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FIRE CONSORTIA FOR ADVANCED MODELING OF METEOROLOGY AND SMOKE—FCAMMS: A NATIONAL PARADIGM FOR WILDLAND FIRE AND SMOKE MANAGEMENT

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1. INTRODUCTION

Fires can be catastrophic, but only when the weather permits. Predicting the weather more than a few hours into the future with accuracy, precision and reliability is an on-going challenge to researchers. Accurate and precise forecasting for more than a few hours into the future has been virtually unrealizable until the latter half of the 20th Century. In the modern era, advances in the atmospheric sciences have led to a far greater understanding of the nature of the atmosphere. Recognition of the inherent stochastic nature of atmospheric circulation, advances in the abilities of modern computers to simulate the earth system, weather observation and communication networks and satellite remote sensing have combined to advance the ability to predict weather and its consequences far better than was possible a few years ago. The USDA Forest Service has developed FCAMMS as an effort to capitalize on these advances and provide information to fire managers and others on a real-time basis using the communications capabilities of the World Wide Web. This job is certainly much too big for the USDA Forest Service alone, indeed for the land management community alone. Thus, the FCAMMS are designed as massively collaborative partnerships, relying on global scale weather information from sister federal agencies (NOAA, NASA, military) and the scientific resources of those agencies, universities, and national laboratories. To insure that FCAMMS products are useful for managers in the "real world," each FCAMMS also includes operational advisors and users to provide guidance on the types of products produced and feedback on accuracy.

Since 2000, the USDA Forest Service and the Department of the Interior have collaborated in implementing a National Fire Plan. The four elements of this plan are: firefighting; rehabilitation and restoration; hazardous fuels reduction, and community assistance. The National Fire Plan is a long-term investment that will help protect communities and natural resources, and most importantly, the lives of firefighters and the public. It is a long-term commitment based on cooperation and communication among federal agencies, states, local governments, tribes and interested publics.

Under the firefighting element of the National Fire Plan, a critical research component calls for the development, improvement, and validation of models for *fire-weather, fire danger, fire behavior prediction, fire hazard rating, and smoke management in wildfires and prescribed fires*.

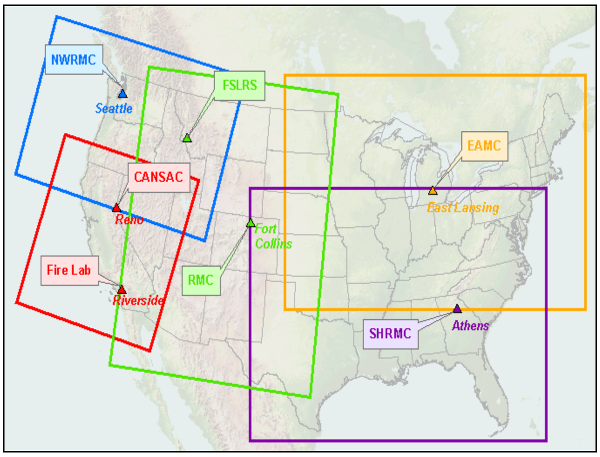

Figure 1. Locations of the five FCAMMS established under the United States National Fire Plan and the 12 KM grid resolution domains covered by the individual consortia.

In response to this need, USDA Forest Service atmospheric sciences researchers developed a research and product development strategy built around the concept of regional modeling consortia. Five USDA Forest Service research groups were funded to implement regional Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS), identified as shown in Figure 1.

Each regional consortium is a multi-agency coalition of researchers, fire managers, air-quality managers, and natural resource managers at the federal, state, and local levels.

The Consortia mission is to:

- **Increase understanding of fire-weather, fire danger, fire behavior, and the transport, diffusion and impact of smoke from fire;**
- **Develop and implement new technologies related to regional fire-weather and air-quality;**
- **Enhance our ability to use fire for land management purposes, and;**
- **Improve tools for fire fighters by better predicting the dangers of wildfire.**

In order to deliver this mission, FCAMMS are developing and maintaining contemporary computational and data processing resources. The computer requirements needed to simulate high-resolution meteorology include very large data processing and storage capacities, high-speed calculation capabilities, broadband communications facilities and web-based, map-based graphical displays. In general, these capabilities are being provided through the use of clusters of multiple PC processors operating under LINUX systems, utilizing large RAID disk array data stores and relying on the World Wide Web for communication. To a large extent these represent new and different ways for USDA Forest Service to do business. FCAMMS have also led to significant improvements in the internal capacity of the USDA Forest Service Research and Development hiring scientists and technicians with modern computer and atmospheric sciences skills.

