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Smoke Science Plan: The Path Forward

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Wildland fire managers face increasingly steep challenges to meet air quality standards while planning prescribed fire and its inevitable smoke emissions. The goals of sound fire management practices, including fuel load reduction through prescribed burning, are often challenged by the need to minimize smoke impacts on communities. Wildfires, of course, also produce smoke, so managers must constantly weigh the benefits and risks of controlled burns and their generated emissions against potential wildfires and their generated emissions and must communicate those benefits and risks to the public. Moreover, research on and the modeling of smoke emissions from fire is a rapidly evolving field and often lies at the cutting edge of atmospheric sciences. The Joint Fire Science Program (JFSP) has supported research related to smoke management since its inception, but a recent analysis of past research and future needs suggests that better coordination of smoke science research could further advance the field and lead to development of better tools for managers. Smoke management and air quality have been identified as top priority areas of research for the JFSP, which has outlined a detailed path forward. The "Joint Fire Science Program Smoke Science Plan" presents a focused and integrated research agenda that is responsive to the needs of land resource managers and air quality regulators.


Ken Forbus, USFS

Smoke and haze created from an aerial ignition prescribed fire at Eglin Air Force Base, Florida.

Smoke Line of Work

In recent years, the Joint Fire Science Program (JFSP) has addressed research needs in a more focused and efficient manner, using the "line of work" concept, outlined by the JFSP Governing Board in the "Joint Fire Science Program Science Delivery and Application Strategy, 2007 through 2010." The goal of using the line of work concept is for scientists and managers to collaborate in assessing high-priority research needs, creating a framework to guide investments in a cohesive manner during a 3- to 5-year period, and suggesting a future research agenda for an even longer timeframe, up to 10 years.

By defining broad issues of national concern, the line of work approach ensures that important areas of research supported by the JFSP fit under a larger umbrella of coordinated projects. Three lines of work have been identified by the JFSP Governing Board: the Interagency Fuels Treatment Decision Support System (see "Fire Science Digest," Issue 7, December 2009), fuel treatment effects and effectiveness, and smoke management and air quality. The "Joint Fire Science Program Smoke Science Plan" (JFSP Project No. 10-C-01-01), which addresses the smoke management and air quality line of work, was published in 2010 after 4 years of careful consideration of past research, input from wildland fire and air quality mangers, and projections of future needs based on an evolving regulatory environment.

With increasing regulatory pressure and threats to public health and safety, a majority of respondents agreed that smoke is a significant concern for natural resource managers and that more should be invested in smoke science research.

The first step in framing smoke research needs and issues was taken in June 2007, when smoke management and air quality roundtables were convened in Arlington, Virginia, and Seattle, Washington. The mission: to conduct a needs assessment of wildland fire smoke research at national and regional levels. The roundtables addressed the need to balance sound fire management practices in an ever-changing regulatory environment, and to identify high-priority research needed in smoke emissions science and management. Invited participants included incident commanders, prescribed fire practitioners, representatives from state regulatory agencies, and nonprofit organizations interested in fire and air quality. The workshops were successful in defining managers' needs, and a followup assessment of the roundtables identified several topic areas that the JFSP could invest in immediately.

The initial assessment also recognized that addressing some of the larger research needs identified by the roundtables would require a master study plan that included logical steps and dependencies among the steps. To develop a focused and detailed plan, a more thorough analysis was needed. To that end, the JFSP called on the expertise of Allen Riebau and Doug Fox with Nine Points South Technical Pty. Ltd., an environmental consulting and technical solutions company with extensive experience in smoke management and air quality research. The first order of business was to place smoke needs assessment into a historical and regulatory context. In the first phase, the team conducted a thorough literature review, analyzed information from the roundtables and the roundtables' initial assessment, collected data from other research assessments, interviewed fire management professionals and scientists, and created an overview of air quality regulations as they relate to smoke management.

