels. The direction of fire spread is often determined by the wind direction. Wind aids fire spread by carrying heat and burning embers to additional fuel, and by bending the flames closer to the unburned fuels ahead of a fire. Atmospheric stability is closely related to wind effects on fire behavior. For example, winds tend to be turbulent and gusty when the atmosphere is unstable, causing fires to behave erratically. Lightning from thunderstorms may set wildland fires and the gusty surface winds from thunderstorms can greatly affect fire behavior.

Under certain conditions, the winds generated by the fire itself can play a dominant role in the local wind patterns. This can lead to highly nonlinear fire/weather interactions, especially for added environmental complexity from variable fuels and terrain. An adequate understanding of fire behavior sometimes requires insight into the interaction of ambient weather and fire-generated winds.

Fire weather is, thus, the observed and predicted atmospheric conditions between the surface and (in the mid-latitudes) 15 km above the surface that affect the onset, spread, and behavior of wildland fires, and the dispersion of smoke from such fires. The interaction between fire and weather has been extended to include post-fire impacts, such as debris flows. When fire weather observations and forecasts are combined with information on fuels and topography, the likelihood of fire propagating if an ignition occurs can be assessed. When fires occur, fire weather information allows likely fire behavior, including direction and rate of spread, to be forecast with appropriate fire modeling tools.

During a wildfire, a wildland fire use event, or a carefully planned prescribed fire, unanticipated changes in weather can result in rapid changes in fire behavior that threaten life and property. Timing a prescribed burn is a particular fire weather forecast challenge because the goal is to optimize burning conditions while minimizing both the probability of the fire escaping control and the deleterious pollution effects of smoke.

Fire management in the nation's wildlands is an ongoing concern to the American public and to the federal wildland management agencies -- Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (FWS), the National Park Service (NPS), their counterpart state agencies, and local land management and firefighting organizations. Incident managers base their wildfire-control plans (or equivalently, resource managers, their prescribed fire burning or wildland fire use plans) on current and expected weather conditions.

Prior to fires, weather information is used by fire managers in planning for firefighting resource allocation (pre-positioning) and pre-suppression work (e.g., fuel removal or reduction, fire prevention activities).

During active fires, weather information – both observations of current weather and predictions of future conditions -- is critical to maximizing firefighter safety, protecting the public and property, and efficiently managing resources. In their decisions, fire managers have three key responsibilities:

- Ensuring the safety of the firefighters on the fire line and of the public in the vicinity of the fire. Past studies of firefighter fatalities point to unexpected events (e.g., a sudden wind shift) happening in small, niche environments on time scales of a few to tens of minutes.

- Controlling and then extinguishing unwanted fire in the most cost-effective manner possible by wise deployment of resources. Decisions are usually made for planning horizons of 6/12/24/48 hours or occasionally even longer in the case of large fires or multiple fires in a region.

- Predicting and monitoring behavior of prescribed fires or wildland fire use events. Decisions can be long term (planning for a prescribed fire) or very short term (in the case of monitoring the progress of a prescribed fire or a wildland fire use event).

These time scales set the requirement for providing fire weather information to fire managers at various levels of command. It can be seen that fire weather forecasting blends short-term prediction (analogous to forecasting severe convective weather) with forecasting over a long term (somewhat analogous to hurricane forecasting).

Following a fire, weather information is critical to rehabilitating and restoring natural resources and protecting the public and environment from phenomena such as debris flows.

Figure 3. Fire at a Wildland-Urban Interface in California (2007 Santiago fire). Based on 2000 Census data, 100 million people are full-time residents of the 46 million homes located in the WUI. *Photo credit: www.wildlandfire.com*

III. A.2 Wildland fire in the U.S. – Increasing Vulnerabilities, Increasing Threats

All across the nation, catastrophic wildfire is a growing national issue. While the dramatic fires of northern and southern California and those in central Florida receive the greatest publicity, wildfires occur in every state in the nation. Not only do wildfires sometimes result in loss of valuable natural resources (timber, grazing land, habitat), but also the continuing expansion of communities in the last three decades into formerly wild areas has dramatically increased the wildfire threat to life, property, and infrastructure. As illustrated by Figure 3, fires in the wildland-urban interface (WUI) are now a significant threat to the one-third of the U.S. population who live in these interface regions. The October 2007 fires in southern California caused an evacuation of one million people on the scale usually associated with hurricanes on the south Atlantic and Gulf coasts.

The number of acres consumed by fire each year is on the increase (see Fig. 4). Experienced fire fighters report that the length of the fire season appears to be increasing, starting earlier and ending later and that more cases of erratic fire behavior are being observed (reliance on such anecdotal reports is necessary because the collecting and archiving of statistics on wildland fire are very limited).

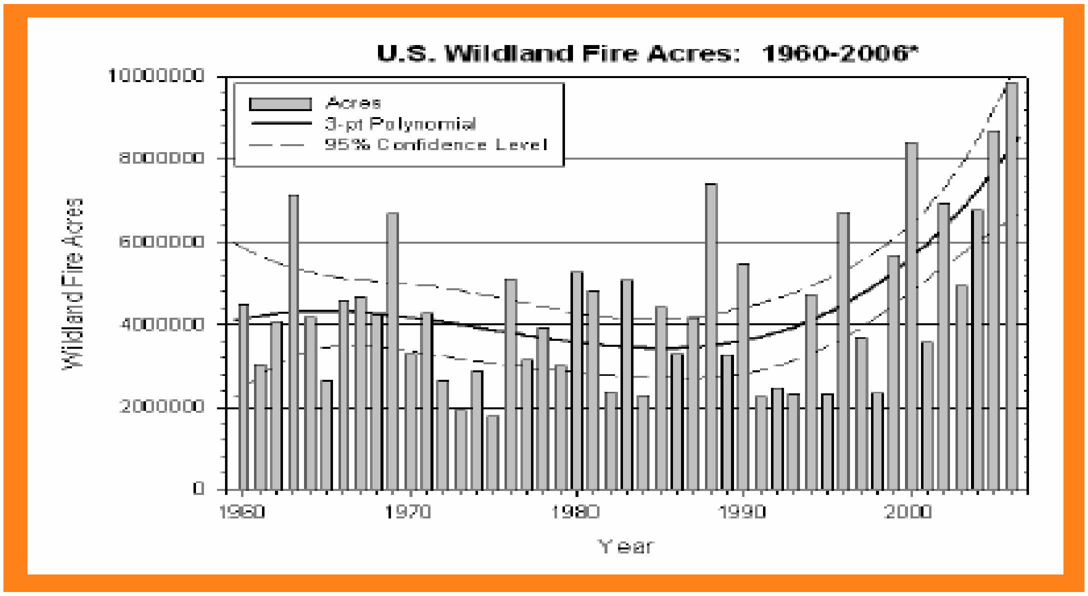

Figure 4. Annual data and trend analysis for U.S. wildfire acreage, as documented by the NOAA National Climatic Data Center (OFCM, 2007)

In 2006, 9,873,745 acres were burned (the record annual total) by 96,384 wildfires; in 2007, 9,328,045 acres burned by 85,705 wildfires. (Values extracted from http://www.nifc.gov/fire_info/fires_acres.htm.) In addition, in 2006, 24,429 *prescribed* fires conducted by the federal wildland management agencies and corresponding state agencies (mostly in the Southeast) burned 2,720,545 acres. For 2007, the corresponding numbers are 24,073 prescribed fires and 3,149,067 acres burned. (Values extracted from http://www.nifc.gov/fire_info/prescribed_fires.htm.)

The number of deaths and the economic losses from wildfires are growing as populated areas and wildlands become increasingly intertwined in the WUIs around urban centers. In the 20 years prior to 2006, historically significant wildfires resulted in over 12 million acres burned, over 100 lives lost, and the loss of undetermined, but very large amounts of resources and property. In 2003 alone, wildfires in Southern California claimed 22 lives, destroyed 3600 homes, burned 740,000 acres of land, and caused over $2B in property losses (OFCM, 2007). Also in 2006, grassland wildfires in Texas, Oklahoma, and New Mexico resulted in over a dozen deaths, and destruction of complete communities. As noted above, during the 2007 fires in Southern California almost 1 million people were evacuated, often with little or no notice.

Figure 5. 2003 California fires from space. Note the heavy smoke and ash clouds covering the whole coastal region, impacting an area populated by 25 million people. *Photo Credit: NASA*

In addition to the immediate threats at the fire line, wildfires can also be hazardous at the regional scale (Figure 5) by increasing air pollution, limiting visibility, and hampering local transportation, both on the ground and in the air. All of these factors impact public safety and commerce. Private businesses may be destroyed or forced to close down. Public health impacts are also increasing as the population increases in the WUI areas. Smoke dispersing from wildland fires impacts vulnerable citizens with respiratory ailments. Water quality may also be degraded through the release of burned debris into streams and lakes, damaging aquatic habitat and contaminating public water supplies.

Following a fire, mudslides and debris flow can threaten people and property, and contaminate or block water supplies. The timber and tourist industries can experience losses of income due to the destruction of the forests and amenities, and loss of fish and wildlife. Another industry beginning to be impacted is the insurance industry. Insurance claims are averaging $1 billion a year this decade (International Code Council, 2008). Recently some insurance companies are not renewing homeowner policies if a home does not have the required minimum clearance of vegetation or defensible space surrounding the house. Such requirements can impact areas many times the size of the burned area, and result in losses/costs many times more than the direct losses/costs from the fire.

Suppressing wildfires and recovering from them are expensive propositions for government at all levels. Based on the experience over the last decade, 98% of wildfires are successfully extinguished following the initial attack at minimal cost; however, *80% of wildfire costs are incurred when managing the two percent of wildfires which grow into large fires* (**N.B.,** emphasis added to indicate commonality with tornadoes and other hazardous phenomena for which a few unfortunately situated, very intense events cause most of the impacts). Over the five-year period from 2000-2004, federal wildfire suppression costs averaged $1.16 billion per year while showing a strong rising trend.

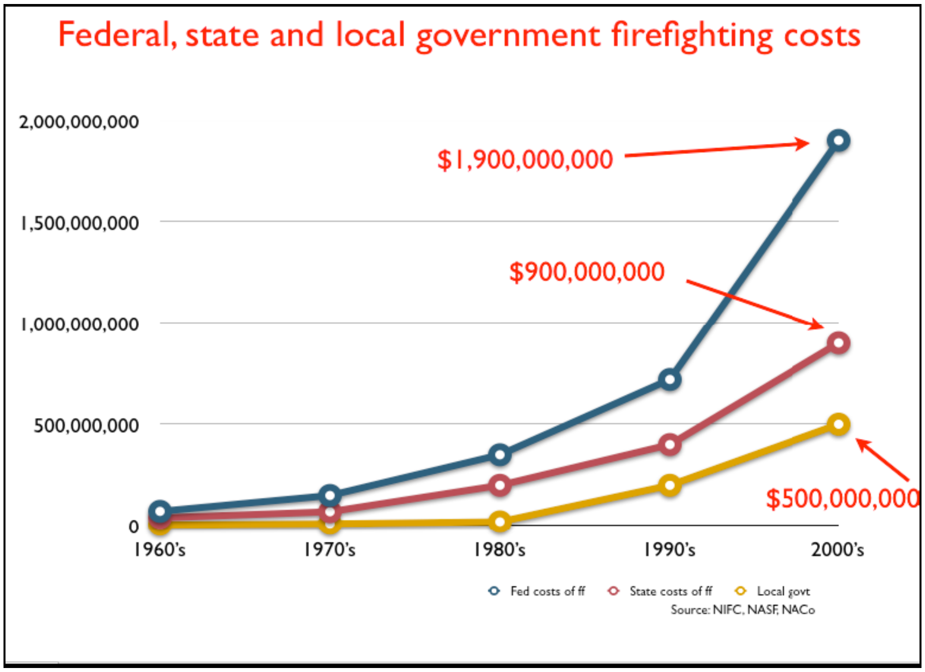

Figure 6. Overview by decade (1960-2000) of federal, State, and local government wildland firefighting costs per year. (International Code Council, 2008)

A recent report of the Blue Ribbon Panel on Wildland Urban Interface Fire (International Code Council, 2008) reported that 2007 was the most severe and expensive on record and five of the ten worst seasons since 1960 in terms of acres burned have occurred in the last eight years. Costs during 2007 for federal and state agencies were in excess of $3 billion (over $1.8 billion for federal agencies alone), with more than 90,000 fires burning close to ten million acres. The trend seems to be continuing into 2008 as indicated by a July 8, 2008 letter from Senator Feinstein (D, CA) to Senator Byrd (D, WV), Chair of the Senate Appropriations Committee asking for $910 million in emergency funding for wildland fire suppression and related costs for the U.S. Forest Service and the Department of the Interior. In that letter, Senator Feinstein states "Indicators suggest that fire suppression this year will even surpass record-breaking costs in 2006 and 2007. For instance, in many areas of my state, moisture levels in fuels, a key indicator in the likelihood of wildfires, is lower than at any point in the recorded 27-year history of such data." (July 9, 2008 press release, Office of Senator Feinstein)

Much of the current wildfire hazard and associated costs can be attributed to past fire-exclusion, and especially, suppression-oriented strategies implemented over the past century. For the last 20 or so years, the situation may have been aggravated by local and regional scale changes in climate resulting in more and typically drier fuels, among other factors (See Section IV.G.1 for additional discussion of the possible impacts of climate change on wildland fire). In any event, escalating firefighting costs are not likely to be alleviated until the federal wildland management agencies have validated fire behavior forecast tools and policies for their application to decide, as appropriate, among nonintervention, containment, or suppression.

III.A.3 NOAA's Role in Dealing with Wildland Fires

Under the same authority that the National Weather Service (NWS) has for providing weather forecasts and warnings in response to natural hazards through the Organic Act of 1890 (15 U.S.C. 313), NOAA, primarily through the NWS, provides critical weather support to federal, state, and local agencies responsible for mitigating and suppressing wildfires and conducting prescribed burns and wildland fire use events. NOAA provides this support to key federal wildland management agencies under an interagency agreement that is described in NWS Instruction 10-406 (for details, see http://www.nws.noaa.gov/directives/sym/pd01004006curr.pdf).

Products and Services

NOAA provides a number of specific products and services related to fire weather: fire weather outlooks, forecasts, advisories, watches and warnings, and on-site services.

- NOAA provides a corps of volunteer forecasters, called Incident Meteorologists (IMETs), who travel directly to fire scenes and serve as integral members of Incident Management Teams. NOAA provides specialized training for its IMETs to enable them to fulfill this role. For several decades, IMETs have served as important support staff for fire fighting management teams.

- NOAA Weather Forecast Offices (WFOs) provide regularly-issued fire weather forecasts, fire weather watches, and warnings, and subjectively-based spot forecasts (detailed definition given in Appendix F) as needed prior to IMET arrival (in the last six years, IMET arrival time has averaged about 14 hours after request by the incident commander).

- NOAA provides operational predictions of smoke transport for large fires, as part of the National Air Quality Forecast Capability.

- Two components of NOAA's National Centers for Environmental Prediction (NCEP) contribute specific products for fire weather:

  - The Storm Prediction Center (SPC) provides broad-area fire weather outlooks for up to eight days in advance, as well as experimental lightning and ensemble model products for specific fire weather variables.

- The Environmental Modeling Center (EMC) provides numerical weather prediction tools for use by WFOs and IMETs in delivering their fire weather forecasts.

- Earth System Research Laboratory's FX-Net software client is the system IMETs employ to issue forecasts on incidents. It works over broadband Internet connections and also in areas where there is relatively poor Internet connectivity. Its advantages to the IMET are:

  - Provision of professional-level meteorological analysis tools in remote areas of the country.

  - An interface that exactly simulates the home office environment, allowing for zero spin-up time in its use on location.

- NOAA's polar orbiting and geostationary operational environmental satellites provide near-real-time monitoring of active fires, which data are distributed though the NOAA National Environmental Satellite, Data, Information Service (NOAA NESDIS) Hazard Mapping System (HMS).

- Flooding guidance and forecasts, including warnings of flash floods, are provided by NOAA's River Forecast Centers and local WFOs. Flash flood warnings are directly tied to warning of debris flows.

NOAA spends about $1 million a year directly on fire weather products and services; other NOAA elements such as EMC and NESDIS support the fire weather program indirectly through their normal operations. This includes forecast guidance issued by the Storm Prediction Center ($0.25M) and program support for on-scene fire weather activities by IMETs ($0.26 M for training, equipment replacement, and $0.43M for FX-Net operations). This funding total does not include the regular forecasts and warning activities by WFOs during fire season. It also does not include the costs for IMET travel, overtime, communications and related costs for which NWS receives $0.8M to $1.2 M annually in reimbursements from the federal wildland management agencies.

Weather Information Needs for Wildland Fire

The 2001 Federal Wildland Fire Management Policy, a review and update of the 1995 Federal Wildland Fire Management Policy conducted by the federal land agencies and the Departments of Commerce, Defense, and Energy, EPA and FEMA, described an increasing need for weather services to support fire management. Among the factors necessitating the increase were "a continued increase in wildland fire severity, a threefold increase in fuel reduction projects, and increasing encroachment of development into the wildland environment." The review cited a fundamental disagreement between the NWS and federal land agencies on the "products, standards, and level of weather services required and how they are provided." While this concern must be addressed largely in the policy arena, it has implications for structuring a responsive NOAA strategic plan for research and operations.

The Federal Wildland Fire Management Policy calls for the development of a national plan for weather services to support the full range of responses exercised by federal and state wildland fire management agencies, including prescribed fire and wildland fire use. Foreknowledge of fire location and duration of a prescribed fire, and to a lesser extent a wildland fire use fire, provides a broader range of weather forecasting tools and services, some of which may require further R&D. These include greater use of weather, fire, and air quality models in combination, and of medium-range numerical forecasts to drive fire and air quality models for long-term prescribed fire or wildland fire use projects (the 2006 Day Fire in California burned for several weeks). The latter poses challenges for predicting long-range smoke transport, dilution from non-fire particulate sources, and multiple fire areas.

B. Calls for Action

III.B.1 Western Governors' Association and National Association of State Foresters

In recent years, applied research throughout NOAA related to fire weather has resulted in new operational products in the areas of fire detection, monitoring and prediction of air quality, smoke dispersion, and lightning. Interest in these products increasingly extends beyond the fire community into the public health, state and local emergency management, and media sectors. NOAA also participates in research efforts with the wildland management community, some of which explicitly include fire weather as a focus.

However, the increasing threat from wildfires to life, property, and infrastructure, coupled with a growing recognition of the importance of weather and climate data to fire management, have led to calls from states, regional associations of states, and professional organizations to improve weather and climate information in the service of wildland management agencies and their associated fire fighting communities. For example, California Senate Concurrent Resolution No. 24, adopted in the Assembly on 23 June 2005, asked the U.S. Congress to develop a National Fire Weather Center within NOAA to provide rapid and accurate meteorological information that is useful for predicting the movement of wildland fire perimeters, guiding evacuations, and enabling government officials to make informed decisions about how most effectively to attack a wildfire and deploy resources. More recently, very detailed recommendations and requests came from the Western Governors Association (WGA) and the National Association of State Foresters (NASF) (for the full text, see Appendices D and E, respectively).

In June 2005, the Western Governors' Association (WGA) approved its Policy Resolution 05-04: National Wildland Fire Weather Program. This call from the WGA for action by the federal government was subsequently endorsed by the NASF in its Resolution No. 2005-3: Ensuring the Fire Weather Mission of NOAA's National Weather Service.

The WGA policy resolution, noting the increasing threat presented by wildfires, particularly at the WUI, calls for applied research and technology development efforts to effect products and services that can be quickly and effectively transitioned into NOAA operations. It states that …

> "Operational fire managers need improved products and services from NOAA's National Weather Service (NWS) which can be seamlessly infused into fire operations decision-making."

Further, the WGA suggested a framework to meet those needs by the NOAA NWS working jointly with the interagency Predictive Services program. The WGA policy resolution also included a recommendation that to ensure the proper attention and funding, the individual governors urge Congress to legislatively add fire weather, including support to federal, state, and local agencies for wildfire suppression and prescribed fire management, as a core mission of the NWS and routinely appropriate funds for this purpose.