2. THE CONSORTIUM APPROACH

FCAMMS are developing as consortia for a number of reasons. First, for the USDA Forest Service to credibly conduct contemporary atmospheric sciences research, partnerships and resource sharing are necessary. The wide array of skills needed to accomplish the FCAMMS mission as well as the very high cost of facilities and tools suggest a partnership approach. Second, the USDA Forest Service cannot maintain a competitive position doing the sort of research "on its own" because of its limited number of research meteorologists. Third, there are others available for partnerships that represent expertise and capabilities well beyond any that the Forest Service might ever hope to develop or maintain.

For example, simply generating the information required to simulate high-resolution, real-time meteorology requires:

- access to data generated by global-scale weather forecast models run by sister federal agencies, international institutions, universities, the U.S. military and others;
- a capability to ingest these model data and simulate timely, higher-resolution, realistic regional meteorology;
- a capability to understand, analyze, and compare with ground based and satellite observations, critique, verify, and improve these regional meteorological simulations, and;
- a capability to ingest fire activity data and use it with the meteorological simulations to estimate smoke emissions, transport, transformation, dispersion and removal.

Land managers are not likely to do this alone because they often lack needed access to satellite observations and forecast model data. The required skills, communications capacities, and research capabilities are well beyond land manager norms. Meanwhile, others especially universities, government agencies including the military, National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Administration (EPA), are on the cutting-edge of developing the technologies and capabilities required. Finally, the expense and complexity of this job is well beyond the capability of land management budgets. Hence, the consortium approach, taking advantage of expertise in other agencies and universities is the only approach that makes sense.

In developing the FCAMMS concept the Northwest Regional Modeling Consortium provided an excellent model for the type of collaboration and cooperation required. This group, under the intellectual leadership of Professor Cliff Mass in the Atmospheric Sciences Department at the University of Washington and a host of others in applied agencies, has pioneered in the application and evaluation of regional scale weather intelligence for a variety of applications, including those related to the interests of the FCAMMS. Following the Northwest model, the FCAMMS have established and continue to seek a wide variety of research and technology transfer partnerships with numerous federal, state, and local agencies and private organizations (see Table 1).

Table 1. FCAMMS current members and partners with model run information.

FCAMMS	Members and Partners	Frequency	Run Time	Model Domain Grid Spacing
Eastern Area Modeling Consortium (EAMC) East Lansing, Michigan http://www.ncrs.fs.fed.us/eamc	USDA Forest Service, North Central Research Station, Northeastern Research Station, USDA Forest Service Region 9 Aviation and Fire Management and Air Resources Management Program, Northeastern Area State & Private Forestry, Eastern Area Geographic Coordination Center, North Carolina State University, University of Utah, Jackson State University, University of Wisconsin, NOAA Air Resources Laboratory	Twice-daily	8hr	36km, 12km, 4km (1 Km planned over New Jersey)
Northwest Regional Modeling Consortium (NWRMC) Seattle, Washington http://www.atmos.washington.edu/pnw_environ/	National Weather Service, University of Washington, Washington State University, USDA Forest Service Pacific Northwest research Station, Port of Seattle, United States Navy, U.S. Environmental Protection Agency, Washington State Department of Ecology, Puget Sound Clean Air Agency, Washington State Department of Natural Resources, Washington State Department of Transportation, Seattle City Light	Twice-daily	72hr 48hr	36km, 12km, 4km
Southern High Resolution Modeling Consortium (SHRMC) Athens, Georgia http://shrmc.ggy.uga.edu/	University of Georgia, Georgia Forestry Commission, USDA Forest Service Region 8, USDA Forest Service Southern Research Station, National Weather Service	4 times - daily	48hr	36km, 12km
California and Nevada Smoke and Air Consortium (CANSAC) Reno, Nevada and Riverside, California http://www.fs.fed.us/fcamms	Desert Research Institute, University of Nevada, University of California – Santa Barbara, University of California – San Diego, Maui High Performance Computer Center, Naval Postgraduate School, Scripps Institute, USDA Forest Service Pacific Southwest Research Station	Twice-daily Twice-daily Twice-daily	48hr 48hr 48hr	36,12,6,4,2km 108,36,12k 27,9,3,1km
Rocky Mountain Modeling Consortium (RMC) Fort Collins, Colorado http://www.fs.fed.us/rmc	USDA Forest Service Air Resources Program, NOAA Forecast Systems Laboratory, Rocky Mountain Area Geographic Coordinating Center, Southwest Area Geographic Coordinating Center, USDA Forest Service Rocky Mountain Station	4 times - daily	24hr	12km, 4km (as of Mar 2003)

Each FCAMMS is developing different and unique cooperative relationships; however, there are a few common elements in these. NOAA is, of course, the source of data and model initialization fields for the FCAMMS simulations. As well, satellite observations and climate data from NESDIS are critical for the FCAMMS research. It is important to note that NOAA maintains the lead responsibility for forecasting weather in general and fire weather in particular. NOAA meteorologists utilize a wide array of weather intelligence in this role and interact directly with the fire community. In no way do the FCAMMS affect this relationship. Rather the FCAMMS high-resolution research oriented information is intended to supplement the NOAA work with a focus on fire, forestry, and smoke applications. NASA also provides critical partnerships with the FCAMMS by providing MODIS data that is being interpreted at the USDA Forest Service Missoula Fire Laboratory to provide critical fire activity, location and emissions information. Various agencies in the U.S. Department of the Interior represent critical partnerships for both providing data and utilizing FCAMMS intelligence, especially within the wildland fire community. Finally, as the list in Table 1 shows universities are key partners providing intellectual as well as logistical support and students for the FCAMMS.