The second phase involved a review of current national and international wildland smoke studies and a series of web-based questionnaires that reached a broader audience of researchers and wildland fire management experts than was possible in the roundtable workshops. The original, brief questionnaire was sent via email to 150 people in the smoke research and management community, in large part fire managers from the U.S. Forest Service (USFS) and agencies within the U.S. Department of the Interior. The respondents were encouraged to pass the survey to colleagues, and eventually 554 people replied. The questionnaire was followed up with personal phone calls and in-person interviews with a subset of the respondents.

"Questionnaire respondents generally agreed that smoke factors are important now and will become more important in the next decade," the authors note in a report published in the USFS's "Fire Management Today" (Riebau and Fox 2010). With increasing regulatory pressure and threats to public health and safety, a majority of respondents agreed that smoke is a significant concern for natural resource managers and that more should be invested in smoke science research.

Using the background information and the original survey and interview results, Riebau and Fox identified four themes to frame the research agenda: smoke emissions inventory research, fire and smoke model validation, smoke and populations, and climate change and smoke. "We believe that the themes are on target with the direction other agencies, including the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration, have been considering for future research investments," says Riebau.

The team then developed and sent out followup, comprehensive questionnaires focusing on each of the four priority themes. These questionnaires also sparked an impressive grassroots response, as survey participants passed them to their colleagues. In all, more than 1,000 people from the fire management and smoke research community responded. According to the report on the questionnaires, this was probably the "largest and most representative response to a wildland fire smoke research needs assessment to date." In fact, air quality and land resource managers in the European Union and Australia have expressed interest in adapting the questionnaire to help guide their own research agenda.

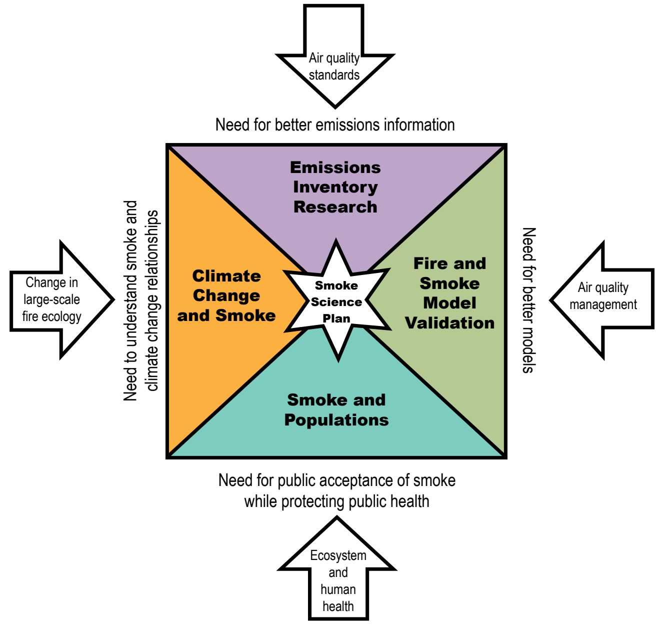
Plan the Work, Work the Plan

The Smoke Science Plan proposes a long-term incremental path forward with an explicit, detailed research focus for each of the four themes through 2015 and a less detailed outline through 2019. "The Smoke Science Plan doesn't attempt to be all things to all people," says Riebau. "Its purpose is to develop for the JSFP a portfolio of research logically tied together that, on a financial and intellectual scale, will fit with the other parts of the JFSP research agenda."

The objectives of the four themes, as outlined in the Smoke Science Plan, are to create:

- A smoke emissions inventory research program to develop new science and knowledge that will support and define an accurate national wildland fire emissions inventory system;

- A fire and smoke model validation program to develop the scientific scope, techniques, and partnerships needed to validate smoke and fire models objectively using field data;



The Smoke Science Plan unites four themes, each of them addressing a need, and each need resulting from a large "driver" that has historically impacted and will continue to impact wildland fire management in the United States.

- A smoke and human populations program to develop the science to objectively quantify the impact of wildland fire smoke on populations and firefighters, elucidate the mechanisms of public smoke acceptance, and increase understanding of the balance between ecosystem health and acceptable smoke exposure risks; and

- A climate change and smoke research program to gain understanding of the implications of wildland fire smoke to and from climate change using the newest climate scenarios from the United Nations Intergovernmental Panel on Climate Change (IPCC) as guidance.