The WGA resolution goes on to note that …

> "An integrated fire weather and fire environment research program is critical for the effective management and health of U.S. forests and rangelands".

Here the term "integrated" was used in recognition of the many disparate research efforts which are ongoing within NOAA research facilities, NCEP, local Weather Forecast Offices; those federal wildland management agencies with research programs; and joint bodies made up of representatives from subsets of these entities.

The WGA urged the Office of the Federal Coordinator (OFCM) to complete a National Needs Assessment Report of federal, state and local fire managers' needs for weather information in the wild- and prescribed fire decision-making processes. In 2007, OFCM, responding in part to the request of the WGA, released the report," National Wildland Fire Weather: A Summary of User Needs and Issues". Prepared by the OFCM's Joint Action Group (JAG) for the National Wildland Fire Weather Needs Assessment, this report identifies many of the pressing research themes and technology development needs required for NOAA to improve or extend its fire weather support to the federal wildland management agencies and their state and local counterparts.

III.B.2 NOAA Science Advisory Board Fire Weather Research Working Group

In late 2006, in response to the resolution from the WGA and in recognition of the needs assessment being conducted by the OFCM, NOAA requested its Science Advisory Board to establish an *ad hoc* working group to

> "(1) ensure NOAA's fire weather research priorities match those of its land management partners and other interested parties outside the fire community who are increasingly using NOAA's products and services, and (2) explore opportunities to leverage current NOAA-internal and external collaborative fire weather research efforts to ensure NOAA's fire weather products and services are implemented in a timely manner."

To fulfill this request, the NOAA SAB established the Fire Weather Research Working Group (FWRWG). The membership of FWRWG is given in Appendix A. The SAB also developed and approved the FWRWG Terms of Reference and Charge (Appendix B).

The FWRWG held four meetings (agendas in Appendix C) with the goal of gathering current information from the federal wildland management agencies, IMETs and WFO forecasters with fire weather responsibilities, state and local fire communities, and federal and university researchers.

Through the four meetings, the FWRWG obtained an understanding of the current state of fire weather operations in NOAA, how NOAA's products and services are applied by the federal wildland management agencies and others, and current and future needs of both NOAA and those agencies it supports. This information was sufficient for the FWRWG to formulate recommendations in response to its Charge from the SAB.

III.B.3 This Report

While charged to examine and make recommendations concerning research needs with respect to fire weather, the FWRWG quickly discovered that those needs were intertwined with and essentially inseparable from agency organizational issues. Consequently, this report provides recommendations and supporting rationale with respect to both organizational issues and needed applied research and technology development. The FWRWG felt that this broadening of scope was in keeping with the overarching goal of improving NOAA's services to the federal wildland management agencies. This report complements the OFCM (2007) report. It should assist

NOAA management in developing a research and development plan and in setting priorities within such a plan.

The substance of the report is contained in Section IV, “Observations, Findings, and Recommendations”. Recommendations are listed in each section in order of priority with highest priority recommendations shown in **bold text**. High priority recommendations are also highlighted in Section V. Summary of Recommendations. Section V. also highlights a few recommendations that could be implemented quickly and have significant impact. The references provided in Section VI are an important part of the report as they provide an introduction to the key literature in this important field.

IV. OBSERVATIONS, FINDINGS, AND RECOMMENDATIONS

IV.A Modeling Improvements

Modeling, which encompasses (and often combines) analytic and numerical and statistical-correlation techniques, is central to all fire weather forecasting, whether pre-, during, or post-fire. This section is devoted to numerical modeling for all aspects of fire weather, in large part because of NOAA’s expertise in developing and operating large numerical prediction systems. This section points out the need to develop specialized numerical tools to address both the atmospheric and fire components of “fire weather”.

IV.A.1 Improve Understanding of Atmospheric Impacts on Wildland Fires

<u>Observations</u>

Fires interact with local and regional 3-D atmospheric conditions; understanding these interactions lies at the core of fire weather forecasting. For example, it is known that unstable atmospheric conditions can cause rapid fire growth which can sometimes result in very erratic fire conditions such as fire whirls (Pirsko et al., 1965). More commonly these conditions can result in lofting and transport of burning brands significant distances in advance of the fire front, greatly enhancing fire spread. Studies of fires that have resulted in firefighter fatalities repeatedly point to small sites and rapid changes in fire behavior occurring on the misoscale or even smaller scale. These niche environments are loaded with light, fast-reacting fuels and terrain effects or changes in the wind that can accelerate fires quickly. Capping clouds sometimes form at the top of the fire plume and are called “pyrocumulus” to denote their fire origin. Highly exceptional cases in the literature point to interactions of ambient vorticity in the atmosphere and fire-producing heat-generated mesocyclones.

To assess the impact of atmospheric condition on fires, it is necessary to have a set of well-defined physical parameters to describe fire behavior. These may include fire travel speed, direction, vertical/horizontal extent, intensity, rate of change of intensity, etc. Unfortunately, little quantitative data is available for many of these parameters.

It is often convenient for purposes of discussion to separate atmospheric dynamics (fire weather forecasting) from wildland fire dynamics (fire behavior forecasting). While this simplification holds in scenarios involving most fires, such a sequential treatment (i.e., one-way interaction) may be inadequate for large, intense fire scenarios in which the interaction of atmospheric dynamics and fire dynamics is significant. These large, intense fires, while relatively rare, are the ones that often pose the greatest threat to lives, property, and the environment, and result in the greatest costs for containment and suppression.

Similarly, the characterization of fires being either wind-driven or landscape-dominated (spread responsive to local topography) is overly simplistic, as fires transition between these characterizations, and may exhibit both characteristics at the same time on different parts of the same fire. Similarly, a fire may be characterized as rapidly spreading or convective-column-dominated at different times during its lifespan. Overall characterization can be simplistic for fire scenarios in which atmospheric dynamics and fire dynamics may interact in multiple ways. Rapidly-evolving situations pose a threat to those firefighters who suddenly find themselves positioned upslope or downwind of the head of a fire line.

Unfortunately, little of this dynamic behavior is captured in current fire weather forecasting, except through the training, experience, and subjective judgment of the fire weather forecaster. Fire weather services are focused on surface atmospheric conditions since this is what current fire prediction tools use.

In current operational practice, linkage of atmospheric stability to wildfire growth and behavior is largely statistical in nature, with limited reference to identified interaction mechanisms. There are many examples in weather forecasting where simple statistical tools are quite useful in supporting subjective judgments. Their use is often justified, especially when knowledge of underlying physics is incomplete. However, little has changed in operational fire forecasting since the development of the Lower Atmosphere Stability Index or Haines Index (Haines, 1988). The Haines Index is a commonly-used, statistically-based tool produced by most NWS WFOs. It describes, in simple measures, an environment that may be conducive to large fire growth, but it does not identify a mechanism by which the growth potential is realized. In some parts of the country, notably along the coastal plain of the southeastern U.S., the Haines Index appears to not relate as strongly to large fires as it does elsewhere, pointing out the varying regional nature of wildland fires as well as our limited knowledge of the underlying physics. Furthermore, in any region, the Haines Index is formally appropriate for only low-wind situations, but is often useful regardless of the winds that are present. Thus, the Index exemplifies the commonly encountered practical utility of forecast aids beyond the parametric regime for which their application is rigorously justified.

Finding #1

Understanding how fires interact with the full 3-D atmosphere is fundamental to both subjective fire weather forecasting and the development of numerical forecast tools. Opportunities to improve current understanding include laboratory (e.g., Fendell and Wolff, 2001) and numerical modeling, detailed analyses of actual wildland fires, and full scale experiments with controlled burns. The first two can be carried out in parallel to build understanding, while the last should be undertaken only after understanding has reached a point to make such expensive experiments worthwhile. To gain maximum value from such experiments and to improve characterization of fires for weather research purposes, well-defined physical parameters for wildland fires are needed.

Given the challenges inherent in observing the interaction of a wildland fire with the atmosphere, consideration needs to be given to making extensive use of remote sensing, ground-based (mobile radars, mobile profilers), unmanned aircraft systems (UAS), and satellite systems. For example, satellite-based estimates of fire energy output have been shown to provide useful information for the estimation of pyrogenic convection processes and the estimation of injection height. Fire radiative power (Kaufman et al., 1998) is a product derived from the current Moderate Resolution Imaging Spectroradiometer (MODIS) and future Visible Infrared Imagery Radiometer Suite (VIIRS) and the Geostationary Operational Environmental Satellite's Advanced Baseline Imager (GOES-R ABI) sensors.

Special sensors, analogs to the dropsondes and air-deployable bathythermographs used to investigate hurricanes, may need to be developed or adapted. An example is a high altitude long-endurance (HALE) UAS with an infrared sensing system to map the fire front, patterned after NASA's Autonomous Modular Scanner and the FireMapper® system co-developed by Forest Service Research (www.fireimaging.com).

Recommendations for Finding #1

NOAA should...

> 1.1… Conduct detailed case studies of the behavior of selected wildland fires as a function of the observed three-dimensional weather conditions with the goals of understanding fire-atmosphere interaction and validating numerical models.
>
> 1.2 … Explore with the federal wildland management agencies through their Joint Fire Science Program and the National Science Foundation the establishment of a jointly-

funded program of wildland fire-related weather research in federal agencies, universities and industry, to include laboratory and numerical modeling, instrumentation development, and comprehensive case studies.

1.3 … Use satellite-derived estimates of fire radiative energy output to specify surface boundary conditions for the characterization of vertical atmospheric structure and transport over the fire.

1.4 … Partner with land management agencies for a series of large-scale controlled burns, conducted under well-characterized conditions and adequately instrumented to examine the response of such fires to three-dimensional atmospheric conditions. Joint development of a set of well-defined physical parameters for quantifying fire behavior under various three-dimensional atmospheric conditions is a necessary pre-condition to assessing the weather impact.

IV.A.2 Observations and Measurements to Initialize Numerical Models

Observations

To achieve accuracy in fire weather monitoring and forecasting, either subjectively or through numerical modeling, it is critical to have observations and measurement for (1) characterizing the current state of the atmosphere, and (2) forecasting the near-term-future states of the atmosphere as they may impact wildland fire dynamics. As previously noted, characterization of wildland fire regimes and of the behavior of an individual wildland fire within any fire regime is dependent on topography (which can be considered fixed), vegetation (which changes seasonally), and meteorology (which can change significantly in a fraction of an hour). Thus, while topography and vegetation are relatively persistent, changes in temperature, in humidity, and in wind speed, direction, and gustiness may mark an onset of high wildfire danger or an abrupt change in wildland fire behavior.

High spatial and temporal resolution (surface) observations and (upper air) soundings to at least 200 millibars of the 3-D atmospheric conditions are needed in the immediate vicinity of the wildland fire for both nowcasting and initialization of numerical models. In particular, *the most needed observations are those of the atmospheric states upwind that will soon be over the wildland fire site, as modified by the local topography*. To meet this need requires that fixed observing sites be quickly supplemented by an integrated set of deployable Remote Automatic Weather Station(RAWS)-type surface and aerial platforms that permit the collection through the depth of the troposphere of misoscale data on temperature, humidity, and wind magnitude/direction/gustiness. This monitoring must be carried out in near-real time and the data passed with minimal latency to the forecaster and the data assimilation systems feeding the numerical models.

Finding #2

Some prototype efforts already in existence support nowcasting and initialization of numerical models. MesoWest/Real-time Observation Monitor and Analysis Network (ROMAN) and MADIS are the vehicles by which WFO forecasters and IMETS currently obtain access to integrated surface observations distributed via Advanced Weather Interactive Processing System (AWIPS) and FX-Net. There are also underway efforts to develop a national Real-Time Mesoscale Analysis (RTMA) by NCEP. This effort is specifically intended to address the needs for nowcasting at 5 km (and planned for 2.5 km) for the nation as a whole. While such resolution is still too coarse for many fire applications, it is a base from which to layer additional data assimilation and modeling systems. It is intended to expand as part of a multiyear effort to develop a fully 3-D Analysis of Record data assimilation system applicable for fire weather as well as other applications. Although the prototypes and plans exist, the process to integrate the systems and funding within the NWS does not appear to be adequate.

The fire community is being well-served by NCEP's efforts to develop the RTMA. This is an example of where the objectives of the fire community are being addressed by a current NOAA project.

Additional support to nowcasting and initialization of numerical models may be obtained using aircraft to monitor wildland fire, though there may be safety, pilot, and aircraft availability limitations. Options are needed for monitoring conditions over and around a wildland fire or a complex of wildland fires: remaining onsite for an extended interval (loitering); "sounding" the atmosphere; and transmitting the resulting data rapidly to a central processing site without interference from the often hilly terrain. (Use of such aircraft also brings other related benefits, such as communications relays.)

Perhaps the most suitable remote sensing instrumentation for atmospheric sounding that has been demonstrated is the suite of airborne infrared and microwave spectrometers developed as part of the risk-reduction effort on the National Polar-orbiting Operational Environment Satellite system (NPOESS) platforms. The proven sensing technology in these instruments could guide the development of less-expensive, non-space rated instrumentation deployable on a HALE UAS. GPS dropwindsondes provide instantaneous measurements of the atmospheric state and may be of value in the collection of data as well.

In addition to the previously mentioned aircraft-mounted IR fire-mapping systems, satellites and surface-based surveillance radars may be suitable for the gathering of certain fire and weather information. For example, the GOES-E/-W Wildfire Automated Biomass Burning Algorithm (WF_ABBA) processing system was developed as a collaborative effort between personnel from NOAA/NESDIS and the University of Wisconsin-Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS), with funding from NOAA and NASA. Real-time active fire detections from WF_ABBA are available from NESDIS: http://gp16.ssd.nesdis.noaa.gov/FIRE/fire.html and archived data are available from: http://map.ngdc.noaa.gov/website/firedetects/viewer.htm. Numerical techniques are used to determine instantaneous estimates of sub-pixel fire size and average temperature. A new derived variable is Fire Radiative Power, characterizing the total radiative output from a fire, and thus the instantaneous intensity of the fire.

The regular repeat cycle of GOES is 30 minutes; however, Rapid Scan (5-minute) and Super Rapid Scan (1-minute) modes also exist with imaging capacity over limited areas. A formal procedure exists within NOAA/NESDIS to switch to these modes to support NOAA warning programs. The 30-minute repeat cycle might be more useful in certain areas and situations. However, for true real-time operations, early detection and detailed monitoring of the temporal development of fire intensity through the Rapid and Super Rapid Scan modes are necessary. There have been case studies to demonstrate the use of rapid scan observations (Weaver et al., 2004), but capabilities for fire characterization have not been fully developed.

Airborne fire sensing systems such as the FireMapper, co-developed by the Forest Service, can resolve hot spots at the meter scale. This kind of data would be especially useful for initializing fire perimeters for fire spread simulations, and for performing near-real-time statistical analyses of fire spread predictions. Fujioka (2002) showed how such analyses can be used to construct probabilistic maps of fire spread, which have recently been introduced to fire managers in the prototype Wildland Fire Decision Support System (WFDSS). However, aircraft which currently bear these monitoring systems cannot be used for sustained periods of fire monitoring.

Recommendations for Finding #2

NOAA should …

2.1 … Assimilate output from all available local observation sources, including data from surface-data networks, ground-based radars and profilers, UASs, and satellite sensors, when generating gridded nowcasting and forecasting products, and fire-danger maps.

2.2 … Explore the use of remote sensing methods, including ground-based radar, HALE UAS, and satellite (including high frequency fire detections and characterization from GOES), for sustained, continuous monitoring and forecasting of the tropospheric misoscale weather, surface conditions, and fire growth during ongoing wildland fires.

IV.A.3 Improve Fire Weather Modeling in Support of Nowcasts and Forecasts of Fire Behavior

Observations

Present day operational fire behavior models are based on semi-empirical or empirical relationships. In the US, the semi-empirical spread rate given by Rothermel (1972) for the head (only) of a fire - termed by some as "historic and time-tested" (see for example, Joint Fire Sciences Program, 2008), and questioned by others (see for example, Mell et al, 2007) - is employed in BehavePlus (Andrews et al., 2005), which infers a firespread rate for all sites on the perimeter, and in FARSITE (Finney, 1998), which advances a fire perimeter over a landscape with vegetation (~30 meter resolution). Similar empirical relationships for firespread are used in Forest Service Fire Behavior Prediction System (Hirsch, 1996) in Canada and in the Mk 4 MacArthur Fire Danger Meters (Noble et al., 1980) and the CSIRO Grassland Fire Spread Meter in Australia.

These present day fire spread prediction systems would be aided greatly by high resolution weather inputs/forecasts, particularly of the wind, precipitation, and humidity fields, which are principal determinants of fuel moisture and spread rate. Current practice relies on climatological data (Stratton, 2006), because evaluation of fire behavior simulations driven by mesoscale models has barely begun (Fujioka, 2002).

The FARSITE fire spread model does not currently account for the influence of the terrain or fire plume on the ambient wind. A research effort in the USFS to include the terrain effects on the ambient wind is in progress (WindWizard, 2008). A number of new generation computational fluid dynamics (CFD)-based coupled fire-atmosphere models are being developed and tested. These models vary in the spatial resolution of their computational grids, the degree of physical fidelity of their atmospheric and fire physics, limitations on the overall domain size, and computational cost. Coen (2005) used a coupled fire-atmosphere model that emphasizes atmospheric physics, running at a grid spacing of 100-500 meters, to simulate fire growth in a case study of the Colorado Big Elk Fire of 2002. Jenkins et al. (2007) have also developed a CFD-based coupled fire-atmosphere behavior simulation model (UULES-wildfire) weighted toward atmospheric physics. CFD-based modeling approaches that also include heat transfer and combustion physics have been reported by Linn and Cunningham (2005) (FIRETEC), Mell et al. (2007) (WFDS), and Morvan et al. (2008). The newer generation CFD-based fire behavior models, while still in a development stage, have the potential to simulate a wider range of fire behavior than the purely empirical or semi-empirical based methods. All require high resolution ambient weather, terrain, and fuels input data. A review of these models is given in Mell et al. (2007). The current version of the models of FIRETEC and WFDS are limited to overall domain sizes of kilometers. UULES-wildfire and Coen's most recent model, called WRF-Fire (2008), operate over larger domains (tens of kilometers).

WRF-Fire (2008) incorporates simple, empirically based firespread and fuel consumption models within the Weather Research and Forecasting Model (WRF, 2008). The simplification of fire physics and fire-atmosphere interaction allows simulations to run faster than real-time, so predictive use is a possibility.

The more comprehensive *research* models of FIRETEC and WFDS include important physics of a wildland fire, yet work with a level of detail comparable to the quality of vegetation data available (1-30 m). Research applications of both models has shown that they are capable of simulating many of the physical processes that are associated with wildland fire behavior, including combustion, radiative and convective heat transfer, turbulent mixing, and the aerodynamic drag of surface vegetation. Both of these models currently run significantly slower than real-time. The ongoing evaluation and development of these models would greatly benefit from weather inputs produced by high resolution atmospheric simulations, such as the WRF model.

The USFS Wildland Fire Decision Support System (WFDSS) includes a modeling component, FSPro, to determine the probabilistic spread of one or more wildland fires, given the location, fuels, and topography. Short-term weather forecasts that include the National Digital Forecast Database (NDFD) drive a fire spread model (Finney 1998; Rothermel 1972), but beyond a few days, climatology from the closest RAWS, an observing system deployed by some of the federal, state, and local land management agencies in support of fire operations -- is used to build a probability model of winds. Monte Carlo methods are then used to generate multiple wind scenarios for the fire spread simulator. Fire spread probabilities are then obtained from a statistical summary of the fire spread simulations. The probability contours represent the resultant surface created by the spatial histogram of fire occurrences within the grid of the simulation domain. Again, validation has yet to be undertaken.

