Joint Fire Science Program

Smoke Science Plan

Final

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Executive Summary

Since the 1970s there have been a number of United States wildland fire smoke research and development needs assessment activities which have successfully provided useful guidance to research and development. However, they have not resulted in a comprehensive government-wide linked research program. Successful efforts have largely been regional with national activities proving difficult to sustain and apply.

In 2007 the Joint Fire Science program (JFSP) conducted a wildland fire smoke needs assessment, hosting two parallel roundtables (in the eastern and western US) in which managers and scientists developed two lists of priorities. The outcome of the roundtables needed to be placed into an historical and regulatory context, considered in light of anticipated future developments and synthesised into a cohesive national smoke science research plan. This project developed that plan to provide the JFSP with guidance for funding smoke research for 2011-2015.

Historically, wildland fire smoke research needs assessments have been controversial. This has arisen for two reasons. Firstly, the issues involved are extremely complex from an air quality regulation perspective, often seemingly close to precipitating a collision between the needs of sound fire management practice and air resources management. Secondly, the scientific issues involved are often at the very cutting edge of atmospheric sciences and in themselves a matter of debate among scientists. These factors make gathering information on people's insights into smoke research needs challenging. The sheer scope and diversity of community interests is also a major influence on these factors

Early in the process of developing the Smoke Science Plan we broke with the traditional approach of holding a series of focus group meetings to gather advice and input. Rather, we chose to address the community of interest through a series of web-based questionnaires. Almost 900 people responded to the questionnaires, which, we believe, is the largest and most diversified set of responses to smoke research needs ever collected in the US.

The resulting plan has four research themes as its foundation:

Smoke Emissions Inventory Research

Fire and Smoke Model Validation

Smoke and Populations

Climate Change and Smoke

Each theme has a clearly defined objective to be achieved within a five-year program of research. Each outlines yearly activities to incrementally move the program of research forward to achieve the thematic goals. These yearly activities are designed to complement research across themes so that synergisms are fostered and perhaps even open the door to serendipitous possibilities. In this way, the Joint Fire Science Program Smoke Science Plan breaks with past smoke research assessments as it creates a program of incremental work to progress towards specific objectives rather than defining science needs in general terms.

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1.0 Introduction

Since the 1970s there have been a number of US wildland fire smoke research and development needs assessment activities which have successfully provided guidance for research and development. However, they have not resulted in a comprehensive government-wide linked research program, Successful efforts have largely been regional, with national activities proving difficult to sustain and apply. In 2007 the Joint Fire Science program (JFSP) conducted a wildland fire smoke needs assessment by hosting two parallel roundtables (in the eastern and the western US) in which managers and scientists developed two lists of priorities. The outcome of the roundtables now needs to be placed into historical and regulatory context, considered in light of anticipated future developments and synthesised into a cohesive national smoke science plan (SSP). The SSP project developed that plan to provide the JFSP with guidance for funding smoke research for 2011-2015.

1.1 Methodology: The Smoke Science Plan (SSP) was developed in three phases. The *first phase* included personal interviews with fire management professionals, a thorough literature search and investigation on past wildland smoke needs assessments as well as a series of web-based questionnaires. This first phase reviewed information gathered during the 2007 JFSP smoke roundtables and data from other sources, including the Riverside International Union of Forestry Research Organizations (IUFRO) meeting in 2006 on smoke research and needs, the recent NOAA Office of the Federal Coordinator for Meteorology (OFCM) Fire Weather Needs Assessment, NOAA Fire Weather Advisory Board deliberations and the National Wildfire Coordination Group (NWCG) Fire Environment Committee. This historical and broad perspective helped to place the SSP in context. As an aid to understanding the results of the needs assessments and the roundtables, a description and timeline of air quality regulations development and other driving factors was matched to the timeline of the completed assessments. In October 2009 the authors interviewed scientists and managers in USDA, USDOI, NASA, EPA, NOAA and selected universities. From all that was learned, three preliminary SSP themes were developed - Emissions Inventory, Smoke Model Validation and Climate Change.

The *second phase* was to review the state of current wildland smoke science, both internal and external to the JFSP. This included reviews of current JFSP and other wildland smoke studies being undertaken in the US and internationally. In this phase we also employed a web-based questionnaire on smoke research needs and the results of the smoke roundtables in which 554 expressed their ideas. The results of this questionnaire led us to add an additional theme to our initial three.