As part of the literature review for the Smoke Science Plan, nearly 40 current or recently completed JFSP projects were identified that fit within the four thematic categories. Future lines of research will build on and expand work that is already underway. Research conducted under these four themes will lead to advances in smoke science and help managers deal with the current and future challenges of smoke management.

Smoke Emissions Inventory Research

Air quality managers and regulators need reliable information on the spatial and temporal distribution of smoke emissions for effective decisionmaking, yet accurate emissions data are not consistently available. While fire occurrence is tracked on a national level, information needed to estimate emissions, such as fire size and location, amount of fuel consumed, and rate of heat release, is often not tracked or is not sufficiently accurate. In addition, calculations of emissions from fire are often not realistic, partly because of our limited understanding of things like emissions factors and fuel consumption in different environments.

"The smoke and emissions inventory theme is extremely important," says Scott Goodrick, atmospheric science team leader with the Center for Forest Disturbance Science in Athens, Georgia, which is part of the USFS Southern Research Station. The current standard used by the EPA is the National Emissions Inventory (NEI) of criteria pollutant emissions from point, nonpoint, and mobile sources. Criteria pollutants have the potential to harm human health and contribute to regional haze and visibility impairment in sensitive wilderness areas and national parks. They include carbon monoxide, nitrogen oxides, sulfur dioxide, ozone, and particulate matter ($PM_{2.5}$ and PM_{10}). The NEI estimates emissions using data provided by state, local, and tribal agencies, but there are uncertainties in the methods of estimation and inconsistencies in how the data is collected. "The NEI is used to set policy, but the smoke emissions inventory is also where some of the biggest uncertainties lie," Goodrick says.

A lot of uncertainty comes from the fact that smoke emissions are not all created equal. Different fires seem to produce different types of emissions and perhaps different quantities for the same area burned, but more understanding of what causes these differences is needed. A prescribed fire in Georgia conducted in January 2007, for example, contributed to a spike in both ozone and $PM_{2.5}$ in Atlanta, but later that same year, big wildfires in the Okefenokee Swamp contributed to exceedances of $PM_{2.5}$ but not of ozone. "We don't know if it was the vegetation type, the growing season, increased moisture content, plume rise and in-plume chemistry, or other factors," Goodrick says. "These are definite unknowns."

The Smoke Science Plan outlines research priorities to support improved emissions inventory, including better understanding of plume dynamics and chemistry, emissions factors of traditional "criteria" pollutants and nontraditional precursors to criteria pollutants (e.g., secondary organic aerosols), fuel consumption, and fine-scale meteorology. In addition, the Smoke Science Plan calls for development of better tools, including new research to guide improvements in remote sensing of wildfires to identify fire size, and increased use of on-the-ground data to ensure quality control of information obtained via remote sensing. An accurate account of smoke emissions and improved emissions inventory science will bolster efforts of fire managers and land management agencies to comply with air quality standards, particularly when planning prescribed burns.

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Fire and Smoke Model Validation

Where smoke is going and how much of it will get there is very difficult to predict. Average patterns can be estimated with some success, but there are always odd bits and amounts that go where they are not expected. When the unexpected happens, particularly in or near densely populated areas, the consequences can be serious. In February 2007, for example, smoke from two routine prescribed fires conducted near the Chattahoochee-Oconee National Forest and the Piedmont National Wildlife Refuge in Georgia unexpectedly drifted about 80 miles north to Atlanta, contributing to $PM_{2.5}$ concentrations that exceeded air quality standards.

In planning the burn, the team used the model VSmoke, a smoke dispersion model used by the USFS for prescribed fires in the Southeast. VSmoke provides emissions impacts at varying distances downwind from the burn unit, under given fuel consumption and meteorological conditions. "VSmoke is a model that produces quite good results in many cases," says Goodrick. However, VSmoke models one burn unit at a time and assumes that wind direction is fairly constant throughout the burn. In this case, the winds changed during the day of the burn, and the two plumes merged together. "Conditions changed so the modeling results were no longer applicable. More advanced modeling showed the smoke going right to

Atlanta, but at the time, the newer models were not standard practice."