NCEP’s Fire Weather IMET Support (FWIS) runs have demonstrated the capability to conduct simulations using a high resolution, non-hydrostatic model over a particular fire area. This system was in place from 2003 through 2005 and produced up to four runs per day for locations specified from coordination by NCEP's Senior Duty Meteorologist of the Boise Fire Center, NWS Western Region, and NCEP's SPC. While this product was suspended in 2006 due to increased computing requirements associated with the implementation of the WRF model, there are plans to reinstate this model-run time slot in NCEP’s operational computing stream in the near future.

Capacity to anticipate accurately the onset of exceptional fire behavior on the misoscale is a high-priority objective. It is anticipated that accurate misoscale fire weather nowcasts for about seven hours into the future should be possible in most circumstances. For forecasts of conditions likely to lead to extreme fire behavior (e.g., occurrence of blowup conditions), comprehensive, detailed computer simulations will be required. A dilemma arises because rapid perishability of the value of the prediction suggests that only a relatively rapidly executed data collection for monitoring, and relatively modest computation for such forecasts, can be accommodated. Such simulations may be in reach of WRF-Fire's capabilities once the fire behavior component is suitably evaluated against field observations and more comprehensive models such as FIRETEC and WFDS.

Ideally, numerical models would be able to replicate events as a fire moves from wildland into progressively more built-up areas, i.e., penetrates into the WUI. As indicated above, this is an area of special interest since the threat to life, property, and infrastructure increases dramatically in such cases. Modeling and forecasting of the behavior of fire in the WUI is in its infancy, with only a limited number of research results available, e.g., Spyratos et al. (2007); Porterie et al. (2007), and perhaps of most interest, Rehm (2008).

Finding #3

While promising in selected cases, the performance of systems that integrate high resolution weather forecasts with fire models to predict fire behavior has not been sufficiently validated. The development and validation of such models remain areas of active research. Further research is also required to bridge the disparity of spatial resolution of weather models (multi-kilometer spacing) and higher-resolution fire behavior models such as FARSITE (10-100 meter spacing). The newer more inclusive models such as FIRETEC (from Los Alamos National Laboratory), WFDS (from the National Institute of Standards and Technology), UULES (from the University of Utah), and WRF-Fire (from the National Center for Atmospheric Research) present a number of complementary approaches to addressing the separation of pertinent spatial scales.

Modeling weather in complex terrain at the misoscale (sometime called the "landscape scale") poses significant challenges because of uncertainties in model physics and in initial and boundary conditions. The relative inaccessibility of wildland fires occurring in rough terrain environments limits experimental studies and makes verification of model predictions difficult, further complicating the confident use of wildfire models in these weather environments. Modeling of the interaction of weather with fire in the WUI is only beginning to occur and suffers from many of the same challenges.

Use of the NDFD for fire behavior predictions may be problematic because the process of manually editing model grids may result in dynamic inconsistencies among weather variables.

Recommendation for Finding #3

NOAA should …

> **3.1 … Increase research and development of integrated fire weather modeling systems, for normal-to-exceptional fire weather conditions (extreme fire weather conditions may require special consideration), leveraging research expertise and**

capabilities where possible from other federal agencies, universities, and the private sector. The long range goals for this larger research community include accurate simulation of fire in complex terrain and, ultimately, the wildland-urban interface; NOAA's weather prediction capabilities are central to attaining these goals.

In regard to recommendation 3.1., the FWRWG is recommending that NOAA should build on one of its strengths, the development of numerical weather prediction systems. NOAA should help extend the current capability to predict fire behavior through advancement of high-resolution wind modeling in complex meteorological and topographic situations and thus enabling faster evolution of the communities coupled fire/weather modeling capabilities and eventually enable coupling fire and weather models for accurate operational forecasting of fire behavior in real time. NOAA should develop strong interactions with agencies and institutions that are active in operational fire modeling and coupled fire/weather research in order to hone the utility of NOAA's activities in this area.

This interaction/involvement of NOAA with the wildfire modeling community is regarded as essential if NOAA is to properly assess the adequacy of its misoscale monitoring and forecasting of fire weather, which require fire spread and fire behavior analyses. Further, from an operational perspective, in a wildfire crisis, there is insufficient time for complicated interagency information transfer. Therefore, the relationships and hand-off protocols between NOAA and those responsible for fire behavior prediction need to be well developed. As noted elsewhere in the report, knowledge of fire behavior is essential to NOAA forecast of air quality and visibility. Clearly, since the combustion aspects of fire lie within the purview of many agencies and not in the exclusive domain of any one agency, and since NOAA itself has need of such capability to meet many of its mission requirements; NOAA is obligated to pursue such capability.

As an extension to recommendation 3.1, the FWRWG believes the following is a reasonable time table for the development and deployment of such a fire weather modeling system:

Short term (within two years): Develop and deploy a means to downscale/interpolate wind, temperature, and relative humidity observations (from current national mesoscale models) to estimate winds and thermodynamic quantities in complex terrain. This capability would form part of the "intelligent assistant" in recommendation 3.2. Verification and validation of the products are to be a high priority.

Medium term (three to five years)**:** Develop a regional numerical model capable of predicting weather events from the storm-scale down to the misoscale in areas one-order of magnitude larger than a fire of concern. This fire weather model should be able to handle flow over complex terrain/vegetation in this area. Provision should be made to incorporate 3-D meso- (from national products) and misoscale (from local observations, radar, and satellites) information for initialization. Verification and validation of the products again are to be a high priority. As a research tool, this model should provide insight into what level of detail is likely to be required in an operational fire weather model.

Long term (five to seven years): Continue to improve the above fire weather model and transition it to operations. Explore simplified approaches for real-time operational utilization of insights gained from coupled fire–atmosphere models.

IV.A.4: Downscaling for Fire Model Calibration and Validation

Observations

As noted earlier, fire behavior is driven by the combined influence of fuels, weather and topography. Fire behavior analysts can currently access high-resolution information on fuels and topography, often at a spatial resolution on the order of 30 meters. Weather information, the most variable input in both space and time, is routinely available only at scales two orders of magnitude larger. This makes it extremely difficult to properly implement a fire behavior model or assess the quality of its projections. It is worth noting that spatial scales characterizing wildland-urban interface (WUI) communities (~hundreds of meters) and the surrounding wildland vegetation are much smaller than the scales at which wind/weather information is currently provided. Thus, even the strategic use of fire behavior models suitable for WUI fire behavior is hindered by the lack of wind and weather inputs at the relevant spatial scales.

NOAA's NDFD provides a number of weather parameters on a 5-kilometer national grid; additional weather parameters are available on local grids from individual forecast offices. Some offices provide specialized grids for use with the FARSITE fire behavior model; however, these grids are typically at only a 2.5 kilometer resolution. The USFS has explored generating high-resolution wind fields using a gradient-diffusion-based computational fluid dynamics model called WindWizard (2008) capable of producing, off-line, possible, as distinct from predicted, wind fields with resolution on the order of 100 meters. Initial case studies reveal there remains significant room for improvement.

Finding #4

NWS currently provides relatively coarse resolution weather data to fire incidents. IMETs currently have no tools for objectively downscaling weather information to a scale closer to that of the vegetation and topography. This mismatch of scale leads to very large uncertainty in the weather input, appreciably larger than the uncertainty regarding input on vegetation and topography.

A number of tools can be found in the literature that are designed for downscaling mesoscale model output to higher resolution in complex terrain, such as Micromet (Liston and Elder, 2006), CALMET (Scire et al., 2000) and NUATMOS (Ross et al., 1988). However, while most of these techniques conserve mass, they do not address thermodynamics. Such tools (and also numerical-model output) require both verification and validation.

The FWRWG finds that the terms "verification" and "validation" are often used interchangeably when, in point of fact they indicate quite different actions. Verification is confirmation that an intended activity was carried out. Validation is confirmation that an activity is pertinent to its objective, typically in weather forecasting, the accurate description of a quantity or an event.

Recommendations for Finding #4

NOAA should …

> 4.1 … Partner with the federal wildland management agencies to establish a central data repository (i.e., an archive), with entries in a standard format, to facilitate post-fire analyses and assist in verification and validation studies.
>
> 4.2 … Explore and validate tools for generating, from coarser forecast grids, detailed weather grids incorporating terrain.
>
> 4.3 … Maintain gridded forecasts (and observed/analyzed weather) in a database to assist future fire model development and testing.

IV.B Better Fire Danger Analysis and Forecast Maps

This section addresses the need for improved observations and forecasts in support of pre-fire management activities. It illustrates the complex arrangements that exist between NOAA and the federal wildland management agencies.

Background

Federal, state and local wildland managers and fire protection agencies regularly formulate and update strategic and tactical plans utilizing weather and climate information. They use the National Fire-Danger Rating System (NFDRS) as an operational tool to predict fire potential from weather, fuel, and topographic variables. The NFDRS is based on scientific research culminating in the early 1970s (Cohen and Deeming 1985). It has changed relatively little since, except that the Internet has drastically changed the way that users send and receive data and information. For completeness, some state and local fire-management agencies, and several foreign countries, have adopted the Canadian Fire Danger Rating System (CFDRS) and/or the Canadian Fire Weather Index (CFWI).

Gisborne in the 1920s and more recently others (e.g., Pyne 1982; Hardy and Hardy 2007) related weather to fire danger. Gisborne described the three components of fire danger (Gisborne 1928): 1) the present number of fires burning, or the probability that fires will be started; 2) the present rate of spread of fire, or the probability that fires will spread; and 3) the loss occurring from existing fires, or the probability that fires will result in loss. The NFDRS still embodies Gisborne's principles today, more than 80 years later (Figure 7).

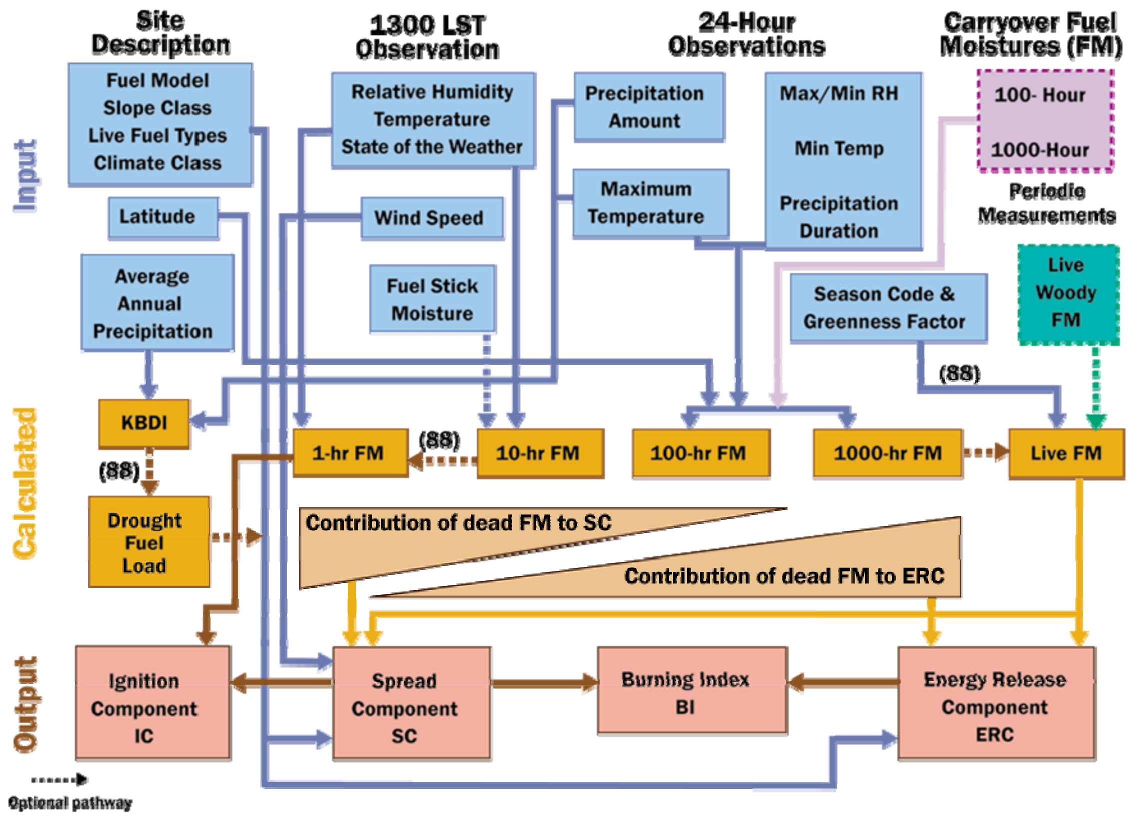

Figure 7. The National Fire-Danger Rating System integrates weather, fuels, and topography to rate fire danger for a given place (region) and time. From Schlobohm and Brain, 2002.

The Ignition Component, Spread Component, and Energy Release Component (bottom of Figure 7) are the three primary indices generated by the system, expressing, respectively, the ignition probability, rate of spread, and energy flux at the flaming front of the fire for the given inputs. The calculated values denoted by "FM" in the middle of the figure represent "fuel moistures" of different fuel size categories ranging from fine fuels such as grasses, leaves and pine needles (1-hour fuels) to large roundwood logs (1000-hour fuels), assumed dead in every case except where denoted as Live FM. The dead fuel moistures of the larger fuels and the Keetch-Byram Drought Index (KBDI; Keetch and Byram 1968) have long memories of antecedent weather conditions. Fuel moisture is a heat sink, and a fuel particle must be sufficiently desiccated for ignition to occur. Relative humidity, temperature, and current weather influence dead fine-fuel moisture, while daily humidity and temperature extremes and precipitation duration control fuel moisture in larger dead fuels (100- and 1000-hour fuels).

The Ignition Component and Spread Component address Gisborne's fire danger factors of probability of fire starting and rate of spread of a fire, respectively. The NFDRS incorporates the

Rothermel fire spread model (1972), in which rate of spread increases nonlinearly with wind speed. The Ignition Component incorporates the Spread Component because spread rate indicates the growth potential of a fire after ignition, information vital for pre-suppression planning. The magnitude of the Energy Release Component is considered in determining the suppression resources required to fight a potential wildfire. The Burning Index, a function of the Spread Component and the Energy Release Component, is proportional to the theoretical flame length characteristic of the fire, as described in seminal research by Byram (1959).

In practice, the NFDRS is used on a variety of spatial and temporal scales. A ranger district in a national forest or a county fire department may use a nowcast of ignition potential in a fire-prevention program. Federal wildland managers use a national forecast of fire severity potential for the upcoming fire season to guide an optimal allocation of national firefighting resources. Fire planning tools such as the Wildland Fire Situation Analysis were developed decades ago to utilize fire climatology to plan firefighting strategies. The Forest Service is modernizing these tools in a national program to build the Wildland Fire Decision Support System (WFDSS). In each undertaking, the fire community depends on good weather and climate information.

Fire practitioners in certain parts of the country employ alternatives to the NFDRS. Some of the northern tier states, for example, use the Canadian Forest Fire Danger Rating System (CFFDRS). The weather data requirements are very similar across systems, and well within the observation and forecasting capabilities of the NWS to implement.

IV.B.1 Enhance the Use of Observations in Production of Fire Weather and Fire Danger Maps

Observations

The USFS generates national maps of *observed fire danger* for the continental US and Alaska, posted daily on the Wildland Fire Assessment System (WFAS) web site (www.wfas.net). The maps present weather data from daily 1400-hours (local standard time) observations in a network of up to 1500 fire weather stations. Consistency of reporting varies from station to station. Currently, the area in which fire danger is taken to be uniform is typically large, on the order of 10^4 acres (Schlobohm and Brain 2002). The possibly appreciable variability at any time of fire danger within this large "cell" is not characterized. (This gridding originated with the rollout of the NFDRS in the 1970s, because at that time the spatial resolution of weather and fuels data was coarse.) Inverse-distance-squared interpolation is applied to the observations to populate a horizontal map grid at 10-km intervals.

A prototype national fire danger forecasting system exists at the Scripps Institution of Oceanography, Experimental Climate Prediction Center, through a partnership with the Forest Service Riverside Fire Lab and NCEP. A national NFDRS fuel model map and NFDRS code were developed to run with NCEP's GFS forecast. The Forest Service Rocky Mountain Center in Ft. Collins, Colorado, also features NFDRS maps at 12 km grid intervals. Research is continuing to improve the forecasts.

Another source of graphic and tabular fire weather observations is the Real-time Observation Monitoring and Analysis Network, ROMAN, developed at the University of Utah for the federal land agencies. The system is used extensively by the fire community in the western US, including IMETs, who use it because the fire weather RAWS network often provides observations closest to an incident. ROMAN derives ancillary support from NOAA through funding for the Cooperative Institute for Regional Prediction, also located at the University of Utah.

Finding #5

The observed fire danger map underutilizes weather observations and analysis tools of the NWS. The inverse-distance interpolation used by WFAS is inadequate for mapping weather fields, particularly wind. Maps of functions of weather, such as fire danger, are thus compromised by the interpolated weather fields. Remote sensing technology and computer models have vastly improved data resolution, but WFAS has not taken full advantage of current capabilities. Hoadley et al. (2006) determined that weather data generated from the MM5 mesoscale model at a four-kilometer grid spacing consistently provided NFDRS indices closer to observed values than coarser model data, in a case study of the 2000 fire season in Idaho and Montana. Limited use is made of remotely-sensed data, such as satellite imagery, to estimate directly the spatial and temporal variations of fuel moisture. This includes maps of various measures of greenness and an experimental live fuel moisture map from the Advanced Very High Resolution Radiometer (AVHRR), but there is a potential of utilizing improved spectral information from current systematic observations from MODIS and from the future operational imager VIIRS.

To facilitate integration of, and quality control on, the many disparate sources of observations relevant to fire weather and fire-weather modeling, a single data network is highly desirable. The NOAA/NWS-funded prototype, intended for eventual operational status, MADIS, is the obvious choice, though issues of capacity and latency need to be addressed.

Recommendations for Finding #5

NOAA should …

> **5.1 …Use data assimilation systems described in Recommendation 2.1 to generate high resolution fire danger maps.**
>
> 5.2 … Use the existing NFDRS processor at the Scripps Experimental Climate Prediction Center or the Rocky Mountain Center to compute fire danger maps with sufficient frequency to depict diurnal variations that may affect fire potential.

IV.B.2 Enhance the Use of Forecasts in the Production of One-To-Ten-Day Fire Weather and Fire Danger Forecast Maps

Observations

The USFS also generates national *fire danger forecasts* for the continental US, utilizing trend forecasts for fire weather zones issued by the NWS. The density of the forecasts depends on season and availability of fire weather observations. Next-day forecast maps of fire danger are created from the point forecasts of fire danger, by the same interpolation process used for the observations. The WFAS web site warns users that trend forecasts are generally issued only at the peak of fire season, which may result at other times in "large data gaps and unrealistic interpolations."

Finding #6

The WFAS forecast maps underutilize NWS forecasts. With the exception of the NDFD, gridded forecasts are not used. WFAS does not forecast diurnal variations of either fire weather or fire danger. Guidance for producing the needed forecasts exists in the peer reviewed literature from joint research conducted by the Scripps Experimental Climate Prediction Center, NCEP, and Forest Service Research (Roads et al. 2001, 2004, 2005). They have demonstrated the use of weather models to produce diurnal, weekly, monthly and seasonal forecasts of fire weather and fire danger.

Recommendations for Finding #6

NOAA should …

> 6.1 … Use NCEP forecasts with the NFDRS, CFFDRS, and other such systems that require weather data provided by the NWS to generate short-to long-term fire weather and fire danger forecasts maps to meet the different spatial scale needs of federal, state and local fire managers.
>
> 6.2 … Make these products available through a web-based GIS platform for users to customize fire weather and fire danger maps to suit their spatial and temporal scales of interest.
>
> 6.3… Develop training plans and packages with the National Wildfire Coordinating Group to familiarize users with the forecast technology.