1. **Smoke Emissions Inventory Research**

2. **Fire and Smoke Model Validation**

3. **Smoke and Populations**

4. **Climate Change and Smoke**

Each theme was explored and introduced for comment and advice using a series of four focus web-based questionnaires to which more than 400 people responded. There was very strong support for the chosen themes and they were further refined through the questionnaire responses and telephone interviews. This phase also identified that many people see the need for an explicit linkage between smoke science and fire behaviour research (e.g., Core Fire Science activity work and also work funded by JFSP, Department of Commerce, EPA and others). During this phase all past JFSP smoke-related projects were mapped to the themes and the social drivers behind them.

The *third phase* was to develop a five-year smoke science plan in the form of a series of projects that incrementally move the JFSP towards achieving the objectives (chosen from the information gathered) for each the SSP themes. This provides a defined five-year program of research and an explicit development plan. We also provide in less detail three out-years beyond the five years explicitly mapped, so that the JFSP has a starting point for work under succeeding smoke science planning.

Because this level of specificity in research planning could raise concerns for some who have invested much thought and effort in their smoke work, a draft of Section 4.0 of the plan was sent to selected scientists and science managers for review. As a result of their input, the plan was refined and the theme objectives were further considered with researchers though telephone, emails and personal visits before the final Smoke Science Plan was completed.

During the course of plan development, an article on the SSP web-based survey results was published in *Fire Management Today* and a paper was presented in Perth, Scotland on smoke issues identified in one of the themes. Two additional papers are planned for follow-up on the Smoke Science Plan (both are in production at the time of writing: the first paper describes past smoke research needs assessments in the US, how such assessments are linked to air quality laws and what significant advancements resulted from these needs assessments; the second paper describes the complete results of all the web-based questionnaires). Additionally, the JFSP Smoke Science Plan is being coordinated and presented to researchers and air quality managers in the European Union and Australia through web-based questionnaires and needs assessments meetings are being conducted extramurally by the authors.

2.0 Wildland Fire Smoke and Air Quality Regulations

2.1 Background: Wildland fire smoke has been an issue of concern since pre-industrial times. However, before the 1952 British Clean Air Act, air pollution of any sort was not generally recognised by governments as something to be managed. Fire smoke as an air pollutant was understood historically by Europeans (and others) as either an unavoidable consequence of nature or the result of necessary human actions. Humans on every continent have carried out burning with its resulting smoke. In Australia, for example, burning of vegetation by the Aboriginal people is postulated by some to have deforested most of the continental interior, changed vegetative structure across the entire country and resulted in the extinction of Australian megafauna. Fire is a natural part of ecosystems, but one may have to conclude that there are no entirely “untouched” ecosystems left on Earth and the Antropocene (the geologic age dominated by human actions) has truly begun and the Holocene ended.

It is a fact that air pollution standards for specific air pollutants are applied to wildland fire, most especially prescribed fire. Although fire is a natural part of ecosystems, smoke is an air pollutant under at least some aspects of air quality law (see Appendix C). This situation will not change, nor should it. Air quality standards are based on levels of exposure to a specific air contaminant that will harm health or welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. Balancing air quality risks against actions necessary for ecosystem management has never been easy. However, good faith and communication on the issue have usually resulted in both objectives of clean air and healthy ecosystems being achieved.

2.2 Smoke and Air Quality Regulations Prior to 1977: Before 1972, wildland fire smoke was generally seen not so much as an air quality management issue, but more an issue of public nuisance. However, concerns about air quality had been growing in the US. In 1969 the National Environmental Policy Act (NEPA) was passed and established the Environmental Protection Agency (EPA). In 1970 the Clean Air Act (CAA) was passed and EPA was charged with the enforcement of the provisions of the CAA. Of the many provisions of the CAA, two had direct implications for smoke. The first was the directive for states to develop air quality management bureaus; such state agencies were required to demonstrate a determined level of competency if the federal EPA was not to take primacy for air quality management within the state. The second provision was that states must monitor and maintain national ambient air quality standards (NAAQS). Among these standards is one for total suspended particulates (TSP). States were required to monitor TSP levels and control sources of TSP. Wildland fires were identified as a source of TSP, and began to come under state scrutiny. In 1976, the Forrest Service Southern Station published the first guidance specifically addressing how to manage smoke from prescribed fires, *The Southern Smoke Management Guidebook*. This was most likely the first guidance on smoke and air quality within the federal land management agencies.