VSmoke does not incorporate information on the vertical distribution of the smoke or vertical wind shear, two factors that are key to predicting long-distance transport of smoke. It also does not account for changes in wind conditions during a burn or for smoke traveling over complex terrain. Researchers are constantly updating models and developing new models to account for factors like these, but much more work is needed on model improvement and validation.

A vision in the Smoke Science Plan includes developing a research plan for cooperative field trials of fire behavior and smoke dispersion to validate smoke models. Evaluating the performance of smoke models in real conditions will require collaboration among multiple parties. Thus, the Smoke Science Plan proposes several interagency workshops on fire and smoke model evaluation. The ultimate objective is to identify the best, state-of-the-art fire emissions, fire plume, and smoke chemistry and dispersion models through testing against real data collected in the field.

"Our hope with the smoke modeling thematic component of the Smoke Science Plan is to coordinate fire and smoke model evaluation across science agencies and institutions to achieve the best possible information on models and their actual performance, compared to observations," says Riebau. "Managers say they don't know how well the models work, particularly under complex conditions. That is why we need a very focused effort to understand the phenomena and gather the observation data to test the models, evaluate them, and have a solid foundation to build better ones."

The JFSP has long been supporting research in this arena and has made it a greater priority since the 2007 roundtables. For example, one recently completed study was aimed at evaluating and improving Daysmoke, a smoke plume rise model (JFSP Project No. 08-1-6-06). Plume height is an important factor in estimating long-range transport of smoke and is needed for running regional air quality models, such as the EPA Community Multiscale Air Quality Modeling System (CMAQ). The researchers improved Daysmoke predictions by incorporating additional key

Yongquiang Liu

Particulate matter can be monitored in the field to validate smoke models.

variables. When the improved Daysmoke model was incorporated into CMAQ, it produced more accurate predictions when compared to field observations.

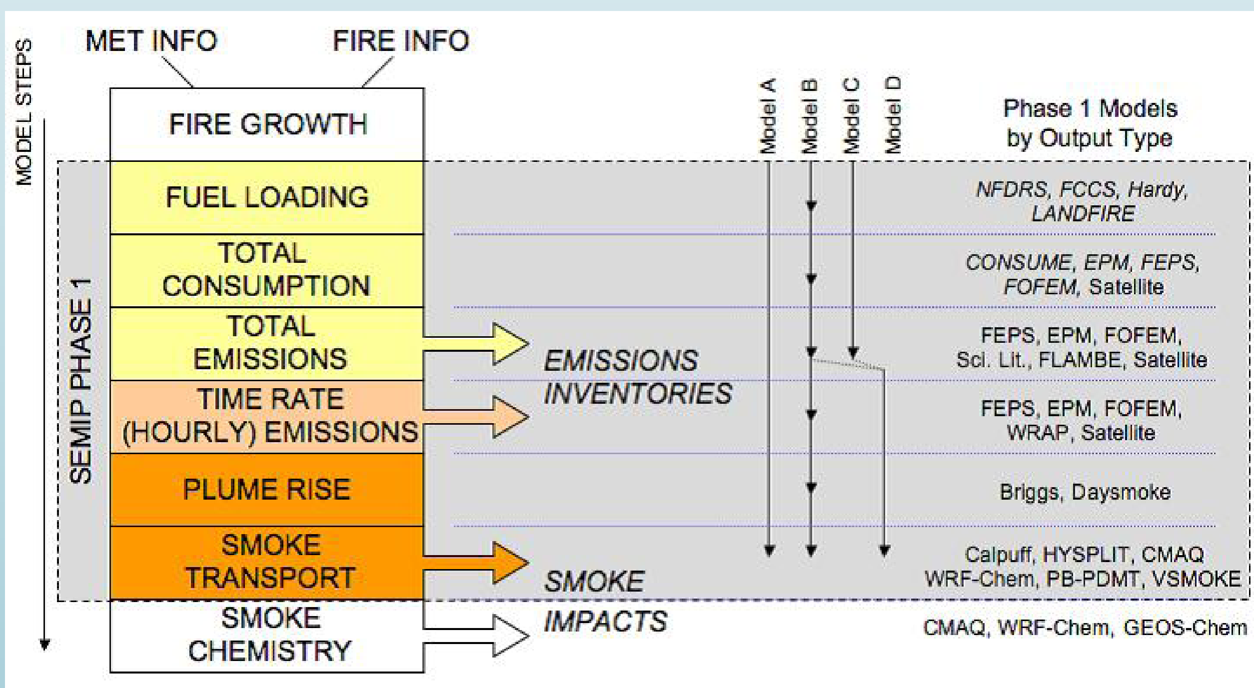
While models are improving in terms of their predictive capacity, they are not always easy to use. “A common complaint is that there are too many tools, they aren’t cohesive, and they are complicated,” says Narasimhan (Sim) K. Larkin, a research physical climatologist with the USFS AirFire Team at the Pacific Northwest Research Station. Research efforts