Each consortium conducts basic and applied research on new fire-weather and fire-climate index development, seasonal fire severity, small-scale fire-atmosphere interaction dynamics, smoke emissions, transport and diffusion, and coupled fire-atmosphere modeling. In support of these research goals, each regional consortium produces daily, regional predictive simulations of weather, fire-weather, and transport/diffusion variables using a common set of modeling tools (e.g., the MM5 mesoscale meteorological model, Grell et al. 1994) over the domains as shown in Figure 1. Individual consortium web sites make this information available to the user community on a daily basis. Users are provided a variety of map products and analyses depicting the current and 24-48 hour atmospheric conditions relevant for fire-weather, fire behavior, and smoke transport and diffusion. All the consortia are committed to improving their products by feedback from their user communities and field verification studies. Table 1 also provides a summary of the FCAMMS simulations and websites.

3. FCAMMS CONCEPTUAL STRUCTURE

The ideal FCAMMS is structured around a small 'inner core' group of scientists and technicians who run high-resolution meteorological simulation models, such as MM5 and similar ancillary models and who make results available to others (scientists). A relatively larger group of specialists take data from the 'inner ring' and combine it with other data, other types of model simulations, and observational data to produce information and information based products for agencies (information suppliers). In the ideal case, the largest component ('outer ring') of the FCAMMS is populated by individuals and agencies that use the information (users). Ideally, the users will provide feedback, guidance, funding, and help in identifying problems for scientists and information providers.

3.1 Fire weather and fire management applications

Within the fire management community it is possible for the FCAMMS to implement this sort of idealized structure, especially as it is applied to fire fighting. For the fire fighting community, there is a well-developed infrastructure of people and resources. USDA Forest Service's Research and Development organization funds FCAMMS and provides other support for the 'inner core' scientists and technicians. At the individual FCAMMS the 'inner core' is mostly Forest Service scientists and technicians working in cooperation with university scientists and students. The 'information suppliers' for the fire management community are represented by both the National Interagency Coordination Center (NIFC) and the predictive services of the Geographic Area Coordination Centers (GACCS). These groups consist of meteorologists and trained fire specialists who are capable of using the high-resolution outputs of weather and fire intelligence products to assist them in providing their user communities the sorts of information they need. Finally, the fire management community as a whole is the user for these products.

3.2 Smoke and air quality applications

Unfortunately, roles for both information providers and users, including state air quality regulators, are not as well identified for applications in air quality and smoke management. First, air quality is not an area where the USDA Forest Service has a natural or clearly defined role. Internally, it is difficult for managers to accept that this is work that the Forest Service needs to do. Research in air quality is not a traditional arena for the Forest Service; however, both the Forest Service and the National Park Service have maintained significant efforts in research on visibility and air quality effects on pristine areas since 1977 when the Clean Air Act mandated a role for them to protect the air quality related values of these areas. This role led both agencies to undertake work on air quality modeling both for industrial sources that might impact federal Parks and Wildernesses as well as for smoke from forest burning.

Nevertheless, the roles of the federal land managers in air quality modeling are somewhat confused. In this case, the users as well as the information providers represent a much broader group of people. They range from regulatory personnel at various governmental levels, to private sector land managers, to members of the general public. Each user has a somewhat distinct set of requirements and a different level of understanding and capability of assimilating the weather and air quality intelligence provided by the FCAMMS. In order for the FCAMMS to be successful in providing smoke management and other air quality products each FCAMMS will need to identify and develop close working relationships with both the information provider and user level of partners.

Dr. Sue Ferguson at the Northwest FCAMMS is leading the way developing appropriate working relationships between the regional modelers, the fire community, and the air quality community. The BlueSky model framework has been developed to support this relationship and FCAMMS around the country are planning on implementing it as soon as it is available. In addition to BlueSky, the FCAMMS will also need to develop partnerships with the various [Regional Planning Organizations]() around the country. RPOs are currently developing procedures for conducting regional air quality modeling for planning purposes. In general, these models are all driven by simulated meteorology from MM5 and similar meteorological models. Hence, there is a clear opportunity for FCAMMS to become involved. However, for the RPOs, regional scale meteorology is a relatively easy component of their work. The more difficult aspects of the RPO job are developing and managing emissions inventories and the results of complex regional scale atmospheric chemistry, transport, dispersion and deposition models. The emissions inventory work, especially as it applies to fire sources, is another area where the FCAMMS might be able to provide assistance.