IV.B.3 Utilize Innovative Forecast Approaches in the Production of Fire Weather Forecast and Fire Danger Maps

Observations

The federal-wildland-fire-agency meteorologists in Predictive Service units at the National Interagency Coordination Center (NICC) in Boise, Idaho and at regional geographic area coordination centers (GACCs) generate 7- to10-day, monthly, and seasonal fire potential outlooks for the country. One of the elements considered is the Energy Release Component for Fuel Model G (ERC-G), which primarily reflects the fuel moisture in 1000-hr fuels. ERC-G is significant because the intensity of fires in large fuels can pose severe suppression problems that require extraordinary resources. Future values of ERC are computed using NDFD forecasts and Model Output Statistics based on the NCEP global spectral model. The Forest Service recognizes the need for numerically based decision aides and so is developing the Wildland Fire Decision Support System (WFDSS) because "Advances in fire modeling, geospatial analysis, remote sensing…, weather and climate forecasting, and other modeling tools can be leveraged". For details, see: http://www.fs.fed.us/fire/wfsa/WFDSSBriefingPaperFinal.pdf.

Finding #7

The interagency Predictive Services program's long-term fire potential outlooks do not currently incorporate the uncertainties inherent in the weather and fire-related forecasts. A recent survey of user needs by the Office of the Federal Coordinator for Meteorology (OFCM, 2007) of the wildland fire organizations suggests that probabilistic forecasts may be needed to characterize the relative likelihood of plausible alternative possibilities. Fire management decision support systems under development already contain probabilistic information which can include fire-related event probabilities or expected outcomes, conditioned on forecasts. Research conducted by the USFS and others exploits the probabilistic content of seasonal (30-60-90-day) and annual (180-day/yearly) climate forecasts for strategic fire planning (Preisler et al. 2005, 2007). The Predictive Service units do not use ensemble forecasts for this purpose, but the products issued by the various operational centers are considered in the process of formulating long-range fire potential outlooks.

Recommendations for Finding #7

NOAA should …

> 7.1 … Utilize ensemble forecasts to develop seasonal to interannual fire weather and fire danger maps.
>
> 7.2 … Provide a source of weather/climate forecasts for annual fire potential forecasts, particularly for ERC-G.
>
> 7.3 … Encourage further research and development of seasonal climate-related fire forecasts to meet strategic fire planning needs.

In acting on these three recommendations, the FWRWG recommends that NOAA work closely with the federal land management agencies and the National Wildfire Coordinating Group.

IV.C Improved Forecast Tools

This section discusses the need for improved tools for preparing fire weather forecasts, lightning prediction, and forecasting air quality/smoke transport and dispersion.

IV.C. 1 Automated Fire Weather Nowcast Assistance Tools

Observations

The Incident Commander's fire intelligence comes from briefings provided by WFO forecasters/IMETs and fire behavior analysts (FBANs). When preparing to brief an Incident Commander in the field, these individuals work together, integrating data from previous fires, updated fuels analysis, fire spread forecasts, and fire weather forecasts. Currently, the forecasters and analysts must assimilate these data in their native formats, without the benefit of being able to seamlessly merge them with data about current fire perimeter and fire spread information, and do any necessary downscaling using subjective techniques. Accomplishing this assimilation seamlessly, accurately, and in a timely fashion is often problematic at best.

Fire weather forecasting in support of on-going wildland fire operations can be thought of as a form of nowcasting. The challenge in such fire weather nowcasting, as faced by duty forecasters in the WFOs and deployed IMETS, is to expeditiously generate forecasts of the weather on misoscale (landscape-scale) for a short time horizon (approximately one to six hours).

Only relatively recently has effort been expended to develop requirements for simple, operationally practical forecast tools dedicated to fire weather nowcasting. What is needed is an integrated suite of diagnostic/prognostic numerical tools that:

- Gathers data from available RAWS, ASOS, AgriMet, and other surface-weather-observing networks
- Monitors forecast model output:
- Complements and smoothes the available thermodynamic data;
- Generates wind fields from the data with cognizance of topography and other local effects;
- Carries out a Lagrangian advection of the neighboring atmospheric air mass to the fire site;
- Computes an updated wind field, accounting for its adjustment owing to modified thermodynamics holding for the landscape;

- Organizes available fire data, such as last reported fuels data, and fire perimeter and fire spread information;
- Highlights fire behavior thresholds; and
- Formats, upon specification of a particular location of interest, a draft spot forecast for review by the forecaster.

The above information needs to be readily available so that the forecaster can respond almost immediately to a request from the field for a spot forecast. This suggests a system – which may be termed an “intelligent forecast assistant” -- that runs in the background in a cyclic manner, continuously searching out new data and updating the relevant forecast information. The importance of terrain in many of the forecast calculations and decisions suggests a GIS-based application.

One caution: cyclic application of this straightforward approach could overlook anomalous dynamical events arising under exceptional circumstances which produce extreme fire behavior. Recognizing the likelihood of the onset of such events becomes the special responsibility of the forecaster and fully justifies having a human in the forecast loop. To provide a forecaster with awareness of these special conditions, it would be useful to have available frequent offline runs from highly detailed and dynamically comprehensive misoscale models.

Finding #8

Use of climatology beyond a few days in lieu of fire weather forecasts ignores the potential contribution of medium-range numerical forecasts, and averages conditions to the obscuration of special circumstances that could foretell exceptional fire behavior.

The WFO forecaster needs a digital tool or “intelligent assistant” to aid in responding rapidly and accurately to requests for spot forecasts. This tool is envisioned as one that continuously gathers data and provides guidance for the forecaster’s otherwise subjective forecast. The tool should also be configured to assist in the dissemination process.

The forecaster needs information from continuously updated model runs of misoscale and mesoscale predictions for the region of interest. The frequency of such runs remains to be determined, but needs to be often enough to provide several hours notice of rapidly evolving weather events that may produce extreme fire behavior.

Recommendations for Finding #8

NOAA should …

8.1 … Develop a standardized "intelligent assistant" or decision-support tool for the WFO forecaster replying to requests for spot forecasts from first respondents and for deployed IMETs providing weather support to Incident Commanders.

8.2 … Develop numerical prediction methods that provide a frequently updated sequence of misoscale and mesoscale forecasts to provide forecasters with the capability to anticipate extreme fire behavior with several hours notice.

IV.C.2 Lightning Detection and Prediction

Observations

Lightning is the major natural ignition source for wildland fires. Consequently, forecasting and monitoring of lightning, is very important to the fire management community. Of particular importance is lightning associated with so-called "dry thunderstorms" that produce little or no rain at the surface.

There are multiple interpretations of the current definition of lightning activity level (LAL) (as evidenced by the NWS 2005 Customer Satisfaction Survey results). This has lead to LAL being measured and forecasted in ways that vary significantly from organization to organization. Bothwell of NOAA/NWS/SPC is currently working on an improved lightning forecast product with funding from the JFSP.

On short time scales, lightning can be a significant safety issue on the fire line. Real time lightning strike information is the least reliable data feed both into AWIPS and FX-Net.

Finding #9

A change of the current LAL product is needed to better represent ignition potential, particularly in dry thunderstorm cases. One approach would be to combine a probability of lightning coverage, along with a forecast of whether rain will accompany the lightning, and to present the product as an index, with a small range of possible, integral values. Development and operational use of such an index would enable forecasters to communicate lightning threat information in a standardized manner. (Similar indices could be developed for other weather-related ignition sources, such as probabilities of wind speeds exceeding thresholds which lead to downed power lines). The interagency Predictive Services program provides a lightning risk element in their seven-day fire- potential forecast that incorporates the LAL index and prolonged dry periods.

A consensus between NOAA and fire agencies is necessary before a new index can be implemented in daily forecasting. Important questions that need to be answered are: 1) How would a change in the index affect the user community, and 2) How would a change affect NFDRS?

Problems with the current Lightning Detection System (LDS) need to be better identified and corrected. An improved LDS which merges strike data from all sources will lead to better scientific understanding of ignition, improved planning and dispatch of resources, and improved fire line safety.

Current LAL forecasts can not be efficiently validated using lightning strikes within 15 minutes. Real time displays of lightning strikes for WFOs and IMETs need improvement.

Recommendations for Finding #9

NOAA should …

> 9.1 … Establish a national LDS managed with full resources, coordinated under one agency with a more robust telemetry. Data collection should be centralized for the continental U.S. as well as Alaska and Hawaii.
>
> 9.2 … Develop and validate better forecasts of lightning activity that have improved representation of ignition potential. Consider partnering with the interagency Predictive Services program's fire-potential product with regard to new ignitions. Develop a new lightning probability product, weighted toward forecasting dry thunderstorm lightning.

IV.C.3 Integrated Air Quality/Smoke Transport and Dispersion Model Development and Validation

Observations

The particulate matter (or smoke particles) produced by wildland fires can be a nuisance or safety hazard to people who come in contact with the smoke – whether the contact is directly through personal exposure, or indirectly through visibility impairment. Reduced visibility from smoke has caused fatal collisions on highways in several states. In the southern United States in particular, meteorology, climate and topography combine with population density and fire frequency to make nuisance smoke a chronic issue. Because of public and governmental concerns about these possible risks to public health and safety, as well as nuisance and regional haze impacts of smoke, increasingly effective smoke management programs have begun to be developed over the past decade.

Air quality impact associated with wildland fires is becoming a critical issue. Each year more fires appear to be occurring in the WUI and as a consequence more people are being impacted by smoke. Smoke intrusions into populated areas can lead to significant increases in respiratory problems and emergency room visits. Local health departments are a key customer for timely forecasts of smoke transport and dispersion.

NOAA shares its responsibilities in the air quality area with the Environmental Protection Agency. The EPA and numerous state and local environmental and public health agencies operate a wide range of air quality monitoring systems both to ensure compliance with federal environmental standards and to advise the public on current air quality conditions. These data are made widely available, usually through the media and websites maintained by the agencies.

NOAA currently provides operational smoke predictions generated at NCEP as part of the National Air Quality Forecast Capability (NAQFC). NOAA has been building the NAQFC in response to Congressional direction to provide operational air quality forecasts; it now provides surface ozone and smoke predictions for the lower 48 states at 12-km resolution, with targeted full operational capabilities to include quantitative ozone and particulate-matter predictions nationwide.

The NAQFC is an end-to-end forecast capability, from observation through analysis, prediction, interpretation (through partners), and feedback. It incorporates a linked numerical prediction system, combining NCEP's operational mesoscale NWP with chemical transport and dispersion models. Required accuracy and reliability performance targets are monitored with near-real time verification, delivery monitoring, back-up procedures, and archiving. Products are disseminated on operational data servers at NOAA (via the National Digital Guidance Database), and at EPA (via AIRNow), with interpretation and feedback loops that include state and local air quality forecasters.

The atmospheric chemical transport and dispersion models (CMAQ and HYSPLIT) in the NAQFC were developed by researchers in NOAA/OAR's Air Resources Laboratory, in collaboration with the EPA. Operational smoke forecast guidance for the continental U.S. is based on ingesting satellite-detected fire locations, USFS BlueSky fire emissions information, and HYSPLIT fine particle dispersion predictions driven by NWS' operational NWP systems. Fire locations, areal extents, and time durations are derived from satellite observations with objective fire retrieval algorithms and filtered by satellite analysts to remove spurious hot spots, and to discriminate various other sources (e.g. dust, clouds) from fire smoke.

Upgrades to BlueSky incorporate recent research efforts of the USFS, as well as contributions from NOAA, EPA, and other government, private-sector and academic researchers, that in turn are included in upgrades to NOAA's smoke forecast capability. BlueSky improvements in development include better representations of fire intensity, fire duration, injection heights of released smoke, and more complete representation of emitted chemical species. NOAA's smoke forecast guidance is verified using NESDIS satellite observations products. The smoke guidance is also being tested, with other sources contributing to airborne particulate matter, for inclusion in a quantitative prediction capability for fine particulate matter that NOAA is developing as part of the NAQFC.

In addition NOAA/ESRL is applying the atmospheric chemistry capabilities of the WRF model to the problem of modeling smoke dispersion from wildland fires. The atmospheric chemistry routines of the WRF model offer a distinct advantage over other currently used approaches in that the chemistry and aerosol routines can be solved in an “inline” fashion, that is, the solution of these equations is occurring at the same time as the meteorological equations, allowing feedback between the two sets of equations. Other models use an “offline” method where the meteorology is solved first and then used to supply the transport terms in the chemistry equations. Wildland fire emissions are being incorporated into the WRF simulations through the use of satellite observations and research in cooperation with NCAR is underway to incorporate fire growth/evolution capabilities into the WRF model to better simulate the complex spatial distribution of a wildland fire as an emissions source.

Other smoke predictions are supplied by USFS through its Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS). The FCAMMS modeling framework links together tools commonly used by land management agencies to estimate fuel consumption and fire emissions in the BlueSky smoke modeling framework. The pollutant commonly forecast is particulate matter smaller than 2.5 microns (PM 2.5). One reservation pertaining to many of these dispersion tools is that they were developed for sources other than wildland fires, specifically volcanoes, point industrial sources, and diffuse area sources.

In 2001, the National Fire Plan funded USFS research units across the country to develop and test a mesoscale weather and smoke modeling system to predict the air quality impacts from wildland fires. The BlueSky modeling framework, developed by the USFS Pacific Northwest research unit and their collaborators, was adopted within each of the other regions, with some local modifications. Each site simulated high resolution weather with the MM5 mesoscale model, which drove HYSPLIT to predict smoke trajectories from known fire locations, and drove Calmet/Calpuff to predict particulate concentrations. An objective that FCAMMS set early was to provide seamless coverage for wildland fire users across the country.

The FWRWG also heard from individuals in the recent California fires that it was difficult to find definitive information on the hazard posed by the smoke and resulting pollution. This reportedly is because the information – plume constituents as well as predicted movement and evolution – is scattered across a number of different agency web sites.

Finding #10

The FCAMMS have been successful at deploying regional weather and smoke modeling systems, while NOAA has implemented an operational smoke forecast tool for the lower 48 states, at 12 km grid resolution with hourly predictions of fine particles in smoke. Although each FCAMMS site has supercomputing capability, none can run weather simulations at the four-kilometer grid resolution for the country, and a strategy for combining regional products seamlessly is still wanting. Increased collaboration between NOAA, EPA, FCAMMS and their partners would facilitate improvements to the fire and smoke modeling components which are necessary to quantify the emission rates and source areas for air pollutants of interest.

Smoke dispersion from wildland fires is not well represented by current generation dispersion models as graphically illustrated by the recent fires in northern California, which filled the Central Valley with smoke and smog. A new study of the 2007 California wildfires found that the fires caused ground-level ozone to spike to unhealthy levels across a broad area including much of rural California as well as neighboring Nevada (Pfister et al, 2008). Fires represent a spatially-complicated, time-dependent source that is strongly controlled by buoyancy and entrainment. The interaction between plume buoyancy and entrainment processes controls the vertical rise of the plume which ultimately governs its dispersion and surface concentrations. The spatial distribution of a fire leads to the development of many interacting plumes which merge and split as the fire evolves. Satellite hot spot detections and fire radiative power and energy estimates provide valuable information to locate and characterize source terms for fire emissions (Al-Saadi et al., 2008)

Smoke is not the explicit responsibility of anyone on an Incident Command Team. Requests for smoke information are often directed to the fire behavior analyst and the incident meteorologist, neither of whom necessarily have training in estimating fuel consumption and smoke emissions. NOAA's predictions of smoke as part of the national air quality forecast capability provide a baseline that can be used for further down-scaling.

During a fire situation, all information regarding the hazard posed by the resulting smoke and air pollution needs to be available to the public from one source. This would require a collaborative effort by NOAA, EPA, FCAMMS, and relevant state and local agencies.

<u>Recommendations for Finding #10</u>

NOAA should …

> 10.1 … Continue to leverage research capabilities to help improve representation of smoke plumes from wildland fires in operational forecasting tools through its ongoing collaborations with NOAA, EPA, and USFS researchers.
>
> 10.2 … Encourage WFO forecasters and incident meteorologists to take an appropriate smoke management course to gain familiarity with the fuel consumption and smoke emissions tools used by land managers.
>
> 10.3 … Work with NIFC, EPA, FCAMMS, and state and local environmental and public health agencies to ensure that complete smoke and pollution information, including current speciated emissions data as well as predicted plume evolution, is gathered, processed, summarized, and made available to the public in a timely and easily accessible manner, preferably from a single information source, e.g., a smoke

web site or a smoke information portal.

IV.D Interagency Communication and Coordination

IV.D.1 Handling of IMET-Produced Information

Observations

NWS produces a wide variety of products and services, most of which are made available on its web site at nws.noaa.gov. From the fire weather perspective, these include regularly-issued fire weather forecasts, fire weather watches, red flag warnings and spot forecasts (issued by the WFOs) and fire weather outlook products (produced by SPC). However, spot forecasts issued by IMETs at the scenes of fires and other incidents currently are made available only to the Incident Commander and other land management staff at the fire scene. Several individuals from the federal wildland management agencies and from WFOs indicated that access to IMET-issued spot forecasts would be helpful in seeing the broader picture in the fire area.

Verification and validation are critical parts of any forecast process. Such information helps forecasters to improve model predictions. It also helps develop in users/customers a level of confidence in forecasts, particularly when they are involved in the verification and validation processes. The recent emergence of forecast grids adds a spatial component to forecast validation that also must be captured. NWS has an established forecast verification process; however, it is focused on verification of maximum and minimum temperature and probability of precipitation forecasts at points. In addition, routine National Fire Danger Rating System (NFDRS) verification is provided for state of the weather, temperature, relative humidity, and wind speed at specific NFDRS stations.

A fundamental aspect of any effort to verify and then validate fire weather forecasts is sufficient knowledge of the wildland fire. Large wildland fires may influence winds at landscape scales. For this reason, verification and validation efforts for high resolution, landscape-scale, fire weather forecasts need to account for the effects of the fire-induced winds. In the future, when computer-processing power is greatly increased, this may be done through the use of coupled fire-atmosphere models. Critical to this effort is information from the fire incident management team (including the fire behavior analyst and IMET) regarding fire perimeter progression, fuels, terrain, and fire weather (measurements and prediction).

Finding #11

The overall goal is for essential information to be disseminated in a timely manner in the most understandable way.

While generally the NOAA family of services dissemination tools (NOAAPORT, EMWIN) provide excellent watch/warning and forecast dissemination, IMET Spot forecasts produced at the scenes of fires and other incidents are of value to emergency and land managers outside of the fire scene and should be made widely available.

There is no formal forecast validation process for IMET and spot fire weather forecasts. For IMETs, forecast validation is often difficult in remote locations for which they forecast and a mature analysis field including the necessary elements is not yet available for spatial validation. This lack of forecast validation of fire weather information makes it difficult for the users to develop high levels of confidence in such forecasts.

Fire weather forecast validation information is not currently available to the land management agencies. Validation should be a routine part of all fire weather forecasts (including spot forecasts and all IMET forecasts). This forecast validation information should incorporate a spatial component to help managers identify geographic areas that may have higher levels of confidence associated with them.

As noted in the findings leading to recommendation 4.3, there is currently no standardized method of collecting, storing, and maintaining fire incident information. Such data are needed not only for research purposes (the intent of recommendation 4.3) but also to adequately support post-fire validation of fire weather forecasts or post-incident analysis/study of other kinds (e.g., fire behavior predictions).

Recommendations for Finding #11

NOAA should …

> 11.1… Disseminate IMET spot forecasts from the field via NOAA web and data-serving capabilities and consider providing automated email distribution/SMS notification of SPOT availability as is done with NHC products.
>
> 11.2… Provide fire weather forecast verification and validation information and include performance standards for each forecast element; include spatial verification information and spot and IMET forecast validation information in final (archival) documentation for all major incidents.

IV.E Incident Communication Infrastructure

Background

When first responders to a wildfire request a spot forecast from the local WFO, the forecaster often does not have access to the local near-ground conditions, even with available RAWS, ASOS, AgriMet, and other surface-weather-observing networks. As noted in IV.A.1, the WFO forecaster, in replying to the spot-forecast request, must rely largely on his/her general expertise with the locality and his/her broader meteorological experience. After an IMET arrives on scene of an incident, typically within 24 hours after request, he/she may have access to a surface-weather station on site, perhaps even one that he or she sets up. However, the IMET still lacks a standardized, validated, quickly executed, objective tool as an aide to guide what is otherwise a subjective forecast for the immediate surroundings.