Smoke and Emissions Model Intercomparison Project

Predicting smoke impacts from wildland fire requires linking output from models that address fuel loading, fuel consumption, smoke emissions, plume rise, and dispersion. For each of those steps, several models are currently available, and the choice of model at each step can have substantial effects on the overall prediction for smoke impacts. Managers have little guidance on what models are most appropriate for any given set of circumstances. In 2008, the JFSP requested research proposals to address the lack of information on accuracy and limitations of available smoke and emissions models.

Sim Larkin with the USFS AirFire Team is leading an effort to create a Smoke and Emissions Model Intercomparison Project (SEMIP), with the primary objective of evaluating current models and datasets used to understand fire information, fuel loadings, consumption of fuels, emissions, and smoke plume rise and dispersion (JFSP Project No. 08-1-6-10). SEMIP is intended to meet the need for a rigorous quantitative assessment of existing smoke and emissions models and to transfer the information to the land management and air quality communities. Project collaborators are conducting model-to-model comparisons of 22 component models, comparing these with observations, and developing performance assessments. SEMIP also includes an assessment of the limitations of existing smoke and emissions models. “These findings will be used to create user guidance through instructions, interactive websites, and training sessions,” says Larkin.

“SEMIP is an effort to look at uncertainties in emissions inventories throughout the entire modeling chain and examine how different models perform and interact in that chain,” says Larkin. To do this, project members are evaluating how the combinations of various models interact using different fire detection systems, fuel loadings, and consumption models to assess emissions and smoke dispersion results. SEMIP also evaluates the differences between the fire detection systems, fuel loadings, and consumption models to quantify the range of results expected by choosing one system or model over another. In addition, SEMIP evaluates how the combinations of models perform in real-world scenarios by using observation data collected near and around prescribed fires and wildfires. See www.semip.org for more information on the project.



Steps and models used to assess smoke impacts from wildland fire. Larkin et al. 2008. Creation of a Smoke and Emissions Model Intercomparison Project (SEMIP) and Evaluation of Current Models. JFSP Project No. 08-1-6-10.

to improve and simplify the models are already underway on several fronts. For example, a JFSP-funded project resulted in the conversion of the BlueSky modeling framework into a collaborative web service architecture and created a smoke modeling application (JFSP Project No. 08-S-07). BlueSky, which was developed by the USFS AirFire Team, links a variety of independent models, including fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion, allowing users to model emissions and smoke dispersion using one interface.

Smoke and Populations

Fire managers recognize that meeting air quality standards is important, as the standards were designed to protect human health and welfare. Balancing air quality protection and the use of fire to maintain fire-adapted ecosystems has always been challenging. With the ever-expanding wildland-urban interface and the pressure to apply more prescribed fire, this balancing act promises to become even more difficult in the future.

Prescribed fires rarely lead to violations of air quality standards, but the public can still get upset when smoke from a prescribed fire enters their community. Anecdotally, managers have noticed that people react differently to smoke in different regions of the country. In much of the rural Southeast for example, residents seem to accept certain levels of smoke in the air, as they are accustomed to a tradition of agricultural use of fire, such as pasture burning to increase browse for livestock or the burning off of dead crops like sugar cane.