4. FCAMMS PRODUCTS

4.1 High-resolution weather variables

All of the consortia provide a range of weather products simulated using the MM5 model on grid resolutions of 36 km and better. Figure 2, from the Eastern Area Modeling Consortium, illustrates a 24-hour forecast of the surface wind vector for the 12 km grid for the eastern U.S. Figure 3, from the Southern High Resolution Modeling Consortium, illustrates a 48 hour forecast providing intelligence about possible future wind and moisture conditions.

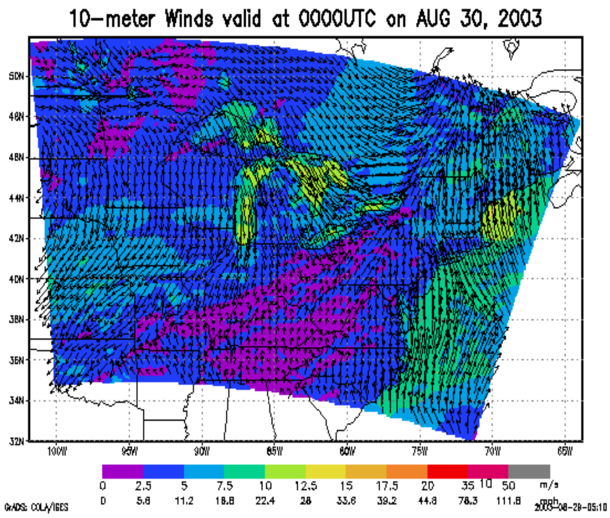

Figure 2. EMAC map of 10-meter Wind (meters/sec) at 12km resolution initialized at 0000 August 29, 2003, 24 hours after model initialization.

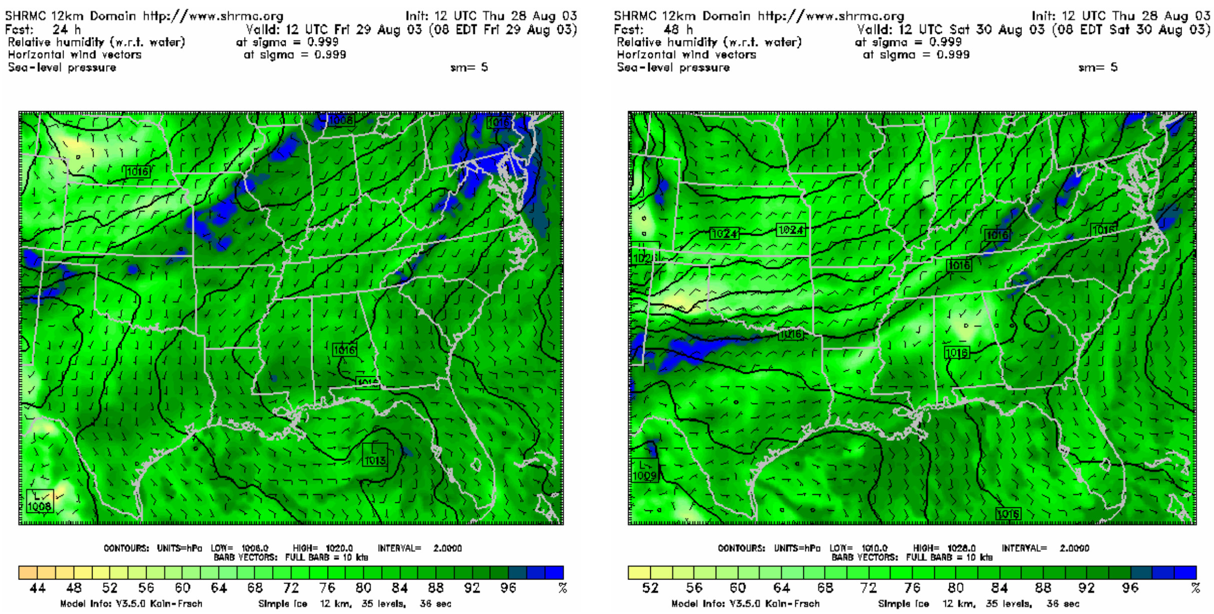

Figure 3. Illustration of forecasts from the 12 km resolution MM5 simulation by the Southern High Resolution Modeling Center (SHRMC) of surface relative humidity, wind vectors, and surface pressure initiated at 12z, August 28 for 24 and 48 hours ahead.