IV.E.1 Communications in Low Bandwidth Environments

Observations

Fire managers at the scene of a wildland fire face unique challenges when making requests for and receiving fire-related weather data. The early stages of fire incident management are often a chaotic, resource-poor environment where priorities change by the minute, and decisions to protect life, property and firefighter safety are paramount. There is need for accurate, timely weather data for a location-specific weather forecast. The technical challenge includes a highly mobile environment where even the simplest forms of communications are difficult due to lack of phone lines, cellular reception and Internet connectivity. The traditional method of requesting and receiving weather data for a wildland fire site is by accessing the NWS web site and completing an on-line spot weather forecast form. However, since fire managers at the scene usually do not have the direct access to the necessary communications tools, these requests are often relayed through busy dispatch centers or verbally through less-than-optimal cellular connections. In addition, most Weather Service web sites are highly graphical, and not well suited to the low-bandwidth wireless communication devices that are most commonly used on wildland fire incidents. Once a spot forecast is received, direct communication with the forecaster, and/or forecast verification is often minimal or absent due to the aforementioned communication limitations. Similarly, highly usable forecast graphics including wind, temperature and humidity plots, are all but impossible to receive for the same reasons.

Finding #12

The overall goal is for the right information to be disseminated in a timely manner in the most understandable way.

Current methods for requesting and obtaining weather data at the scene of a fire usually require a high-bandwidth Internet connection or other wired communication method that is typically not available during the initial stages of a wildland fire. Additional tools and technologies are needed to improve and maintain communications and to transfer weather-related data between WFOs, IMETs, and fire managers.

Recommendation for Finding #12

NOAA should …

> **12.1 … Explore emerging communication formats and low-bandwidth technologies with the goal of allowing fire managers to access site data and to initiate and receive both spot weather forecasts and extended nowcasts; emphasis should be placed on maximizing the capabilities of currently-available low-bandwidth wireless devices such as Blackberries, iPhones, PDAs, and cellular modem-equipped laptops.**

IV.E.2 Integrated 3-D Weather Data and GIS tools

Observations

In a wildland fire, geospatial awareness is critical to the safety of responders and the public and to supporting the fire containment and suppression effort. Forecasters currently do not have the model resolution or the coupled weather-GIS technology needed to provide fine-scale, location-based information.

While weather data can be prepared for visualization in GIS programs such as ArcMAP and Google Earth, existing GIS tools do not allow the interrogation or overlay of traditional 3-D atmospheric data. Further, as new, high resolution fire weather and fire behavior models become available, a visualization tool to allow model output to be draped over complex terrain will become a critical need.

Finding #13

WFO forecasters and deployed IMETs need 3-D visualization of terrain-following weather, fire perimeter, and hydrometeorological data keyed to wind and relative humidity, and which account for local effects that are critical to fire weather monitoring and forecasting.

In the near term, the technologies used by common GIS tools such as Google Earth and the ESRI suite of applications can be adapted to integrate currently generated operational weather data. By utilizing Common Graphical Language (CGL), programmable graphics cards, and Open Geospatial Consortium (OGC) standards, the tools needed to visualize terrain-following weather, the fire perimeter, and hydrometeorological data may become available to incident commanders, emergency managers, and the public.

There is a desire by many users outside of NOAA to produce their own customized maps of fire-related weather conditions on a variety of GIS platforms. An example is provided by some of the tools on the University of Utah's MesoWest network (see http://www.met.utah.edu/mesowest).

Recommendations for Finding #13

NOAA should …

13.1 … Develop and deploy improved three-dimensional weather visualization tools for use by the interagency Predictive Services program, WFO forecasters, and deployed IMETs for decision making, forecasting, and briefings.

13.2 … Make fire weather products available through a web-based GIS platform for users to produce their own customized fire weather and fire danger maps to suit their spatial and temporal scales of interest.

13.3 … Ensure its data and forecast products are compatible with protocols such as the Wildland Fire Decision Support System (WFDSS).

IV.E.3 Connectivity in the Field for Real Time Data and Information

Observations

In the field, an IMET and a Type I or Type II Fire Incident Commander require data and information from a large and distributed array of web sites, direct-access servers and transient and in situ data sources. NOAA has done an admirable job in the last decade in equipping IMETs with the equipment and communications capabilities they need to access this information. This has been critical to the success of the IMET Program.

In order to organize and assimilate these data into informed, meaningful decision support information, IMETs must view them in a variety of media and formats. At the heart of the array of weather information needed by the IMETs is a NWS-based data system that provides on-demand, integrated atmospheric observations and forecast information. The current system, called FX-Net, creates an 'in the WFO" experience for NWS forecasters who need information fast but can access it only over low-bandwidth links, in the same format, with the same analysis tools that they use everyday in the office. They access these data via laptop computers equipped with remote communications capability and specialized software created and maintained by NOAA's Earth System Research Laboratory in Boulder, CO.

A new thin client capability will be included in NOAA's "AWIPS II" system, which is targeted for initial deployment in Fiscal Year 2011 at the earliest.

Finding #14

The "thin client" capability currently provided by FX-Net is critical to ensure IMET access to needed observational and forecast data sets at fire scenes. Ensuring availability of usable FX-Net software requires regular software maintenance, as well as hardware and software upgrades to ensure the current FX-Net version matches all AWIPS updates.

The existing thin client capability via FX-Net must be dependably supported until such time as this capability is fully deployed in AWIPS II. This includes ensuring a smooth transition from the current FX-Net technology to the new AWIPS II thin client. The new AWIPS II thin client then will replicate WFO operations in the field, perhaps using a mobile satellite dish that can directly ingest NOAA Satellite Broadcast Network (SBN) data feeds.

The development of this capability is of interest to others, such as the interagency Predictive Services program and other federal partners.

Recommendation for Finding #14

NOAA should …

> **14.1 … Ensure availability of live weather data via the current FX-Net and subsequently the AWIPS II thin client to facilitate IMET support at fires.**

IV.F Flash Flooding and Debris Flows

IV.F.1: National Implementation of the NOAA-USGS Debris Flow Project

Observations

Vegetation, particularly grasses, deep rooted plants, and trees, protect soil and tie it together, resisting erosion and minimizing runoff. In the aftermath of a wildfire, the land surface is nearly bare of vegetation and detritus. If the soil is hard, when rains come, great amounts of water can run off quickly and the soil can erode rapidly. In such cases, in steep terrain the risk of flash flooding downstream is greatly increased in the months following a fire. Where there is unconsolidated soil and loose rock, water may permeate the soil and trigger landslides or slumping. In either case, debris flows may occur. These may start as a slumping of saturated soil that continues to flow down hill or as a flash flood that entrains large amounts of rocks, mud, and detritus. However debris flows start, they are highly destructive to property and infrastructure. With little warning, such flows can endanger human life, exert great loads on structures in their paths, can strip vegetation, and block streams, producing other hazards. This danger can persist for several years, until enough vegetation returns to stabilize the soil.

NWS, NOAA's Office of Oceanic and Atmospheric Research (OAR), and National Ocean Service (NOS) have collaborated with the U.S. Geological Survey (USGS) on a demonstration flash-flood and debris-flow early warning system for recently burned areas in southern California. This demonstration was started in the fall of 2005 and involves NWS WFOs Oxnard and San Diego. The demonstration area covers eight counties in southern California (NOAA, 2005).

In this collaboration, USGS developed precipitation thresholds that could potentially trigger debris flows in the areas of interest, and provided this information to the WFOs. The WFOs then use this information to issue flash flood warnings for debris flows when rainfall approaches or exceeds the thresholds. The WFOs also meet with local emergency management officials to educate them on the project and to obtain important contact information.

During an event, WFOs monitor precipitation in these areas based on capabilities of the WSR-88D Weather Surveillance Radar, the Flash Flood Monitoring and Prediction tool, and ground truth rain gauge information. When the USGS-provided thresholds are expected to be exceeded, the WFOs issue Flash Flood Watches for debris flows 6 - 48 hours prior to an expected event.

Figure 8. Homes in the Monterey Park, CA area destroyed by a small debris flow during the winter of 1980. Note the short distance down slope this narrow debris flow traveled. (*Photo credit: http://geology.wr.usgs.gov/wgmt/elnino/scampen/examples.html*)

This system is currently in an experimental mode. Each season, a Demonstration Project Test Bed (also referred to as the Intensive Research Area) is established whereby a recent burn area is identified as having an enhanced threat of debris flows; this area is preferably located within an urban interface. This Test Bed is instrumented by the USGS with special monitoring equipment, including tipping bucket rain gauges and sediment traps. For the past three years, NOAA has provided temporary use of the NOAA National Severe Storms Laboratory's truck-mounted Shared Mobile Atmospheric Research and Teaching Radar (SMART-R) and two wind profilers provided by the NOAA Earth System Research Laboratory (funded by the NOAA Hydrology and Coastal Storms Programs). The SMART-R is positioned to provide intense remote sampling of rainfall over the Demonstration Project Test Bed. These SMART-R data are primarily used in post-event analysis, although these data are now available in real-time through web page access (see below).

The NOAA/USGS prototype warning system has entered its third year of operations and several new tools have been implemented to improve the debris flow (and flash flood) warning program at the two southern California WFOs:

- Hazard maps – USGS research has generated burn-area-specific hazard maps based on debris flow likelihoods and debris volumes. These maps, which are available for electronic access, allow the WFO forecasters to produce watches and warnings to highlight specific places of concern for debris flow activity.
- SMART-R – NSSL's SMART-R mobile radar has been deployed to the Los Angeles International Airport to monitor precipitation over the Canyon and Corral burn areas near Malibu. The Canyon burn area has also been instrumented by the USGS. For the first time in the project, the 2007-08 radar data was available in real-time via the Internet for the WFO and others.
- Interactive Applications – WFO Oxnard has developed an Intranet tool suite that gives forecasters burn area specific interactive information in an easy to understand format. It combines important information including the hazard maps, critical rainfall thresholds, and contact information for emergency managers in a single application.
- USGS field enhancements – The addition of a web camera by the USGS at the Santiago Creek gauging station is providing valuable information to the NWS and emergency managers to evaluate existing conditions in the creek channel during storms. The visual record of flooding and potential for debris flows also provides valuable research data for USGS. Monitoring and research data are being collected in partnership with the NWS, the Orange County Fire Authority, and the Orange County Environmental Resources Division. A web camera has also been installed in the Canyon burn area in Malibu. This instrumentation (rain gauges, surface runoff sensors, soil moisture sensors, and LIDAR surveys) placed in the Test Bed by USGS will also help the NWS to fine-tune its flash-flood models.
- Coordination - Post-event conference calls are conducted between the USGS and NOAA (WFOs. Western Region Headquarters, and NWS Headquarters) to discuss the event, and to identify event response successes and needed adjustments.

From this point (summer 2008) forward, the responsibility for expansion and operational implementation of the project lies entirely within USGS. The current plan is that, following the pilot project in Southern California, the system developed there will be utilized at other recently burned areas nationwide to issue Debris Flow warnings using the current technology (i.e., based on thresholds and *NWS Flash Flood Monitoring and Prediction* software).

The original deployment plan, as presented in the USGS Circular 1283, called for the nationwide implementation of this system, followed by the introduction by the USGS of more advanced models into operations. These models would have a physical (as opposed to empirical) basis. Furthermore, the plan stated that it would be the responsibility of the USGS to operate the models in a 24/7 mode. Clearly, such a system would require additional resources. Once there was nationwide implementation, the role of the NWS would be to provide observations and forecasts of precipitation, send them to the USGS so the Survey geologists could run the models, analyze the results, and determine whether the NWS should consider issuance of a watch or a warning. This guidance would then be passed to NWS which, in turn, would use its warning dissemination schemes to issue the watch or warning to emergency managers, the public, and the media. The experience from the last three years of experimental operation of the prototype system, the knowledge gained in the analysis of the information provided by the debris-flow testbeds, and the challenge facing the USGS to obtain the additional funding needed to implement the original approach, indicate that the original plan must be reformulated. The effort to develop a revised plan is under way.

Finding #15

The FWRWG found this to be an excellent illustration of interagency collaboration on a pressing multidisciplinary problem.

The FWRWG also found that the operational concept for moving forward to national implementation seems very cumbersome with data moving back and forth, especially in a flash-flood emergency. Is it appropriate for the NWS to issue a USGS warning?

Recommendations for Finding #15

NOAA should …

> **15.1 … Continue, in collaboration with USGS, to develop thresholds of rainfall rates and totals for public warnings of impending debris flows.**
>
> 15.2 … Continue to work with USGS on national implementation, but refine the concept of operations to minimize the handling of the data, the forecast, and the warning.

IV.G Other Considerations

IV.G.1 Wildland fire and Climate Change

Observations

While not specifically mentioned in the terms of reference and charge to the FWRWG, the role played by climate and changes in local and regional climates entered discussions several times. Consequently, the FWRWG decided to comment on the role of climate in its considerations of fire weather. However, what is presented here is a just a synopsis of a few points the FWRWG felt were especially relevant to the fire weather discussion. The topic of the occurrence and role of wildland fire in a world possibly undergoing global warming is a topic worthy of a study in its own right.

Dr. Susan Conard, National Program Leader for Fire Ecology, U.S. Forest Service, in a presentation to the FWRWG, suggested the following points (taken verbatim from her presentation) with regard to increasing fire hazard in a warming world:

- The extent and severity of drought, timing of spring snowmelt, and changes in ocean circulation patterns have all historically contributed to the extent and severity of wildfire on forests and rangelands.
- Many areas of the US have warmed significantly over the past 40 years, with the greatest changes occurring in northern latitudes and in the west; these changes are projected to continue.
- Much of the recent increase in fire in the western United States can be correlated with increasing temperatures, changes in precipitation patterns, and longer fire seasons since the mid 1980's. No single event, however, can be specifically linked to climate change.
- There is growing scientific evidence that climate change will increase the number and size of wildfires, both globally and in North America. The effects of climate change on wildfire occurrence, extent, and severity will vary in different regions of the country.
- Climate change and changing wildfire patterns will cause changes in the distribution of individual plant species and of forest and rangeland ecosystems.
- Even where rainfall remains the same or increases, warming temperatures can greatly increase plants' need for water, and increase drought stress and fire hazard.
- As fires burn more frequently, burn larger areas, or burn more severely, the carbon stored in ecosystems will decrease, and carbon gases and particulates in the atmosphere will increase.

- These increases will add to air pollution and have the potential to increase the intensity of greenhouse warming. The net impact of fires on global warming potential, however, is not fully understood.

- Forest management techniques such as prescribed burning or thinning dense forests, can make forests more resilient to wildfire and decrease fire emissions.

- While the Fall 2007 fires in Southern California cannot be specifically attributed to climate change, they are an example of the types of fire activity that we can expect to see more frequently in many areas of the western US, and are consistent with projections from climate change models.

Further, according to the report of the Intergovernmental Panel for Climate Change(IPCC, 2007), globally "disturbances from pests, diseases, and fires are projected to have increasing impacts on forests with an extended period of high fire risk and large increases in area burned."

Finding #16

Climate clearly is an important influence on the wildland fire hazard; for example, vegetated areas experiencing drought conditions often are at increased risk for wildfires (OFCM, 2007). Projections from climate models suggest that in the future, much of the western and northern United States may become progressively warmer and drier than they have been in the recent past. However, it is hard to interpret the impact of such predictions on wildfire occurrence. One might anticipate that burned areas and fire severity in these regions will increase in the future. However, this trend might be offset by increased desertification that reduces the fire prone area. Nature may use fire in such cases as a way of transitioning from one vegetation regime to another.

Research in recent years has documented links between past climate variability on seasonal and interannual time scales and changes in area burned by wildfires, particularly in the western United States. These signals appear strong enough that they could be used to develop seasonal fire danger outlooks.

Climatic impacts of the type described by Conard, coupled with demographic, population density, and economic trends leading to continued growth of the WUIs around major urban areas suggest that vulnerability to wildfire will continue to increase for the foreseeable future. There is a need to consider this increasing vulnerability as part of climatic impact assessments.

Recommendations for Finding #16

NOAA should …

16.1 … Use its climate modeling capabilities to better understand the role of fire in the climate system; anticipate and prepare for increased threat from fire in the future; and, at regional scale, assess propensity for increased fire hazard as the global temperature warms, and winds and relative humidity patterns change..

16.2 … Use fire detections from NOAA's operational environmental satellites to develop a large-scale fire climate data record.

IV.G.2 International Considerations

Observations

Wildland fires occur in almost all land areas where there is vegetation and consequently are a global issue (e.g., Cheney and Sullivan, 1997; Coleman and Sullivan, 1996; Fendell and Wolff, 2001; Lopes et al., 2002; Mallet, 2002). The fire experiences of Australia and Canada parallel those of the U.S. in many ways. Both of these nations have active fire research programs and it should be no surprise that their respective fire danger rating systems share common characteristics with that used in the U.S.

Research collaborations between Australia, Canada, and other countries and the federal wildland management agencies developed early and continue to the present. The network extends informally, through between-country agreements, to Europe, Australasia, Africa, China, Russia, and Central and South America. Fire research programs have recently accelerated in European countries with funding from the European Union. For example, representatives from 13 countries in the European Union recently initiated a new effort called Fire Paradox (www.fire.paradox.org). The Australian Bureau of Meteorology is leading an effort to secure funding from the World Weather Research Programme for a limited joint research project in fire weather forecasting with the US Forest Service, the Canadian Forest Service, and the National Center for Atmospheric Research.

With respect to fire weather operations, the WMO Commission for Agricultural Meteorology has set a priority on determining operational guidelines for fire weather agrometeorology by 2009. It co-sponsored an international workshop in July 2008 on operational fire weather/fire danger rating with the Canadian Forest Service, and the panel on Global Observation of Forest and Land Cover Dynamics.

Finding #17

Many nations around the world, including the U.S., need operational fire weather support to manage fires within their boundaries or within regional consortia through which they share fire management resources. Developed countries conduct fire research activities on a range of spatial scales, from laboratory-scale fuel arrays to field plots from which much can be learned by all, e.g., Australian work such as Coleman and Sullivan (1996) and Cheney and Sullivan (1997), and European work such as Lopes et al. (2002) and Morvan et al. (2008). Canada, Australia and Russia in particular have much to offer in regard to large field experiments on fire. No national weather organization has assumed pre-eminent leadership in fire weather research and operations.

Recommendations for Finding #17

NOAA should …

> 17.1 … Develop and formalize exchanges of operational and research personnel, to share knowledge about weather and climate aspects of wildland fire management and incorporate this knowledge into NOAA research and operations.
>
> 17.2 … Explore with other countries opportunities to collaborate on prescribed burns as experimental fires to test new tools, models, and techniques under real-world conditions.

IV.H Organizational Concerns

This section discusses how fire weather is addressed in NOAA to serve NOAA's own direct responsibilities to its primary user community, the federal wildland management agencies, and secondary users such as Department of Defense and the EPA. It also stresses the importance of collaboration with the university community to leverage the wide array of basic and applied research done there and with the on-going fire research programs in other government agencies to assist those agencies in meeting their responsibilities.

IV.H.1 Making Fire Weather a High Priority in NOAA

Observations

While collecting information for this report, the FWRWG consistently heard praise for both the services provided by WFOs and the IMETs deployed to command posts and regional centers. The IMETs have been accepted as part of on-site fire management teams and play critical roles in the containment and/or suppression of those fires to which they are deployed (usually the small fraction of wildfires that are very large and very dangerous).

Having seen what products NOAA can provide, fire managers consistently asked for more extensive, flexible, and easily accessed support for those products. Telecommunications availability and interoperability were common concerns. Fire managers also asked for more frequent and earlier deployment of IMETs, especially in light of the growing number of large fires.