Currently, there is very little understanding of the levels of smoke that are acceptable to the public in other regions or what factors influence the public's acceptance of smoke. The Smoke Science Plan aims to bring clarity to these issues by quantifying the impacts of wildland fire smoke on human health. Ultimately, this will help managers maintain fire-adapted ecosystem health while at the same time limiting the public's exposure to smoke. Additional information will also aid in communicating with the public.

Smoke from the Station Fire above Los Angeles in September 2009. (http://www.epa.gov/region9/annualreport/10/epa-progress-report-2010.pdf)

"Good faith and communication on the issue has usually resulted in both objectives of clean air and healthy ecosystems being achieved," note the authors of the Smoke Science Plan. They are confident that these objectives can be met in the future if the benefits and risks of prescribed fire and risks of smoke from wildfire can be effectively communicated to the public and if managers are diligent in applying appropriate smoke management tools and techniques.

Climate Change and Smoke

The IPCC, in its Fourth Assessment Report "Climate Change 2007," underscored the growing scientific consensus that "warming of the climate system is unequivocal." The IPCC has developed potential climate scenarios that have been widely used by the ecological community to assess the consequences of changing climate on ecosystems. The Smoke Science Plan supports efforts aimed at harmonizing JFSP-funded research with the global climate change community by also using IPCC-generated climate scenarios. With this approach, "the JFSP will fund work to develop likely fire climate scenarios that will form the backdrop for researchers to move forward with their smoke research programs," says Riebau.

The Smoke Science Plan encourages research on potential regional smoke loading assessments under projected future climate scenarios in different regions of the country. The Smoke Science Plan also calls for an assessment of the contribution of prescribed fire and wildfire to greenhouse gas emissions. Such efforts should provide vital information to policymakers charged with revising air quality regulations to deal with climate change.

There is also growing concern about black carbon emissions in the Northern Hemisphere, which occur as a result of open biomass burning and diesel exhaust emissions from mobile and stationary sources. "Smoke emissions from fire are a major source of black carbon," says Larkin.

Fires burning in ecosystems with deep organic soils can smolder for weeks and produce significant amounts of black carbon. JFSP Project No. 08-1-3-03 final report.

In some seasons, black carbon from certain fires in more northern latitudes can actually reach the Arctic. When it does, it can change the color of the ice and snow, producing a feedback that causes the snow to melt faster. This is a particular concern, as the pace of warming in the Arctic has been much faster than the rest of the globe. "We have been working closely with our EPA partners," says Larkin. "One of our goals is to determine where and when smoke emissions from fire might contribute to the transport of black carbon; we are working to get useful information into the hands of the EPA as they go through their decision process of evaluating and potentially regulating black carbon emissions from fire."

The JFSP is following the recommendations of the Smoke Science Plan by supporting three projects that deal with production of black carbon from wildland fire. Researchers are measuring black carbon emissions from fires burning in organic peat soils. Fires in these systems are a particular concern because the smoldering combustion typical in these types of fires tends to produce more black carbon. In addition, in a modeling study, researchers are seeking to understand the contribution of wildfires and prescribed fires to black carbon emissions across the United States and to project changes to these emissions in the future.

Future Trends

In 2006, the EPA strengthened the air quality standards for particle pollution, and stricter standards for ozone were implemented in 2008. Currently (2012), the particulate matter standards are being reviewed, and further tightening is anticipated. These trends, caused by improved scientific understanding about human health effects, have raised some concern that the levels will be so strict that states will need to adopt significant smoke emission restrictions in state implementation plans in order to meet the standards. According to the Smoke Science Plan, "a major concern is that the new standard is so close to ambient levels that the likelihood of stringent control of in-state sources may not be sufficient to reach attainment." Thus, the new standards may make it "extremely difficult for wildland fire managers to maintain their mission requirements [in land management] and comply with air quality regulatory requirements."