4.2 High-resolution fire indices

Figure 4 from the Northwest Regional Modeling Consortium MM5 simulations illustrates the change over time in the pattern of the forecasted Haines Index. The Haines Index is a simple measure of the chance that an existing fire will become a dangerous, erratic fire. It reflects atmospheric stability and moisture in a layer of the atmosphere roughly 1 to 5 km above the surface. High values indicate higher risk of dangerous fire behavior (Haines, 1988). Figure 5, from the Rocky Mountain Modeling Consortium's southwestern window, illustrate the forecast changes on a 4 km resolution of the Fosberg Fire Weather Index. The Fosberg Index is a measure that reflects expected flame length and fuel drying based on wind speed, temperature and humidity. High values indicate high flame lengths and rapid drying (Fosberg, 1978).

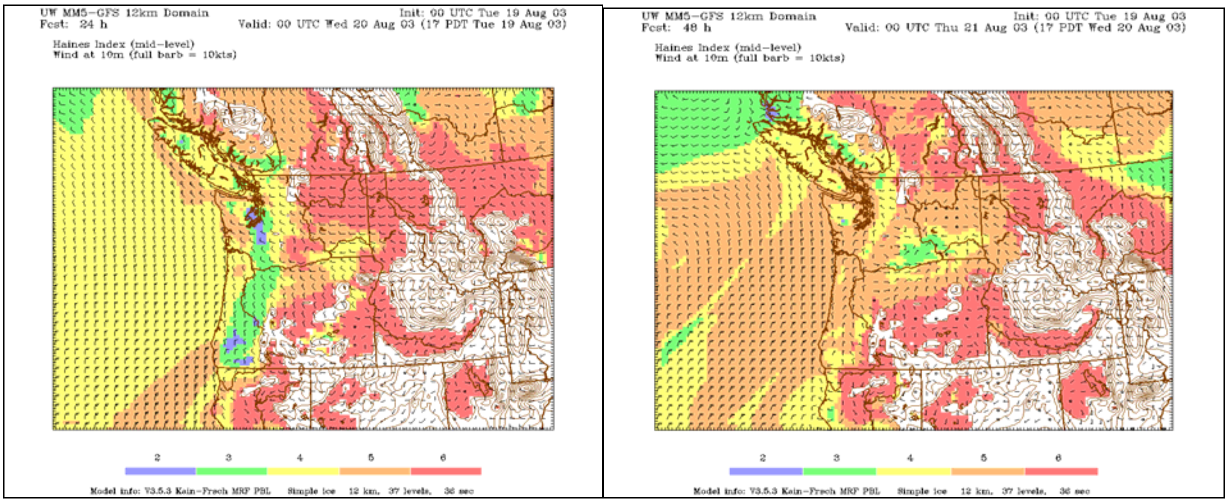

Figure 4. Illustration of the forecast Haines index, initialized at 00z 19 August, 24 hours into the forecast and the same after 48 hours based on a 12 km resolution MM5 simulation from the Northwest Regional Modeling Consortium (NWRMC).