The FWRWG was pleased to see several local, expediency-driven research and development efforts in NOAA WFOs, centers, and laboratories to develop new tools or improve existing ones for use in WFOs or by IMETs. However, operational units of the NWS, and laboratories with other missions, have not furnished adequate new tools to meet fire weather requirements. The OFCM (2007) report captures much of what needs to be done from customer/user perspective. The FWRWG was surprised to learn there is neither (1) a NOAA research facility specifically charged with the responsibility for developing or improving tools and techniques for fire weather services; nor (2) a corresponding dedicated NOAA operational test bed facility specifically charged with the responsibility for transferring such tools and techniques to operational practice.

The FWRWG also noted the minimal attention – two brief references -- given to fire weather support in NOAA strategic plans.

Finding #18

NOAA strategic plans do not identify fire weather as a core element, equal in importance to the agency's other responsibilities in severe and hazardous weather. However, wildfire is a major threat to the nation's populace, infrastructure, and economy, one that may grow with continued global warming. Perhaps this can be explained by the lack of clear authorizing language from the Congress or the Executive Branch, in conjunction with no specific line item in the agency's budget. Making Fire Weather a core element of NOAA's Strategic Plan is critical. This level of priority would ensure the Fire Weather Service Program competes fairly with other service programs in terms of funding and insertion into the PPBES process.

The FWRWG strongly endorses the efforts of WFO forecasters providing fire support services and especially those volunteers serving in the IMET program. The IMET program is a remarkable success story for NOAA. Overall, the number of personnel involved in the IMET program, ~100 individuals, appears to be reasonable in light of demands. However, the FWRWG has concerns that such a key element of the NOAA fire weather program relies on volunteers (whose availability for deployment is determined in large part by local management at WFOs and not national need) and that there is no budget line to provide dependable funding for this program. Further, the FWRWG notes the desirability of fire weather training for more WFO forecasters since in practice they provide the majority of routine fire weather support services. As discussed in detail in the following sections, the FWRWG finds that the major shortfall is not human resources in the field, rather it is the lack of availability of accurate, objective, rapidly-executed, misoscale forecast tools to assist the WFO forecasters and IMETs.

Further, even though NOAA has provided fire weather support in one fashion or another for many years, there is an *ad hoc* feel to current efforts. Many in NOAA seem to assume fire weather is just one more routine task to be handled, and are not aware of the severity or extent of the threat, or how tenuous the support situation can get at times, or the degree to which expertise in fire weather support is based on familiarity with a particular fire regime (i.e., the fire "profile" of a region). This is surprising in light of the national extent and level of threat, yet local idiosyncrasy, posed by wildfire.

It was noted previously that NOAA lacks a research-and-operations tandem, that is, a laboratory plus an operational center pairing, dedicated to wildland fire. As a consequence, while NOAA provides many broad-scale objective forecast guidance tools to support the WFO forecasters and IMETs, it provides none on the misoscale where the most difficult forecast challenges are to be found. Currently, forecasts made in support of fire containment or suppression operations depend on WFO meteorologists and IMETs subjectively adjusting local observations and downscaling model output. These subjective techniques require extensive training, experience, and efficient application of conceptual models for terrain adjustments. These conceptual models are limited in the physics they can incorporate, often being based on simple mass conservation, with limited or no consideration of thermodynamics. This line of argument leads to a requirement for a research and operations tandem focused on providing and exercising both fundamental-principles-based and semi-empirically-based tools to assist forecasters in adjusting local observations and downscaling mesoscale model output.

Further, NOAA also lacks a fire weather test bed. Such a simulated operational environment, perhaps modeled after the seasonal Hazardous Weather Test Bed, could bring together annually those with fire weather responsibilities such as the national Storm Prediction Center, IMETs, WFO forecasters with fire weather responsibilities, the interagency Predictive Services program members, fire behavior specialists, state and local counterparts, researchers from the federal government and the universities, and relevant individuals from the private sector. It would have the mission of demonstrating, proving out, and transferring to operational practice new technology and techniques relating to fire weather forecasting by forecasters and fire weather-related decision-making by the federal wildland management agencies. For serving the mission of model tuning/validation, the test bed should include laboratory-scale-physical-simulation, as well as numerical-simulation, facilities.

While the test bed could be co-located with the research-and-operations tandem, other configurations are possible and perhaps desirable. A recurrent theme in this report (and also in the comments received from a public review of an early draft) is the need for NOAA to engage in a full partnership with the fire community to improve fire weather research and operations. A fire weather test bed could be multi-agency to leverage the research carried on by other agencies. Establishing such a test bed dedicated to improving fire weather products and services, and involving representatives of the federal wildland management agencies, could go a long way toward addressing the request by the WGA for a new joint interagency effort to transfer new weather information into operational fire management decision making and planning.

The FWRWG does not want to make specific suggestions as to location for the recommended research-and-operations tandem or the fire weather test bed. The FWRWG does note, however, that within NOAA, opportunities for the research-and-operations tandem exist with the National Severe Storms Laboratory/ Storm Prediction Center/Weather Forecast Office in Norman, Oklahoma and the Earth System Research Laboratory/Weather Forecast Office in Boulder, Colorado. If the fire weather test bed were made a joint agency endeavor, then the National

Interagency Fire Center/Weather Forecast Office in Boise, Idaho and the USDA/FS Forest Fire Laboratory in Riverside/the Weather Forecast Office in Oxnard are candidate locations.

Recommendations for Finding #18

NOAA should …

> **18.1 … Increase its focus on fire weather support in the next update of its Strategic Plan, making fire weather a higher priority, and seeking additional authorization and funding as needed.**
>
> **18.2 … Designate a research laboratory (one with an operational counterpart within the NWS, along the lines of the NSSL/SPC and AOML-HRD/NHC tandems) to lead its fire weather-related research and development efforts and provide it with appropriate budget and authority.**
>
> **18.3 … Work with the federal fire agencies and other members of the National Wildfire Coordinating Group to establish a fire weather test bed, select a location for it and determine a strategy to leverage funding to build and staff it.**
>
> 18.4 … Institutionalize the local "fire season", giving it the same priority and emphasis as "severe convective weather season (thunderstorms and tornadoes)", "hurricane season", and "winter weather season".
>
> 18.5 … Provide enhanced support for fire weather forecasting in WFOs and IMET operations, including funding for training, necessary equipment maintenance and replacement, and current and future communications (including FX/Net)..

IV.H.2 Collaboration with Other Agencies in Fire Weather R&D

Observations

The nation's wildland fire management community is a complex, interlocking multi-jurisdictional web of agencies extending from federal cabinet-level agencies to local fire departments. At the federal level, the community is lead by the U.S. Department of Agriculture (USDA) (through the USFS) and the Department of the Interior (DOI) (primarily through the Bureau of Land Management (BLM), but also with several other agencies); these agencies routinely deal with wildland fire and, to varying extents, maintain weather observing networks (e.g., Remote Automatic Weather Stations operated by the wildland management agencies) to support operations, and conduct fire and fire weather research. The Department of Commerce (through its National Institutes of Standards (NIST) Building and Fire Research Laboratory (BFRL)), the Department of Energy (DOE), and the National Aeronautics and Space

Administration (NASA) also conduct some wildland fire-related research efforts. These range from funded programs to *ad hoc*, sometimes opportunistic, sensor demonstrations.

The federal wildland management agencies share firefighting responsibilities with state, county, and local organizations whose interrelationships, often of long standing, vary by region. It is realistic to say that "all fire fighting is local", reflecting the wide variations in fire type and method of response across the U.S. While NOAA is recognized as an important player in wildland fire by the federal wildland management agencies, it is viewed traditionally as having a supporting, not a central role in wildland fire management, because NOAA as an environmental-monitoring-and-prediction agency, does no firefighting. However, with the dawning of an era in which wildland-fire use is an option, NOAA may have a leading, central role in federal land-management decision-making.

As described above, smoke and subsequent air pollution can be major impacts in the region. NOAA, through its Air Quality Matrix Program, shares responsibility with the Environmental Protection Agency for advising the public on such air quality issues. In many cases, state and local environmental and public health agencies may be involved.

Given the time available, the FWRWG did not carry out an exhaustive search to determine the extent to which fire weather research is being conducted across the country. This report probably describes the major current research efforts addressing fire weather and related topics. However, if the JFSP is any indication, there are likely numerous small wildfire research projects of potential interest to NOAA. Certainly there are significant research and development efforts underway in the nation's university community, which includes NCAR. While space does not permit a detailed discussion of all these efforts, the ones which came to the attention of the FWRWG are indicated in Appendix G.

Finding #19

In providing fire weather support and developing and executing a fire weather research agenda, NOAA must interact with a large number of entities. Given the modest resources NOAA has available in this area, it is challenged to be open, adaptable, and flexible in its approach to the several federal wildland management agencies and the university community. It must define its unique roles in fire weather research, avoiding overlap and direct competition with other agencies, and leveraging to the maximum extent possible the work done by others.

The FWRWG finds that as the nation's provider of environmental information, NOAA has unique roles to play in providing information to those charged with wildfire countermeasures, ensuring safe conduct of prescribed burns (including air quality and visibility concerns), and pre- and post-fire activities (e.g., "red flag" warnings and debris flows warnings, respectively). It can and should conduct the applied research and technology development necessary to support those roles.

Given this, NOAA needs to decide how much of fire and smoke physics and prediction is within its purview and how much should be left to others. As one senior NOAA administrator stated, in reviewing an early draft of this report, *"Fires significantly affecting meteorology are at the ragged edge of NOAA's regime."* However, this is a difficult area in which to draw a boundary as it remains to be determined under what conditions a coupled fire/atmosphere model is necessary for operational fire weather predictions. From an operational point of view, resolving the extent to which the fire/weather coupling requires development of advanced fire weather models cannot be accomplished based on field experience alone. A much better understanding of what prognostic utility can be provided by members of a spectrum of numerical prediction tools, from the more simplistic to the more comprehensive, is needed before it can be decided what models ought to be operationalized. As indicated by this report, the FWRWG finds that, from a research point of view, NOAA *should* be involved in fire weather and fire behavior research and work toward the development of a coupled fire/atmosphere prediction system, with a goal of increasing understanding as well as developing new tools and techniques.

Full implementation and utilization of new or improved NOAA products and services entails close, continuous coordination and collaboration with the well-established wildland fire management communities, as well as other federal agencies such as the Department of Defense, Department of Homeland Security, NIST, EPA, and USGS. Several of the federal wildland management agencies have in place programs that parallel programs underway or being considered in NOAA. These programs include numerical modeling, surface-based observing platforms, telecommunications, and aerial observations. Numerous opportunities for partnership and leveraging exist. A good example is in the exploration of unmanned aerial systems (UAS) to improve several aspects of fire scene monitoring and firefighting operations. These include observations of the fire front, hot spots, telecommunications relay, and monitoring of atmospheric conditions. At present, several efforts, all targeting the fire area, are being pursued more or less independently by NOAA, various federal land management agencies, and the Department of Defense.

NOAA needs a comprehensive understanding of the fire weather research currently underway nationwide. This will identify additional areas for partnerships and leveraging.

<u>Recommendations for Finding #19</u>

NOAA should...

> 19.1 … Identify clearly its unique niches in operations and research in the fire weather area. Where necessary, it should seek the appropriate legislative authority from the Congress.
>
> 19.2 … Commission a survey of fire-weather-related research underway nationwide to identify potential leveraging opportunities.

19.3 … Establish formal, but flexible, partnerships with research organizations in the federal wildland management agencies and the university community in its efforts to develop new products and services, especially in the numerical modeling area and in the development of new aerial observing systems.

V. SUMMARY OF RECOMMENDATIONS

The Fire Weather Research Working Group (FWRWG) has developed 46 recommendations in responding to the Terms of Reference and Charge provided by the NOAA Science Advisory Board. For convenience, a list of all 46 recommendations is provided here, retaining the finding number to which they apply. The eleven highest priority recommendations are shown in bold text:

1.1… Conduct detailed case studies of the behavior of selected wildland fires as a function of the observed three-dimensional weather conditions with the goals of understanding fire-atmosphere interaction and validating numerical models.

1.2 ….Explore with the federal wildland management agencies through their Joint Fire Science Program and the National Science Foundation the establishment of a jointly-funded program of wildland fire-related weather research in federal agencies, universities and industry, to include laboratory and numerical modeling, instrumentation development, and comprehensive case studies.

1.3 … Use satellite-derived estimates of fire radiative energy output to specify surface boundary conditions for the characterization of vertical atmospheric structure and transport over the fire.

1.4 … Partner with land management agencies for a series of large-scale controlled burns, conducted under well-characterized conditions and adequately instrumented to examine the response of such fires to three-dimensional atmospheric conditions. Joint development of a set of well-defined physical parameters for quantifying fire behavior under various three-dimensional atmospheric conditions is a necessary pre-condition to assessing the weather impact.

2.1 … Assimilate output from all available local observation sources, including data from surface-data networks, ground-based radars and profilers, UASs, and satellite sensors, when generating gridded nowcasting and forecasting products, and fire-danger maps.

2.2 … Explore the use of remote sensing methods, including ground-based radar, HALE UAS, and satellite (including high frequency fire detections and characterization from GOES), for sustained, continuous monitoring and forecasting of the tropospheric misoscale weather, surface conditions, and fire growth during ongoing wildland fires.

3.1 … Increase research and development of integrated fire weather modeling systems, for normal-to-exceptional fire weather conditions (extreme fire weather conditions may require special consideration), leveraging research expertise and capabilities where possible from other federal agencies, universities, and the private sector. The long range goals for this larger research community include accurate simulation of fire in complex terrain and, ultimately, the wildland-urban interface; NOAA's weather prediction capabilities are central to attaining these goals.

4.1 … Partner with the federal wildland management agencies to establish a central data repository (i.e., an archive), with entries in a standard format, to facilitate post-fire analyses and assist in verification and validation studies.

4.2 … Explore and validate tools for generating, from coarser forecast grids, detailed weather grids incorporating terrain.

4.3 … Maintain gridded forecasts (and observed/analyzed weather) in a database to assist future fire model development and testing.

5.1 …**Use data assimilation systems described in Recommendation 2.1 to generate high resolution fire danger maps.**

5.2 … Use the existing NFDRS processor at the Scripps Experimental Climate Prediction Center or the Rocky Mountain Center to compute fire danger maps with sufficient frequency to depict diurnal variations that may affect fire potential.

6.1 … Use NCEP forecasts with the NFDRS, CFFDRS, and other such systems that require weather data provided by the NWS to generate short-to long-term fire weather and fire danger forecasts maps to meet the different spatial scale needs of federal, state and local fire managers.

6.2 … Make these products available through a web-based GIS platform for users to customize fire weather and fire danger maps to suit their spatial and temporal scales of interest.

6.3… Develop training plans and packages with the National Wildfire Coordinating Group to familiarize users with the forecast technology.

7.1 … Utilize ensemble forecasts to develop seasonal to interannual fire weather and fire danger maps.

7.2 … Provide a source of weather/climate forecasts for annual fire potential forecasts, particularly for ERC-G.

7.3 … Encourage further research and development of seasonal climate-related fire forecasts to meet strategic fire planning needs.

8.1 … Develop a standardized "intelligent assistant" or decision-support tool for the WFO forecaster replying to requests for spot forecasts from first respondents and for deployed IMETs providing weather support to Incident Commanders.

8.2 … Develop numerical prediction methods that provide a frequently updated sequence of misoscale and mesoscale forecasts to provide forecasters with the capability to anticipate extreme fire behavior with several hours notice.

9.1 … Establish a national LDS managed with full resources, coordinated under one agency with a more robust telemetry. Data collection should be centralized for the continental U.S. as well as Alaska and Hawaii.

9.2 … Develop and validate better forecasts of lightning activity that have improved representation of ignition potential. Consider partnering with the interagency Predictive Services program fire potential product with regard to new ignitions. Develop a new lightning probability product, weighted toward forecasting dry thunderstorm lightning.

10. 1 … Continue to leverage research capabilities to help improve representation of smoke plumes from wildland fires in operational forecasting tools through its ongoing collaborations with NOAA, EPA, and USFS researchers.

10.2 … Encourage WFO forecasters and incident meteorologists to take an appropriate smoke management course to gain familiarity with the fuel consumption and smoke emissions tools used by land managers.

10.3 … Work with NIFC, EPA, FCAMMS, and state and local environmental and public health agencies to ensure that complete smoke and pollution information, including current speciated emissions data as well as predicted plume evolution, is gathered, processed, summarized, and made available to the public in a timely and easily accessible manner, preferably from a single information source, e.g., a smoke web site or a smoke information portal.

11.1… Disseminate IMET spot forecasts from the field via NOAA web and data-serving capabilities and consider providing automated email distribution/SMS notification of SPOT availability as is done with NHC products.

11.2… Provide fire weather forecast verification and validation information and include performance standards for each forecast element; include spatial verification information and spot and IMET forecast validation information in final (archival) documentation for all major incidents.

12.1 … Explore emerging communication formats and low-bandwidth technologies with the goal of allowing fire managers to access site data and to initiate and receive both spot weather forecasts and extended nowcasts; emphasis should be placed on maximizing the capabilities of currently-available low-bandwidth wireless devices such as Blackberries, iPhones, PDAs, and cellular modem-equipped laptops.

13.1 … Develop and deploy improved data/information visualization tools for use by the interagency Predictive Services program, WFO forecasters, and deployed IMETs for decision making, forecasting, and briefings.

13.2 … Make fire weather products available through a web-based GIS platform for users to produce their own customized fire weather and fire danger maps to suit their spatial and temporal scales of interest.

13.3 … Ensure its data and forecast products are compatible with protocols such as the Wildland Fire Decision Support System (WFDSS).

14.1 … Ensure availability of live weather data via the current FX-Net and subsequently the AWIPS II thin client to facilitate IMET support at fires.

15.1 … Continue, in collaboration with USGS, to develop thresholds of rainfall rates and totals for public warnings of impending debris flows.

15.2 … Continue to work with USGS on national implementation, but refine the concept of operations to minimize the handling of the data, the forecast, and the warning.

16.1 … Use its climate modeling capabilities to better understand the role of fire in the climate system; anticipate and prepare for increased threat from fire in the future; and, at regional scale, assess propensity for increased fire hazard as the global temperature warms, and winds and relative humidity patterns change..

16.2 … Use fire detections from NOAA’s operational environmental satellites to develop a large-scale fire climate data record.

17.1 … Develop and formalize exchanges of operational and research personnel, to share knowledge about weather and climate aspects of wildland fire management and incorporate this knowledge into NOAA research and operations.

17.2 … Explore with other countries opportunities to collaborate on prescribed burns as experimental fires to test new tools, models, and techniques under real-world conditions.

18.1 … Increase its focus on fire weather support in the next update of its Strategic Plan, making fire weather a higher priority, and seeking additional authorization and funding as needed.

18.2 … Designate a research laboratory (one with an operational counterpart within the NWS, along the lines of the NSSL/SPC and AOML-HRD/NHC tandems) to lead its fire weather-related research and development efforts and provide it with appropriate budget and authority.

18.3 … Work with the federal fire agencies and other members of the National Wildfire Coordinating Group to determine a location for the fire weather test bed and a strategy to leverage funding to build and staff it.

18.4 … Institutionalize the local "fire season", giving it the same priority and emphasis as "severe convective weather season (thunderstorms and tornadoes)", "hurricane season", and "winter weather season".

18.5 … Provide enhanced support for fire weather forecasting in WFOs and IMET operations, including funding for training, necessary equipment maintenance and replacement, and current and future communications (including FX-Net)

19.1 … Identify clearly its unique niches in operations and research in the fire weather area. Where necessary, it should seek the appropriate legislative authority from the Congress.

19.2 … Commission a survey of fire-weather-related research underway nationwide to identify potential leveraging opportunities.

19.3 … Establish formal, but flexible, partnerships with research organizations in the federal wildland management agencies and the university community in its efforts to develop new products and services, especially in the numerical modeling area and in the development of new aerial observing systems.