"From my perspective, none of the air quality regulation changes are done in a hasty way," says Riebau. "The process is long with much opportunity for public comment, and it is informed by the result of research and understanding of the best science the EPA can get its hands on. The EPA has done a lot of listening to experts on considerations of health and public welfare. The historic relationship between fire and smoke emissions managers and the air quality community has not been one of conflict but one of partnership."

Regardless of future changes in regulations, with expanding wildland-urban interface and climate change, the challenges of managing smoke emissions from wildland fire are likely to increase. The four themes of the Smoke Science Plan—smoke emissions inventory research, fire and smoke model validation, smoke and populations, and climate change and smoke—are designed to provide the science to build tools that will help managers deal with future challenges. Research conducted under the guidance of the Smoke Science Plan will allow for better smoke emissions inventories to aid cooperative management of smoke across jurisdictions, help managers conform to regulations designed to protect public health and the environment, improve communications with the public concerning smoke emissions, and provide a sounder scientific basis for strategically managing smoke under a changing climate.

Suggested Reading

Joint Fire Science Program. 2007. Joint Fire Science Program Science Delivery and Application Strategy, 2007 through 2010. http://www.firescience.gov/projects/06-S-02/project/06-S-02_final_report.pdf.

The Smoke Management and Air Quality Line of Work: Early Investments

After the initial smoke roundtables, the JFSP quickly began investment in the smoke management research needs that were identified. It took time to develop the full Smoke Science Plan, but certain topics were addressed immediately. Two of those topics included smoke dispersion from low-intensity fires and regional haze.

Low-Intensity Fire

Low-intensity fire produces emissions that do not have a tendency to rise to high levels in the atmosphere. Because the emissions stay relatively low to the ground, they have the potential to result in significant impacts to human health and safety. These emissions can contribute to respiratory problems and impair visibility along roadways. The creation of superfog in the southeastern U.S. is of particular concern.

Superfog is extremely dense fog that results from the addition of moisture to air that is already very humid. The moisture in a smoke plume is one possible source. The combination of the plume's moisture with that of the air can result in a condition referred to as supersaturation, which produces very dense fog that hangs close to the ground and can cause serious reductions in visibility and make driving extremely hazardous. It is a phenomenon that primarily affects the Southeast. "Superfog is a more specific concern in the Southeast because of higher humidity and a denser road network," says Scott Goodrick with the Center for Forest Disturbance Science in Athens, Georgia.

Superfog. (http://www.srs.fs.usda.gov/pubs/su/021/threats.htm)

Research supported by the JFSP is underway to better understand superfog creation by using laboratory simulations of smoke plume behavior under controlled conditions and building on previous research on smoke plumes emitted from cooling towers. Wind tunnel experiments in the laboratory, where variables such as moisture and the composition of various fuels can be manipulated, are being used to create mechanistic models to better understand superfog formation (JFSP Project No. 09-1-04-5).

Regional Haze

Federal regulations mandate that states develop and implement plans to minimize human contributions to regional haze, which is air pollution composed of particles that scatter and absorb light and ultimately limit visibility. Emissions from prescribed fire and wildfire certainly contribute to regional haze, but how much they contribute relative to other sources is not well understood. For example, some research has suggested that secondary organic aerosol (SOA), which is produced photochemically from primary fire emissions, contributes substantially to particulate matter and organic carbon emissions from fire.

The JFSP is investing in basic research on SOA emissions from fire (JFSP Project No. 09-1-03-1). Using experimental fires in laboratory settings and archived filters of smoke collected in experimental settings and burns throughout the country, researchers are determining SOA production as a function of smoke age and fuel type. With this work, they intend to update air quality models and develop easy-to-detect markers for SOA in smoke. Ultimately, this will help determine the contribution of fire emissions to regional haze.

Intergovernmental Panel on Climate Change. 2007. Summary for Policymaker. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY.

Larkin, S., T. Brown, P. Lahm, and T. Zimmerman. 2010. Wildland Fire Decision Support System Air Quality Tools. Fire Management Today 70 (2): 36-40.

Riebau, A.R., and D.G. Fox. 2010. Joint Fire Science Program Smoke Science Plan. JFSP Project No. 10-C-01-01.