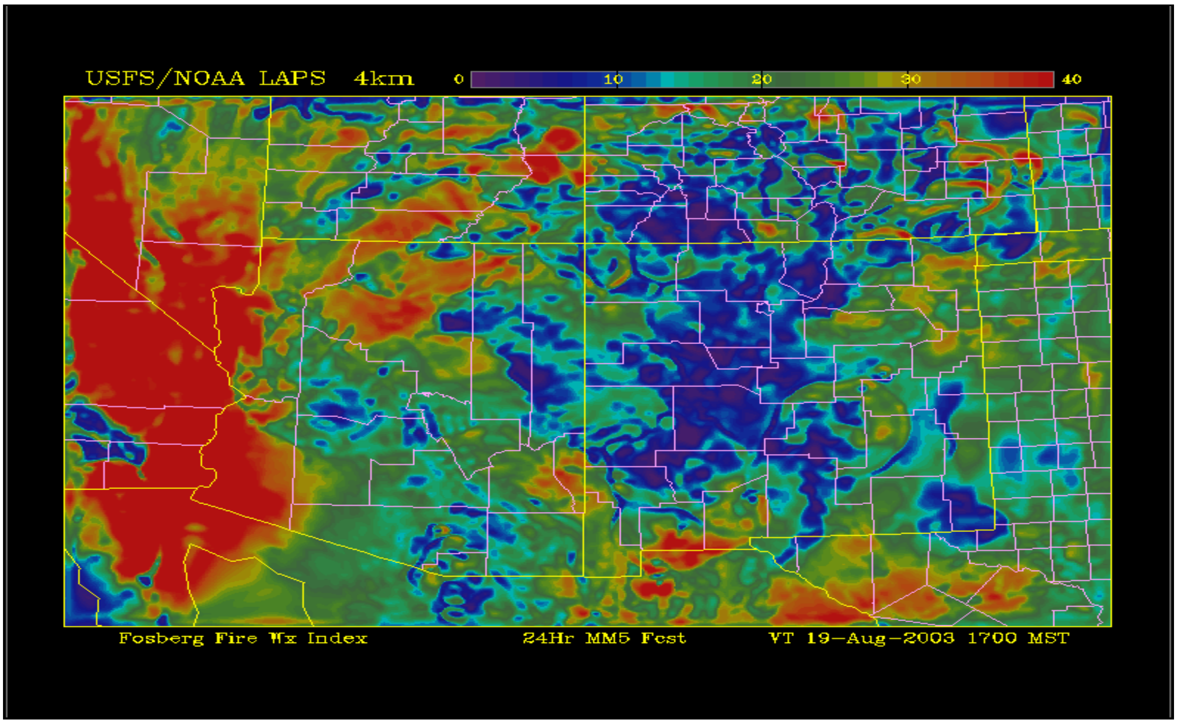

Figure 5. Illustration of Fosberg Fire Weather Index (red highest value) predicted from the Rocky Mountain Modeling Center's 4 km MM5 simulation over Arizona and New. Mexico.

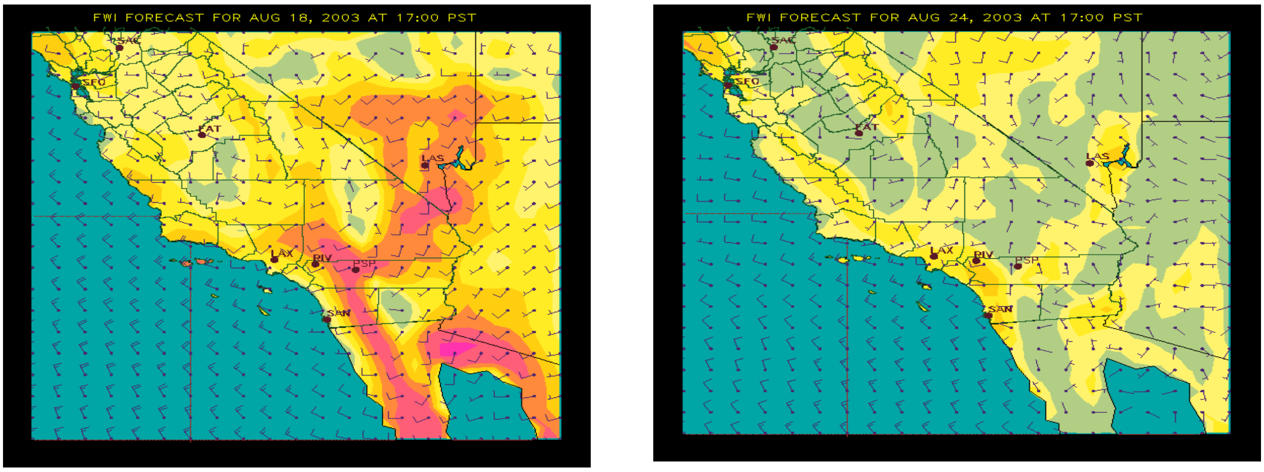

Figure 6. California Fire Weather Index (red as highest index value), produced by the California Smoke and Air Consortium in collaboration with Scripts Institute. The forecast is for 7days, illustrated as a 24-hour forecast at 17:00 August 18 and 168 hour forecast at 17:00 for August 24.

Figure 6 illustrates the California Fire Weather index, a variant of the Fosberg Fire Weather Index. This index results from combining wind, temperature, and humidity information as used by the National Fire Danger Rating Program (NFDR; Deeming, et.al. 1977). In essence, the CFWI suggests where it will be hot, dry and windy, hence increasing the likelihood of fires. The color-coding goes from low values in green toward higher values in red. Figure 6 illustrates a 7-day forecast done by the CANSC at the USDA FS Riverside Fire Laboratory and University of California at San Diego, Scripps Institute of Oceanography's Experimental Climate Prediction Center. The figure illustrates the value of longer range, higher-grid resolution model information for fire fighters

4.3 Smoke Dispersion Products

A major application and justification for the FCAMMS is providing intelligence for managing smoke from forest burning. Smoke management has strategic planning, tactical planning and operational aspects to it.

4.3.1 Strategic planning

Strategic planning applications are needed to assess wildfire and prescribed fire impacts on regional and local air quality. The Clean Air Act requires States and Tribes to maintain the National Ambient Air Quality Standards (NAAQS) for a set of "criteria pollutants" that include NOx, CO, Ozone and PM. There are additional regulatory requirements for States and Tribes to return visibility to its 'natural condition' at 153 'Class 1' areas (National Parks and wilderness areas) through out the US. Both of these requirements involve States and Tribes developing and promulgating so called State (Tribal) Implementation Plans, or S/TIPs.