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APPENDICES

Appendix A: FWRWG Group Membership

Chair:

- Dr. John Snow - Dean, College of Atmospheric and Geographic Sciences, University of Oklahoma

Members:

- Dr. Leo Andreoli - Director, Environmental Systems, Northrop Grumman
- Mr. John Barborinas – Wildland Fire Management Planner, National Interagency Fire Center, DOI Bureau of Indian Affairs
- Dr. Ivan Csiszar - Associate Research Scientist, University of Maryland-now with the NOAA/NESDIS Center for Satellite Applications and Research
- Dr. Philip Cunningham - Associate Professor, Florida State University
- Mr. Pete Curran - Fire Captain, Orange County. (CA) Fire Authority
- Dr. Francis Fujioka - Research Meteorologist, USDA Forest Service, Riverside, CA
- Dr. Scott Goodrick - Research Meteorologist, USDA Forest Service, Athens, GA
- Dr. Rodman Linn - Deputy Group Leader, Los Alamos National Laboratory
- Dr. William (Ruddy) Mell - Program Leader, Wildland-Urban Interface, NIST
- Dr. Patrick Pagni - Professor Emeritus, University of California, Berkeley
- Mr. Merrill Saleen - National Incident Management Specialist, National Interagency Fire Center, Bureau of Land Management.

Appendix B: FWRWG Terms of Reference and Charge

NOAA Science Advisory Board

Fire Weather Research Review Working Group

Terms of Reference

March 2007

Background

The National Oceanic and Atmospheric Administration (NOAA) provides critical weather support to federal and state land management agencies responsible for mitigating and suppressing wildfires. Support is provided via fire weather outlooks, forecasts, advisories, watches and warnings and on-site services.

There now exists an imperative to enhance and expand this level of support due to:

Increased volume of biomass in the Wildland forests, resulting in hotter, more costly fires, (2) Increased level of community development at the boundary of wildland forests, and (3) Expanded use of NOAA's products and services beyond fire needs in the post-9/11 world.

These factors, combined with rapidly evolving science and technology, imply an increased need to ensure applied research efforts are quickly and effectively transitioned into NOAA operations. This need was underscored by The Western Governors' Association in their June 2005 Policy Resolution as "An integrated fire weather and fire environment research program is critical for the effective management and health of U.S. forests and rangelands". The term "integrated" is mentioned due to the many disparate research efforts which are ongoing within NOAA, the U.S Department of Agriculture, (U.S. Forest Service); local Weather Forecast Offices (WFO); and joint bodies made up of representatives from each of these entities.

NOAA provides a number of specific products and services related to fire weather. The WFOs provide regularly-issued fire weather forecasts, fire weather watches, warnings, and spot forecasts as needed, and Incident Meteorologist (IMET) services directly to fire scenes. NOAA provides specialized training to its volunteer IMETs to enable them to fulfill this role. In addition, NOAA's Storm Prediction Center provides fire weather outlooks for up to eight days in advance, as well as experimental lightning and ensemble products for specific fire weather variables. Finally, NOAA's Environmental Prediction Center provides high-resolution numerical weather prediction products for use by WFOs and IMETs in delivering their fire weather products and services.

NOAA's applied research in areas related to fire weather has resulted in new operational products in such areas as monitoring and prediction of air quality, smoke, and lightning. Interest in these products increasingly exists beyond the fire community; including among public health officials and emergency managers. NOAA also participates in research efforts with the land management community, some of which explicitly include fire weather as a focus.

NOAA Science Advisory Board Charge

NOAA has requested the NOAA Science Advisory Board establish an *ad hoc* working group to (1) ensure NOAA's fire weather research priorities match those of its land management partners and other interested parties outside the fire community who are increasingly using NOAA's products and services, and (2) explore opportunities to leverage current NOAA-internal and external collaborative fire weather research efforts to ensure improvements to NOAA's fire weather products and services are implemented in a timely manner.

Representation on this working group should include fire weather researchers from the federal and academic communities, management representatives from federal, state, and local land management agencies, and fire/emergency management personnel from the federal, state, and local levels. The working group members should have the following qualifications:

National recognition in the topical areas served by NOAA's fire weather products, including (but not restricted to) land, smoke, and/or air quality management;

Knowledge of and experience with the science that supports NOAA's fire weather and related programs;

Knowledge of and experience with the organization and management of complex mission-oriented research and development programs; and

No perceived or actual vested interest or conflict of interest that might undermine the credibility of the review.

Fire Weather Research Review Working Group (FWRWG) Charge

The FWRWG should carry out an independent review of current fire weather research being conducted by NOAA and other federal agencies, and in universities and elsewhere, and examine how the results of that research are being further developed and transitioned to operations by NOAA. The FWRWG should examine fire weather-related research efforts conducted by groups external to NOAA and identify areas of commonality where research activities might be leveraged for mutual benefit. The FWRWG should develop findings and recommendations to ensure these research results lead to improved operational fire weather information and forecasts. In addition, the FWRWG should examine related research within NOAA not necessarily specific to fire but which could result in improved fire weather services or other NOAA emergency support operations. Such areas may include (but are not restricted to) Homeland Security and remote sensing.

Specific questions to be addressed:

Science and Science Planning

Are NOAA's fire weather-related research, development, and transition programs appropriately focused on the most critical operational needs among fire weather forecasters, public health officials, and emergency managers?

Where should NOAA increase collaboration with external research entities (e.g., JSFP, FCAMMS, USFS Fire Research Labs, academia, other) to maximize leverage potential?

Transition of Research to Operations

How should NOAA ensure it provides maximum benefit to its federal, state and local partners based on the fire weather and fire weather-related research and development that it and other entities conduct?

In which research areas would improved products/services result in the most significant operational improvements related to protecting life and property?

What operational needs are not being addressed by NOAA's research, development, and transition activities?

Resource Planning

Are current and planned NOAA resources (financial, institutional, & intellectual) adequate to make significant advances in improving fire weather forecasts?

Are current and planned resources allocated to fire weather consistent with NOAA's plans, goals, and objectives as articulated in the NOAA Strategic Plan, NOAA 5-Year Research Plan, NOAA Goal and Program Plans, and science and technology infusion plans?

Term

The FWRWG will carry out this review in approximately twelve months once convened. It will prepare a preliminary report of its analysis and findings within six months of its first meeting, and a final report, including recommendations, will be completed within twelve months. The working group will be dissolved after completing any follow-on requests regarding the final report by the SAB.

Appendix C Meeting Agendas

First Meeting of the NOAA Fire Weather Research Working Group (FWRWG)

October 1-2, 2007

1325 East-West Highway, Silver Spring, Maryland

(Silver Spring Metro Center Building #2), Room 2358

Day 1

Session 1: Setting the Stage:

8:15 Welcome to the FWRWG

Mr. Scott Rayder, NOAA Chief of Staff

8:30 FWRWG Introductions, Discussion of Charge, and Desired Outcomes

Dr. John Snow, Chair; Dr. Cynthia Decker, NOAA Office of Atmospheric Research

Session 2: Fire Weather Products, Service and User Needs:

9:15 NOAA's Fire Weather Operations, Products, and Services – An Overview

- Current products and services
- Observed service gaps
- Current research activities and groups, and opportunities for discussion

Mr. Eli Jacks, Chief, NOAA/NWS Fire and Public Weather Services Branch

9:45 Break

10:15 An Overview of NOAA's Fire Weather Operations – Incident Meteorologist (IMET) Perspective

- The IMET role at fire (and non-fire) incidents
- Interactions with land management partners
- Perspective on the various observing platforms used at Incidents

Mr. Heath Hockenberry, Fire Weather Program Leader, NOAA/NWS

10:45 An Overview of NOAA's Fire Weather Operations – Partner Perspective

- Ground truth: The nuts and bolts of Incident Command
- How NOAA's products and services are used
- Strengths and weaknesses – where can we improve?

Mr. Merrill Saleen, Incident Commander

11:15 OFCM Wildland Fire Needs Assessment Process

- Origin, process and current status, identified functional areas of need
- Potential implications for the FWRWG and NOAA based on Assessment results
- Feedback from WGA interaction

Mr. Mike Babcock, NOAA Office of the Federal Coordinator for Meteorology

11:45 Lunch

Session 3: The Operationally-Based Research Perspective

1:00 Current and Planned Fire Weather Research at NOAA's Earth Sciences Research Laboratory

Ms. Sher Schranz, NOAA GSD

1:45 Very Fine Scale fire modeling for the WUI and Potential Synergies with NOAA

Dr. Ruddy Mell, NIST

2:15 Operational Weather Support for Urban Interface Wildfires

Mr. Mark Jackson, Meteorologist-In-Charge, NWS Forecast Office, Oxnard

2:45 Break

3:15 Experimental Probabilistic Forecasts of Lightning and Dry Thunderstorms

Dr. Phillip Bothwell, NOAA SPC

3:45 Climate Concerns: Potential Impacts on Research Priorities

Dr. Susan Conard – USFS

4:15 Public Comment Period

4:45 Wrap-up of day, working group comments—Working group and staff only

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Day 2

8:00 NWS Welcome

Ms. Vickie Nadolski, Acting Deputy Director, NOAA/NWS

8:15 Fire Weather Research from the USFS/FCAMMS Perspective

- Current Fire Weather Related Activities within the Forest Service Labs
- Collaborations with NOAA, FCAMMS, Joint Fire Science Program

Dr. Brian Potter, USFS Seattle Fire Science Laboratory

Session 4: Integrating the Input

8:45 Impressions of Highest Priority Needs for NOAA based on Day 1 Presentations

Open Discussion – Dr. Snow leads

10:00 Break

10:15 Continuation of Priority Discussion and Formulation of Action Items

11:45 Lunch

Session 5: Setting the Course

1:00 Action item review and plans for next meeting

1:30 Working Group session: Working Group and NOAA Steering Group staff only

3:00 Meeting Adjourns

Second Meeting of the NOAA Fire Weather Research Working Group (FWRWG)

January 9-11, 2008

Oxnard and Redondo Beach, California

Day 1

12:30 Transport to the Oxnard Weather Forecast Office

2:00 Tour of the National Weather Service Forecast Office.

Hosted by Mr. Mark Jackson, Meteorologist-In-Charge

Demonstration of IMET equipment by Oxnard IMET, *Rich Thompson*

Discussion on WFO use of digital grids for GIS applications, *Jayme Laber*

Day 2

Meeting held at Northrop Grumman Space Park Facility

8:00 Welcome and Logistics, *Dr. Leo Andreoli, Northrop-Grumman and FWRWG member*

8:15 Opening Remarks and Plan for Meeting, *Dr. John Snow, FWRWG Chair*

8:45 Predictive Services – Forecasting Large Fire Potential, *Mr. Tom Rolinski, Riverside Geographic Area Coordination Center, NIFC*

9:30 An Overview of the Fire Behavior Analyst Position and Its Challenges in the Urban Interface, *Mr. Drew Smith, Fire Behavior Analyst, Los Angeles County Fire Department*

10:15 Break

10:30 Use of NWS' National Digital Forecast Database and GIS in Urban Incident Planning, *Mr. Tom Gikas, LA City Fire Department's Tactical Planning Special Projects Section*

11:15 Orange County's Use of Weather-Related Information on the Santiago Fire, *Mr. Pete Curran, Orange County, CA Fire Authority and FWRWG member*

12:00 Lunch

12:30 Drive to Building 67, Northrop Grumman campus

12:45 Fire Tunnel Research Apparatus Demonstration and Environmental Sensing Control Center Briefing and Demonstration, *Brian Balduf and Dr. Leo Andreoli*

2:30 Review of Outline for Report, Group Discussion, *Dr. John Snow leads*

5:00 Adjourn for Day

Day 3

7:30 Writing Assignments for FWRWG—Group Discussion

9:30 Writing Assignments (cont.), Action Item Review

11:30 Lunch

12:00 Adjourn

Third Meeting of the NOAA Fire Weather Research Working Group (FWRWG)

April 15-16, 2008

National Interagency Fire Center, Boise, ID

Day 1

8:00 Logistics—Merrill Saleen, *FWRWG member*

Welcome-*Lyle Carlile, BIA Fire Director and Chair of the National Multi-Agency Coordination Group*

Opening Remarks and Plan for Meeting, *Dr. John Snow, FWRWG Chair*

8:30 National Interagency Coordination Center (NICC) Briefing and Tour, *Kim Christensen, NICC Center Manager*

9:15 Predictive Services- National Program Collaboration and Season Update, *Mr. Rick Ochoa, Fire Weather Program Manager*

9:45 Break

10:00 Joint Fire Science Program Collaboration and Coordination, *Mr. John Cissel, Program Manager*

10:45 Remote Automated Weather System (RAWS) Program Update, *Mr. Steve Brown, Field Operations Manager*

11:30 National Interagency Collaboration for Incident Communications Technology, *Mr. Robert Rogh, FSWO Engineering, Technical Applications and Support*

12:15 Lunch

1:30 Wildland Fire Decision Support System, *Mr. Tom Zimmerman, Technology Transfer Specialist*

2:15 Review of Draft Report Topics, *Dr. John Snow, FWRWG Chair*

5:00 Adjourn for Day

Day 2

8:00 Continue Review and Writing Assignments (continued)—*FWRWG members*

11:00 Tour of NIFC, Firefighter Memorial and Smokejumper Program

12:00 Lunch

1:30 Writing Assignments (cont.), Action Item Review

5:00 Adjourn

Fourth Meeting of the NOAA Fire Weather Research Working Group (FWRWG)

June 19-20, 2008

National Weather Center, Norman, OK

Day 1

8:30 Introductions and Review Plans for the Meeting and for the Day, *Dr. John Snow, Chair, FWRWG*

9:00 Tour of the National Weather Center

9:30 Tour of the NOAA Weather Forecast Office and Storm Prediction Center and Discussion

10:15 Break

10:30 Fire Weather Forecasting at the Storm Prediction Center-*Phil Bothwell, Storm Prediction Center*

11:00 Fire Weather Modeling, *J.D. Carlson, Oklahoma State University*

11:30 Decision Making using Fire Weather Products, *Mark Shafer, Oklahoma Climate Survey*

12:00 Lunch

Executive Session—Working Group and Staff Only (1-5 pm)

1:00 Review Current Draft Report, Focusing on Recommendations. Break into writing teams as necessary

2:30 Break

5:00 Adjourn for Day

Day 2

8:30 Continue Work on Draft Report

12:00 Lunch

1:00 Resume Work on Report

2:30 Review of Next Steps, *Dr. John Snow, FWRWG Chair*

3:00 Adjourn

Appendix D: Western Governors' Association Call for Action

Policy Resolution 05-04

June 14, 2005
Breckenridge, Colorado

National Wildland Fire Weather Program

A. BACKGROUND

1. As a consequence of decades of fuel accumulation in our nation's forests and rangelands coupled with persistent drought, state and federal fire managers are faced with larger, more explosive, and more costly wildfires than in any period in history.

2. Catastrophic wildfire is a growing national issue, demonstrated by the Florida wildfires in 1998 and 1999 and wildfires in Western states over the past five years. Between 2000 and 2004, Western states experienced severe fire seasons that set new benchmarks in terms of damages, losses, and cost.

3. Large, damaging wildfires are costly to suppress, and they can also cause severe economic impacts to communities and state economies. Based on the experience over the last decade, 98% of wildfires are successfully extinguished during initial attack, however, 80% of wildfire costs are incurred when managing the 2% of wildfires which grow into large fires. Over the 5-year period from 2000-2004, federal wildfire suppression costs averaged $1.16 billion per year and are rising. With the addition of state and local fire suppression efforts, these costs likely approach $2 billion in severe years. Public health impacts are also increasing as the population increases in the wildland urban interface areas and smoke dispersion from wildfires and prescribed fires impact vulnerable citizens with respiratory ailments.

4. In order to reduce the risk of loss, the fire management agencies in the United States have begun moving aggressively to deal with the tremendous accumulation of biomass which contributes to unwanted wildfire behavior. Much of this work is accomplished through prescribed fire projects and increasingly the management of natural ignitions.

5. In order to effectively and cost-efficiently manage and suppress wildfires, including through the use of prescribed fire, it is critical that fire managers have timely, accurate and detailed information regarding current and predicted fire weather and associated climate services. The National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS), through its fire weather program, is the national agency in the Department of Commerce (DOC) which provides this critical information. The federal wildland fire agencies' Predictive Services integrate weather, climate and fuels information into fire environment products for the allocation and prioritization of fire management resources. The fire environment refers to those elements comprising fire meteorology, fire climatology, fire danger, fire behavior and fuel conditions as derived from weather and climate.

6. NOAA's NWS does not have a clear, legislative mandate or identified funding line items to operate its fire weather program. As a consequence, their capability to support sound fire management decisions may not be able to keep pace with the increasing demands.

7. The current NWS policy on issuing site-specific spot forecasts is to only issue spot forecasts for prescribed burns for federal lands and federal assets, and for requests from public safety officials. Unless a state or local government can represent that there is a public safety concern or that federal assets are at risk, state and local governments must pay the private sector for spot forecasts.

8. Coordination currently exists on the operational side of wildland fire programs, including:

• *The Wildland Fire Leadership Council (WFLC)* was established in April 2002 by a Memorandum of Understanding between the Secretaries of Agriculture and the Interior. The purpose of the council is to support the implementation and coordination of the National Fire Plan and the Federal Wildland Fire Management Policy.

• *The National Wildfire Coordinating Group (NWCG)* – the purpose of NWCG is to coordinate programs of the participating wildfire management agencies so as to avoid wasteful duplication and to provide a means of constructively working together. The NWCG's Fire Environment Working Team (FENWT) was recently created to provide strategic guidance to Fire Danger, Fire Weather, and Fire Behavior issues and includes NOAA's NWS.

• *The National Interagency Fire Center (NIFC)* in Boise, Idaho is the nation's support center for wildland fire management. Seven federal and state agencies work together at NIFC to coordinate and support wildland fire and disaster operations.

9. To increase the fire community's ability to plan and mitigate our Nation's fire and fuel problem, federal research entities were established to study fire and its effects. These research stations operate mainly within the USFS and have broad missions and goals. Valuable research is also being done at Universities, the University Corporation for Atmospheric Research (UCAR), NOAA, NASA, United States Geological Survey (USGS), the Environmental Protection Agency (EPA) and the private sector.

10. Despite current research programs on fire weather and fire environment, additional research and better coordination of existing research is needed to improve decision support for decision-makers charged with protecting the public and our natural resources. At the present, there is inefficient communication and collaboration on problem-solving between science and fire weather operations.

11. The fire weather observation network, called Remote Automated Weather System (RAWS), is not integrated into a comprehensive observing strategy, for example as part of the Integrated Surface Observing System (ISOS) and Global Earth Observing System of Systems (GEOSS).

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12. Fire Weather information is critical for effective wildland fire managers and for the safety of firefighters. However, methods for using fire weather information are subjective and have changed little in decades. The advent of *digital weather databases, fire potential forecasts,* and the improvements of *high resolution multidisciplinary computer models* puts this nation on the cusp of a quantum leap in decision-making tools to support fire operations.

13. The Western Governors' Association (WGA) has related programs and resolutions that complement a fire weather program. Goal One of the 10-Year Comprehensive Strategy (*A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment*) calls for improved prevention and suppression strategies, and Goal Two speaks to reducing fuels in the wildland urban interface. The WGA resolution regarding drought (02-02) recognizes the relationship between drought and wildfire, stating that "extremely dry conditions have led to numerous forest and rangeland fires, burning tens of thousands of acres of land, destroying homes and communities, and eliminating critical habitats for wildlife and grazing lands for livestock." Finally, the Governors created the Western Regional Air Partnership (WRAP) for the purpose of developing data, tools, and policies needed by states and tribes to improve visibility in parks and wilderness areas across the West.

B. <u>GOVERNORS' POLICY STATEMENT</u>

1. Operational fire managers need improved products and services from NOAA's National Weather Service (NWS) which can be seamlessly infused into fire operations decision-making. To ensure the program has proper attention and funding, the Governors urge Congress to legislatively add fire weather including support for wildfire and prescribed fire management to federal, state, and local government agencies as a core mission of NWS and carry it as a funded line item in their appropriations.