Riebau, A.R., and D.G. Fox. 2010. The Results of a Brief Web-Based Questionnaire on Wildland Fire Smoke. Fire Management Today 70 (3): 19-24.

Current Projects under the Smoke Science Plan Umbrella

Emissions Inventory Research

Evaluation of Smoke Models and Sensitivity Analysis for Determining their Emission Related Uncertainties (JFSP Project No. 08-1-6-04).

Evaluation and Improvement of Smoke Plume Rise Modeling (JFSP Project No. 08-1-6-06).

Creation of a Smoke and Emissions Model Intercomparison Project (SEMIP) and Evaluation of Current Models (JFSP Project No. 08-1-6-10).

Experimental Determination of Secondary Organic Aerosol Production from Biomass Combustion (JFSP Project No. 09-1-03-1).

Deterministic and Empirical Assessment of Smoke Contribution to Ozone (DEASCO3) – An Online Technical Resource to Support FLMs in Air Quality Planning (JFSP Project No. 11-1-6-6).

Critical Assessment of Wildland Fire Emissions Inventories: Methodology, Uncertainties, Effectiveness (JFSP Project No. 12-1-07-1).

Fire and Smoke Model Validation

Conversion of BlueSky Framework into Collaborative Web Service Architecture and Creation of Smoke Modeling Application (JFSP Project No. 08-S-07).

Validation of Fuel Consumption Models for Smoke Management Planning in the Eastern Regions of the United States (JFSP Project No. 08-1-6-01).

Airborne and Lidar Experiments for the Validation of Smoke Transport Models (JFSP Project No. 08-1-6-09).

Development of Modeling Tools for Predicting Smoke Dispersion from Low-Intensity Fires (JFSP Project No. 09-1-04-1).

Sub-Canopy Transport and Dispersion of Smoke: A Unique Observation Dataset and Model Evaluation (JFSP Project No. 09-1-04-2).

Superfog Formation: Laboratory Experiments and Model Development (JFSP Project No. 09-1-04-5).

An Investigation of the Differences between Real Time Mesoscale Analysis and Observed Meteorological Conditions at RAWS Stations in the Northeast United States (JFSP Project No. 10-1-07-28).

Forecasting Integrated Lightning and Fuels Ignition Potential in a System with Real-Time Analysis of Fire Weather Prediction Accuracy (JFSP Project No. 10-1-07-29).

Sensitivity Analysis of Air Quality to Meteorological Data in Fire Simulations (JFSP Project No. 12-3-01-6).

Data Sets for Fuels, Fire Behavior, Smoke, and Fire Effects Model Development and Evaluation (JFSP Project No. 11-2-1-11).

Smoke and Populations

Public Perceptions of Smoke: Contrasting Tolerance amongst WUI and Urban Communities in the Interior West and the Southeastern United States (JFSP Project No. 10-1-03-2).

Impacts of Mega-Fires on Large U.S. Urban Area Air Quality Under Changing Climate and Fuels (JFSP Project No. 11-1-7-2).

Future Mega-Fires and Smoke Impacts (JFSP Project No. 11-1-7-4).

Public Perceptions of Smoke and Agency Communication: A Longitudinal Analysis (JFSP Project No. 12-3-01-21).

Climate Change and Smoke

Measuring the Optical Properties and Climate Impacts of Aerosol from Wild and Prescribed Fires in the U.S. (JFSP Project No. 11-1-5-12).

Identification of Necessary Conditions for Arctic Transport of Smoke from U.S. Fires (JFSP Project No. 10-S-02-1).

Modeling Study of the Contribution of Fire Emissions on Black Carbon Concentrations and Deposition Rates (JFSP Project No. 11-1-5-13).

Smoke Consequences of IPCC's Scenarios Projected Climate and Ecosystem Changes in the U.S.: A Review Paper (JFSP Project No. 12-S-01-2).

NASA image courtesy of the MODIS Rapid Response Team, Goddard Space Flight Center

Smoke from southern California wildfires spreads over the Pacific Ocean in October 2007.

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