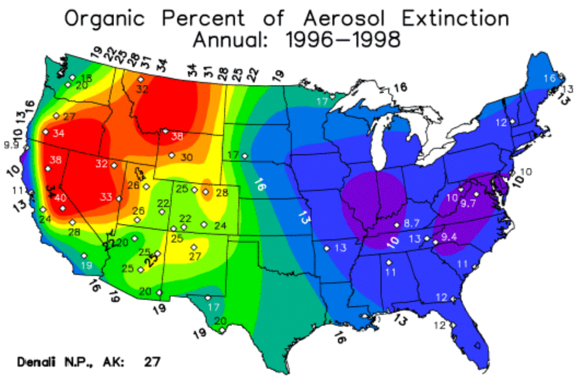

Figure 7. Aerosol data showing the percentage contribution to visibility impairment of organic aerosol illustrating that fire sources may be a significant influence on western US visibility.
http://vista.colostate.edu/views

Figure 7, shows data from the IMPROVE monitoring network that suggests significant visibility impairment may be attributed to organic air pollution sources in the western, especially the northwestern, U.S. While it is understood that smoke from wildfire is a natural condition, it is also clear that the fire management community, at the very least, must quantify pollutant inputs to the air shed resulting from wildfire, prescribed fire and agricultural burning. The S/TIP process is one that increasingly requires the use of sophisticated, multiple-pollutant, atmospheric chemistry simulation models, such as CMAQ and REMSAD. For the land management community to play a significant role in developing the S/TIPs and in the negotiation of emissions limitations that is their ultimate purpose, FCAMMS will need to include regional air quality modeling in their activities. To date, this remains an area that will be considered in the future. However, a significant advantage of the collaboration that is inherent in the FCAMMS is that regional air quality modelers will be welcome as partners and will find much of the data and computational resources they require available through the FCAMMS.

A critical need from the fire management community for both the strategic planning discussed here and the tactical planning and operations discussed in the next section is quantification of fire activity and the associated emissions that result from that fire activity. (Battye and Battye, 2002; Sestak, et. al., 2002).

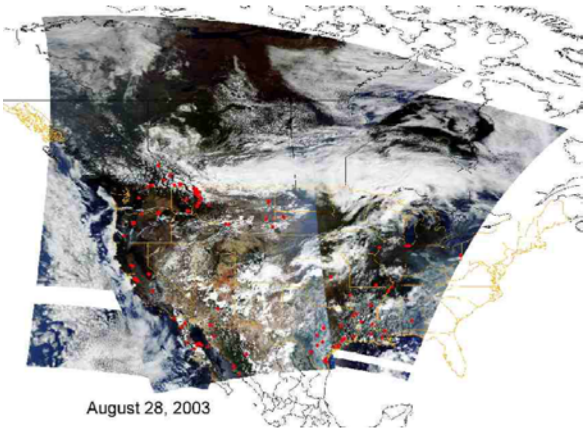

Figure 8. A MODIS image of the western United States taken on 28 August illustrating hot spots. Details at http://www.firelab.org/rsl/.

Although not strictly an FCAMMS, nevertheless a very closely associated activity is the research being conducted at the USDA Forest Service Missoula Fire Laboratory on utilizing the MODIS instrument on the TERRA and AQUA satellite platforms to identify fire boundaries and emissions. Figure 8 illustrates a recent scene from the new fire boundary algorithm developed by Dr. WeiMin Hao and his team of researchers.

4.3.2 Tactical Planning & Operations

Tactical planning and operational applications, both a need a smoke management tool that provides an indication of where smoke is likely to go once a fire is ignited allowing real-time forecasts of smoke impacts from individual and groups of potential and actual fires. For this purpose the FCAMMS are in the process of implementing the **BlueSky modeling framework.** The BlueSky smoke-modeling framework, developed by Dr. Sue Ferguson and her team of scientists at the FS Seattle fire laboratory, is a flexible framework for obtaining smoke impacts by combining fire location information, forest fuels, outputs from MM5 meteorological simulations and air quality dispersion models (e.g., the CALPUFF) to illustrate where smoke will go and how much of it will get there. The NWRMC is cooperating with the U.S. EPA to prototype the BlueSky/RAINS program. BlueSky/RAINS links the BlueSky smoke-modeling framework with the Rapid Access INformation System (RAINS) based web serving technology. RAINS utilizes the ArcIMS / geographic information system (GIS) to allow for data overlays from a variety of geographical data. BlueSky/RAINS is currently being tested in the U.S. Pacific Northwest. Figure 9 illustrates some of the capability of the BlueSky/RAINS system to provide information about the likely trajectories and ground level concentration impacts from prescribed fire activity. The GIS provides great flexibility displaying the results.