2. The Western Governors urge NOAA to:

• Incorporate a robust national wildfire and prescribed fire weather program into its strategic plan, and its 5 and 20 year research plans, and funding requests.

• Complete a National Needs Assessment Report, by NOAA's Office of the Federal Coordinator for Meteorology, of federal, state and local fire managers needs for weather information in their wildfire and prescribed fire decision making processes and a framework to meet those needs by the NWS and Predictive Services.

• Enhance and incorporate the fire weather observational network (RAWS) through agreements with the land management agencies into an integrated surface observing strategy, for example through ISOS and GEOSS.

3. The Western Governors believe an integrated fire weather and fire environment research program is critical for the effective management and health of U.S. forests and rangelands. To ensure the program has proper attention and funding, the Governors urge Congress to legislatively direct the National Academy of Sciences to conduct a review of the research programs related to fire weather and fire environment (including Department of Agriculture, Department of the Interior, EPA, NOAA, NASA, and academia). This review should focus primarily on the coordination process between research programs and on processes to transfer research results into fire operations.

4. The Western Governors believe the nation would reap significant economic benefits by a new joint interagency effort to transfer new digital weather information and technology into operational fire management decision-making and planning. This new effort would have a high economic return on investment and significant public health benefits from improved smoke dispersion forecasts. The Governors urge Congress to legislatively identify and fund NOAA to organize a new joint interagency effort for improved fire weather, fire environment and smoke dispersion information with NOAA, USFS, DOI, EPA, NASA, states, and other federal and non-federal stakeholders to:

a. Facilitate, integrate and transfer new science and technology into wildfire and prescribed fire operations

b. Perform verification, validation, evaluation and assessment of operational fire weather data, products and applications.

c. Provide science and technology training for forecasters and fire management decision-makers, technical support for new decision-support tools, and grant support for joint collaborative applied fire weather and fire environment science research.

5. The Western Governors believe the new robust applied fire weather, fire environment and smoke dispersion program needs to be effectively leveraged, integrated and coordinated with the 10-Year Comprehensive Strategy, the WGA drought program, and WRAP.

6. The Western Governors believe that weather, climate and hydrology data generated by the federal government should be available to all levels of government in an open and unrestricted manner. The Governors oppose making such data available only to the private sector for purposes of resale to states and local governments.

C. GOVERNORS' MANAGEMENT DIRECTIVE

1. The Western Governors' Association (WGA) shall post this resolution to its Web site to be referred to and transmitted as necessary.

2. WGA staff shall work with the states, the appropriate federal agencies, and Congress to implement this resolution.

Appendix E: National Association of State Foresters Call for Action

NASF Resolution No. 2005-3: Ensuring the Fire Weather Mission of NOAA's National Weather Service

ORIGIN OF RESOLUTION: *NASF Forest Fire Protection Committee

ISSUE OF CONCERN: Ensuring the Fire Weather Mission of NOAA's National Weather Service

BACKGROUND:
As a consequence of decades of fuel accumulation in our nation's forests and rangelands, coupled with persistent drought, state and federal fire managers are faced with larger, more explosive and more costly wildfires than in any period in history. Catastrophic wildfire is a growing national issue, demonstrated by the Florida wildfires in 1998 and 1999 and in many Western states over the past five years. Between 2000 and 2004, Arizona, New Mexico, Colorado, Oregon, Montana, Washington, Wyoming, California, South Dakota and Alaska all experienced severe fire seasons that set new benchmarks in terms of damages, losses and cost.

Large, damaging wildfires are costly to suppress, and they can also cause severe economic impacts to communities and state economies. Based on the experience over the last decade, 98% of wildfires are successfully extinguished during initial attack. However, 80% of wildfire costs are incurred when managing the 2% of wildfires which grow into large fires. Over the five-year period from 2000-2004, federal wildfire suppression costs averaged $1.16 billion per year and are rising. With the addition of state and local fire suppression efforts, these costs will likely approach $2 billion in severe years. Public health impacts are also increasing as the population increases in the wildland-urban interface areas and smoke dispersion from wildfires and prescribed fires impact vulnerable citizens with respiratory ailments.

In order to effectively and cost efficiently manage and suppress wildfires, including through the use of prescribed fire, it is critical that fire managers have timely, accurate and detailed information regarding current and predicted fire weather and associated climate services. The National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS), through its fire weather program, is the national agency in the Department of Commerce (DOC) which provides this critical information. The federal wildland fire agencies' Predictive Services integrate weather, climate and fuels information into fire environment products for the allocation and prioritization of fire management resources. The fire environment refers to those elements comprising fire meteorology, fire climatology, fire danger, fire behavior and fuel conditions as derived from weather and climate.

NOAA's NWS does not have a clear, legislative mandate or identified funding line items to operate its fire weather program. As a consequence, its capability to support sound fire management decisions may not be able to keep pace with the increasing demands. Further, the current NWS policy on issuing site-specific spot forecasts is to only issue spot forecasts for prescribed burns for federal lands and federal assets and for requests from public safety officials. Unless a state or local government can represent that there is a public safety concern or that federal assets are at risk, state and local governments must pay the private sector for spot forecasts.

RESOLUTION

* Operational fire managers need improved products and services from NOAA's NWS which can be seamlessly infused into fire operations decision-making. To ensure the program has proper attention and funding the National Association of State Foresters (NASF) urges Congress to legislatively add fire weather, including support for wildfire and prescribed fire management, to federal, state and local government agencies as a core mission of NOAA's National Weather Service (NWS) and carry it as a funded line item in their appropriations. In addition, NASF urges NOAA to:

* Incorporate a robust national wildfire and prescribed fire weather program into its strategic plan and its 5- and 20-year research plans and funding requests.

* Complete a National Needs Assessment Report, by NOAA's Office of the Federal Coordinator for Meteorology (OFCM), of federal, state and local fire managers needs for weather information in their wildfire and prescribed fire decision making processes and a framework to meet those needs by the NWS and Predictive Services.

* Enhance and incorporate the fire weather observational network (RAWS) through agreements with the land management agencies into an integrated surface observing strategy, for example through ISOS and GEOSS.

Further, NASF supports all recommendations in the June 2005 resolution by the Western Governors Association titled, "National Wildland Fire Weather Program."

NASF ACTION: (X) Approved
DATE OF ACTION: October 5, 2005

Appendix F: Acronyms and Definitions of Key Terms

ASOS - Automated Surface Observing System of the National Weather Service http://www.nws.noaa.gov/asos

AWIPS - Advanced Weather Interactive Processing System is an interactive computer system that integrates all meteorological and hydrological data, and all satellite and radar data, for the first time, and enables the forecaster in a Weather Forecast Office to prepare and issue more accurate and timely forecasts and warnings.

AVHRR – Advanced Very High Resolution Radiometer

BIA - Bureau of Indian Affairs, U.S. Department of the Interior. http://www.doi.gov/bia/

BLM - Bureau of Land Management, U.S. Department of the Interior http://www.blm.gov/wo/st/en.html

BlueSky - BlueSky is a modeling framework operated by the U.S. Forest Service which brings together the latest state of science for modeling fuels, fire, smoke, and weather into one centralized processing system. http://www.fs.fed.us/bluesky

CFFDRS – Canadian Forest Fire Danger Rating System is Canada's national system of rating forest fire danger. http://fire.cfs.nrcan.gc.ca/research/environment/cffdrs/cffdrs_e.htm

CMAQ - Community Multiscale Air Quality Modeling System operated in a partnership between NOAA and the Environmental Protection Agency http://www.epa.gov/asmdnerl/CMAQ/

CFD - Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows.

Debris flow - A multiphase gravity flow, also referred to as a mudslide, mudflow, lahar, or debris avalanche. Such a down slope flow, often rapid, generally occurs in connection with intense rainfall or rapid snow melt.

EMWIN - The Emergency Managers Weather Information Network -- EMWIN -- is a service that allows users to obtain weather forecasts, warnings, and other information directly from the National Weather Service in almost real time.

EPA - Environmental Protection Agency http://www.epa.gov/

ERC-G - Energy Release Component of Fuel Model G; reflects moisture level in 1000 hour fuels.

ESRI - Commercial provider of GIS software systems

ESRL – Earth System Research Laboratory in Boulder, CO, a laboratory of OAR, NOAA http://www.esrl.noaa.gov

FARSITE - A fire behavior and growth simulator used by Fire Behavior Analysts from the USDA FS, USDI NPS, USDI BLM, and USDI BIA. It is designed for use by trained, professional wildland fire planners and managers familiar with fuels, weather, topography, wildfire situations, and the associated concepts and terminology.

FCAMMS - Fire Consortia for Advanced Modeling of Meteorology and Smoke http://www.fcamms.org/

Firestorm - Extreme fire behavior owning to high heat-release rate over an area, and indicated by circumferential indrafts and a tall column of smoke and flame above the burning area.

FIRETEC - FIRETEC is a coupled atmosphere/wildfire behavior model developed at Los Alamos National Laboratory, and is based on conservation of mass, momentum, species, and energy.

Fire weather - The observed and predicted atmospheric conditions between the surface and the tropopause that affect the onset, spread, and behavior of fire, both wild and prescribed, and smoke dispersion

Fire whirl - A tornado-like vortex that forms from the stretching of vorticity due to local inflow and updraft in a fire

FS - Forest Service or U.S. Forest Service, U.S. Department of Agriculture http://www.fs.fed.us/

FSPro - FSPro (Fire spread Probability) is a spatial model in the Wildland Fire Decision Support System that calculates the probability of fire spread from a current fire perimeter or ignition point for a specified time period

FWS - Fish and Wildlife Service, U.S. Department of the Interior www.fws.gov

FX-Net - A meteorological PC workstation that provides access to the basic display capability of an AWIPs forecaster workstation (as in a Weather Service Forecast Office) via the Internet http://www-tod.fsl.noaa.gov/fxnet.html

GIS - Geographic Information System

GOES-R ABI - the Advanced Baseline Imager on the next-generation Geostationary Operational Environmental Satellite (GOES)

GPS - Global Positioning System

HALE – High-Altitude Long-Endurance. In this report, the acronym refers to a type of unmanned aerial system.

HYSPLIT - HYbrid Single-Particle Lagrangian Integrated Trajectory model is a system for computing simple air parcel trajectories for complex dispersion and deposition simulations.

IMET - Incident Meteorologist—The National Weather Service has a cadre of 84 certified meteorologists (as of report date) that are specially trained to go to wildfires and other incidents and give weather briefings and forecasts to the incident responders and command staff. The meteorologist's forecasts ensure the safety of operations and allow responders to plan operations taking into account one of the most changeable aspects of an incident, the weather. http://www.noaawatch.gov/themes/fire.php

Landscape scale - see **misoscale.**

LAL - Lightning Activity Level

MADIS - Meteorological Assimilation Data Ingest System

Misoscale - The scale of meteorological phenomena that range in size from about 40 meters to about 4 kilometers. It encompasses coherent vertical structures within a thunderstorm. Some call this the "landscape scale".

MM5 – Fifth-generation Mesoscale numerical weather Model developed by the National Center for Atmospheric Research and Pennsylvania State University

MODIS – Moderate Resolution Imaging Spectroradiometer

MOS – Model Output Statistics is a statistical technique used to objectively interpret numerical model output and produce site-specific guidance.

NASA -National Aeronautics and Space Administration http://www.nasa.gov

NASF - National Association of State Foresters

NCDC - NOAA's National Climatic Data Center, Asheville, NC http://www.ncdc.noaa.gov

NCEP - National Centers for Environmental Prediction of the National Weather Service http://www.ncep.noaa.gov

NDFD - National Digital Forecast Database

NESDIS - National Environmental Satellite and Data Information Service, NOAA http://www.nesdis.noaa.gov

NFDRS - National Fire Danger Rating System

NIFC - The National Interagency Fire Center (NIFC), located in Boise, Idaho, is the nation's support center for wildland firefighting. Eight different federal agencies and organizations are part of NIFC. Decisions evolve from interagency cooperation because NIFC has no single director or manager.

NOAA - National Oceanic and Atmospheric Administration www.noaa.gov

NOAAPORT - The NOAAPORT broadcast system provides a one-way broadcast communication of NOAA environmental data and information in near real time to NOAA and external users.

Nowcast – As defined by the National Weather Service a nowcast is a short-term forecast designed to give specific detailed forecast information for the next 0 to 6 hours on a county basis.

NPOESS - National Polar-orbiting Operational Environmental Satellite System

NPS - National Park Service, U.S. Department of the Interior http://www.nps.gov

NSSL - National Severe Storms Laboratory, Norman, OK, a laboratory of OAR, NOAA http://www.nssl.noaa.gov

NWCG - The National Wildfire Coordinating Group (NWCG) is made up of the USDA Forest Service; four Department of the Interior agencies: Bureau of Land Management (BLM), National Park Service (NPS), Bureau of Indian Affairs (BIA), and the Fish and Wildlife Service (FWS);and State forestry agencies through the National Association of State Foresters. The purpose of NWCG is to coordinate programs of the participating wildfire management agencies, to avoid wasteful duplication and to provide a means of constructively working together. http://www.nwcg.gov

NWP - Numerical Weather Prediction

NWS - National Weather Service, NOAA http://www.nws.noaa.gov

OAR - Office of Oceanic and Atmospheric Research, NOAA http://www.oar.noaa.gov

OFCM - Office of the Federal Coordinator for Meteorology http://www.ofcm.gov/

Predictive Services-This interagency wildland fire program provides decision support information needed to be more proactive in anticipating significant fire activity and determining resource allocation needs. Predictive Services consists of three primary functions; fire weather, fire danger/fuels, and intelligence/resource status information.

Predictive Service staff units are located at the National Interagency Coordination Center (NICC) and the Geographic Area Coordination Centers (GACCs) across the country.

Prescribed Fire-Any fire ignited by management actions to meet specific objectives. A written, approved prescribed fire plan must exist, and requirements of the National Environmental Policy Act must be met (where applicable), prior to ignition.

RAWS – Remote Automatic Weather Station http://www.fs.fed.us/raws/

Red Flag Warning - Warning forecast issued by the National Weather Service to inform area firefighting and land management agencies that conditions are conducive for wildland fire ignition and propagation.

ROMAN – Real-time Observation Monitor and Analysis Network. ROMAN provides access to environmental observations from thousands of weather stations around the country. Observations collected by federal, state, and local agencies as well as commercial firms are integrated into tables and maps. http://raws.wrh.noaa.gov/roman.index.html

SMART-R - Shared Mobile Atmospheric Research and Teaching Radar operated by NOAA's National Severe Storms Laboratory http://www.nssl.noaa.gov/smartradars/

SPC - National Weather Service Storm Prediction Center, Norman, OK http://www.spc.noaa.gov

Spot forecast- A special, highly detailed, non-routine forecasts for a specific location within a forecast area. It is prepared upon request of any federal agency, or state agency when there is some aspect of federal resources involved and/or an interagency protection agreement is in place. In the event of an emergency which threatens life and/or property, spot forecasts can also be provided to any federal, state, or local agency. The format of the spot forecast is specified in National Weather Service Directive 10-401. The forecasts will begin with a discussion, and may contain any or all of the following weather elements: sky conditions; maximum and minimum temperatures, minimum and maximum relative humidity values, wind speed and direction; probability of precipitation; precipitation type, duration and amount; mixing heights; transport wind; inversion height; inversion onset and burn-off times or temperatures; ventilation and smoke management levels; wind profiles and stability indices (i.e., Haines Index), and lightning activity levels (LAL). Since these are site specific and can be initiated because of critical circumstances, tailored products can be requested (e.g. temperature, relative humidity, and wind speed forecasts on a two hour incremental time period).

Storm-scale - A spatial scale on the order of the dimensions of individual thunderstorms

Thin client – An inexpensive terminal for accessing computers on a network

UAS - Unmanned Aircraft System, which includes the aircraft (UAV), a suite of technology, and teams of people working to support various missions. http://uas.noaa.gov/

UAV - Unmanned Aerial Vehicle

USFS - See Forest Service.

VIIRS - Visible Infrared Imagery Radiometer Suite—an instrument on the NPOESS satellite

WFAS - Wildland Fire Assessment System

WFDS - Wildland-urban Interface Fire Simulator, a NIST computer model

WFDSS - Wildland Fire Decision Support System. Developed and operated by the U.S. Forest Service, this system is intended to assist fire managers and analysts in determining the appropriate management response (AMR) for fire incidents. WFDSS is expected to be fully operational in 2009.

WFO - Weather Forecast Office of the NOAA National Weather Service

Wildfire - is an unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out.

Wildland Fire - Any non-structure fire that occurs in the wildland. Three distinct types of wildland fire have been defined and include wildfire, wildland fire use, and prescribed fire.

Wildland Fire Use - The application of the appropriate management response to naturally-ignited wildland fires to accomplish specific resource management objectives in pre-defined designated areas outlined in Fire Management Plans.

WRF – The Weather Research and Forecasting (WRF) Model is a next-generation mesocale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. http://www.wrf-model.org/index.php

Appendix G: Fire Weather Research and Development in the University Community (as known by the FWRWG)

Academic Institution	Research Activities	Primary Participants
Florida State University	Physics-based fire modeling, large-eddy simulations of fire and plume behavior	Dr. Philip Cunningham
San Jose State University	Micrometeorological measurements of wildland fires	Dr. Craig Clements
Desert Research Institute	Climate & weather relationships with wildland fire, and related product development for management and decision making. Prototype development for CA/NV FCAMMS.	Dr. Timothy Brown
Scripps Institute of Oceanography	Seasonal fire weather forecasts, fire and climate prediction	Dr. John Roads (deceased)
SUNY, University at Albany	Fronts and boundaries in the planetary boundary layer and fire weather	Dr. Daniel Keyser
North Carolina State University	Predictive fire spread indices in a mesoscale numerical model	Dr. Yuh-Lang Lin
University of Georgia	High-resolution numerical weather prediction for smoke and fire management (Southern High Resolution Modeling Consortium, joint with USDA FS	Dr. Tom Mote
Michigan State University	Fire risk in changing climates	Dr. Julie Winkler
University of Wisconsin–Madison	Synoptic and mesoscale evolution of Great Lakes wildfire environments	Dr. Jon Martin
University of Idaho	Remote sensing and wildland fires	Various faculty
Washington State University	Air quality modeling for wildland fire applications	Dr. Brian Lamb
University of Washington	High-resolution numerical weather prediction for smoke and fire management	Dr. Cliff Mass
University of Utah/York University	Physics-based fire modeling	Dr. Steve Krueger/Dr. Mary Anne Jenkins

Academic Institution	Research Activities	Primary Participants
Oregon State University	Terrestrial Ecosystem Research & Regional Analysis (TERRA-PNW)	Dr. Beverly Law, Director
University of Houston	Air quality model development for impact of forest fires on regional air quality	Dr. Sharon Zhong, Dr. Daewon Byun
Oklahoma State University	Weather-based decision support systems for wildland fire managers	Dr. J. D. Carlson
Columbia University	Fire spread analysis and prediction	Dr. David Keyes
University of California, Berkeley	Wildland fire tests and fire modeling	Dr. Scott Stevens
University of California, Berkeley	Statistical modeling of fire spread at the wildland-urban interface	Dr. David Brillinger
Rochester Institute of Technology	Remote sensing of wildland fire	Dr. Robert Kremens
University of Michigan	Fire modeling	Dr. Arvind Atreya
University of Hawaii	High resolution weather model evaluation and development	Dr. Yi-Leng Chen
University of Hawaii	Statistical relationships between climate and fire activity	Dr. Pao-Shin Chu
University of Maryland	Fire Risk – fire danger and changing climate	Dr. Tatiana Loboda
Ohio State University	Smoke transport from wildland fires	Prof. Valerie Young
University of California, Santa Barbara	Fire weather modeling applications	Dr. Charles Jones
University of California, Riverside	Air quality impacts from wildland fires	Dr.Gail Tonnesen, Dr. Zion Wang
University of California, Riverside	Experimental and numerical modeling of fire spread in live fuels	Dr, Shankar Mahalingam