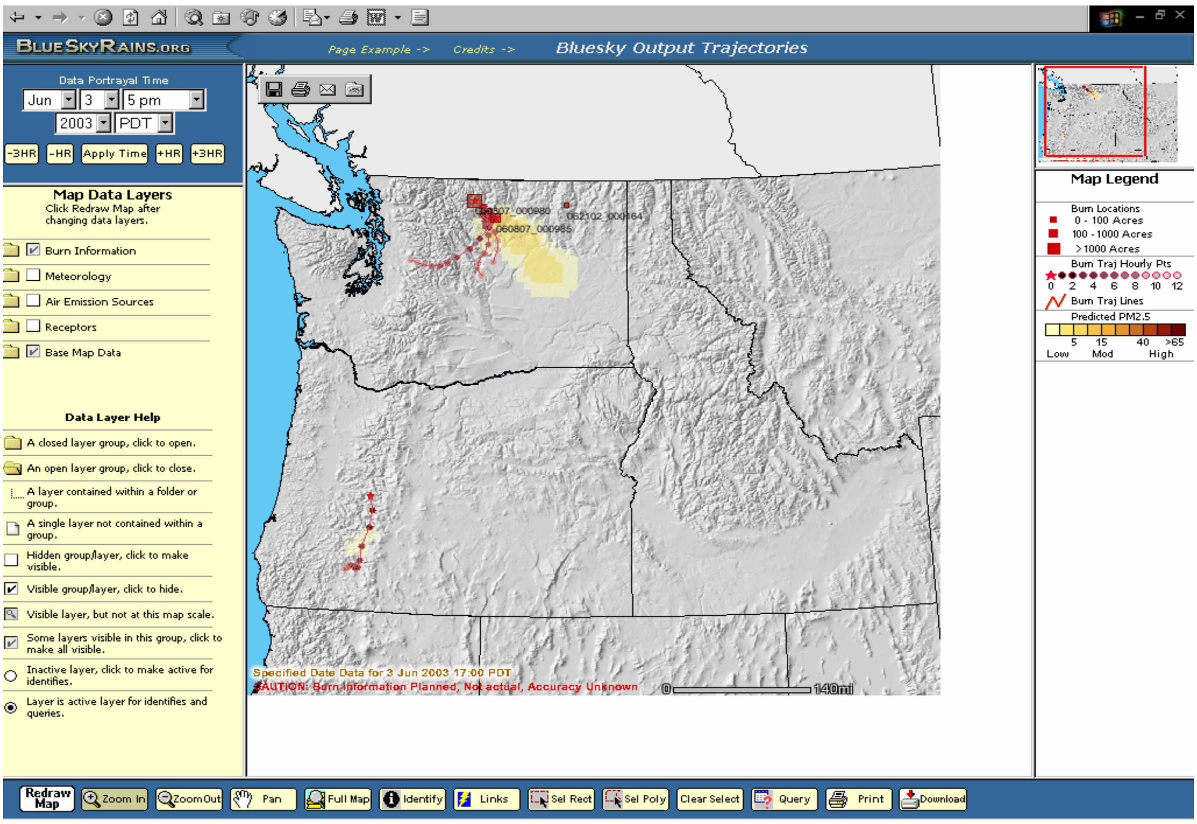

Figure 9. Wildfire smoke trajectories and concentrations as illustrated by the BlueSky/RAINS (NWRMC) system for prescribed fire activity on June3, 2003.

5. CONCLUSIONS AND NEXT STEPS

Continuing issues associated with the FCAMMS include solidifying each consortium including its participants (through formal agreements), funding, and projects. FCAMMS must also be provided a national overlay to the regional activities of each consortium. Each consortium has grown naturally, based on the interests and capabilities of the scientists and managers involved in its development. While this spirit will continue, there remains a need for nationally common products.

The BlueSky framework represents a significant step forward in dealing with smoke emissions, and the FCAMMS plan to implement it in each consortium. However, there are challenges in doing this. One is a concern for how to provide data on fire locations and fire emissions for the system nationally. Secondly, there is a need to add additional dispersion modeling capabilities to the BlueSky framework, to broaden its applicability for strategic planning. For example, applications, such as Clean Air Act required state implementation plans (SIPs), require a specialized inventory of fire data including the date, duration, and location of all major wild and planned fires along with an accurate estimate of emissions and plume rise from such fires. SIPs also require hourly estimates of emissions for a “typical” year, detailed chemical characterization of the emissions for the purpose of driving regional air chemistry models and an ability to “game” the emissions for future years. “Gaming” might include tradeoffs between prescribed and wildfire, as well as alternative locations for fire and the potential for drought and major fire activity. Tactical planning might require more accurate, precise, and detailed information about the location and nature of the planned burning. Operational activities will need real-time information, not simply what is planned but what has actually been ignited, for which ground-observations, aircraft over-flight information, and remote sensing will need to be intelligently combined with mesoscale meteorology and dispersion model simulations.

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