2.3 Smoke and Air Quality Regulations 1977-1997: In 1977 the Clean Air Act was amended in a way that significantly increased the responsibility of federal land managers for air quality management. The Act established so-called Class I areas, federally managed lands such as national parks and wilderness areas, where better than NAAQS air quality was to be maintained and where visibility was also to be protected. Visibility protection attracted considerable attention from fire managers, who emphasized the naturalness of smoke and the fine particulates within smoke, while air quality managers began establishing monitoring for fine particulates to protect visibility. During this period smoke management programs began to be formalized. Initially, smoke management was addressed in the Pacific Northwest in order to minimize visibility and pollution impacts from slash and harvest residue burning in cities such as Portland, Oregon. Oregon and Washington were among the first states to formalize smoke management. In the Southeast, as well, smoke from prescribed burning created significant highway visibility impacts, occasionally closing interstate highways and, when combined with fog, disrupting transportation. Florida established one of the most sophisticated permitted-burning programs to deal with smoke and pollution.

During this period the Interagency Monitoring of Protected Visual Environments (IMPROVE) network of speciated fine particulate monitoring began. It established monitoring in national parks and wilderness locations around the country and has become the primary source for information on air quality and visibility in these areas. Another growing concern at this time was that the nation's forests were being subjected to acid deposition caused by atmospheric sulphates and nitrates transported from urban and industrial regions.

EPA allowed wildfires and prescribed fires to be dealt with on a case-by-case basis through its “exceptional event” policy and a closely related PM policy for "natural events" that specifically was designed for wildland fire, volcanic eruptions, and high wind episodes. An “exceptional event” is defined as “an event that affects air quality but is not reasonably controllable or preventable; is an event caused by human activity that is unlikely to recur at a particular location or is a natural event” and is determined as an "exceptional event" by EPA through a process established in regulations. States successfully used this policy to eliminate episodes of high particulate caused by wildfire from the state’s air quality database. However, visibility continued to be a concern as did the effects of fire on fine particulates, especially when EPA revised the NAAQS to include PM_{10} (particles less than 10 micrometers in diameter) in 1987 and to an even greater extent again in 1997 when EPA promulgated NAAQS for $PM_{2.5}$ (particles less than 2.5 micrometers).

There was much concern and debate among fire managers as to how air quality regulations would impact prescribed fire programs. In 1985 the National Wildfire Coordinating Group (NWCG) Prescribed Fire and Fire Effects Working Team produced the *Prescribed Fire Smoke Management Guide*. This proved to be very useful. In 1978, a national workshop on fire effects provided the impetus for a series of reports on the effects of wildland fire on ecosystems, including one on the effects of fire on air. The interagency National Wildfire Coordinating Group asked Forest Service research leaders to update and revise the series in 1993 and the revised report on air has proven useful to educate and demystify smoke and air quality concerns (see:http://depts.washington.edu/nwfire/project.php?projectID=358&microweb=0).

2.4 Smoke and Air Quality Regulations 1997-2010: The 1990 amendments to the Clean Air Act reinforced the national goal for improving visibility (which later came to be formalized as the Regional Haze Program) as well as continuing all the Class I area air quality programs. It also addressed acid deposition by generating a cap-and-trade program to reduce SO_2 and NOX emissions from industrial facilities, especially in the eastern US.

In 1998 EPA published the Interim Air Quality Policy on Wildland and Prescribed Fires report, which was designed “…to provide incentives to states and tribes to adopt and implement programs to minimize the public health and environmental impacts of smoke from fires that are managed to benefit resources or the environment, while providing the flexibility to tailor these programs to meet unique state and tribal needs”. This policy directly addressed the conflicts between the need for fire, especially in locations that had experienced too many years of fire suppression, and its impacts on air quality. The interim policy also addressed the new (at the time) $PM_{2.5}$ standards and Regional Haze program. It recommended and encouraged their adoption through wide development and utilization of Smoke Management Plans as well as regulatory incentives that were difficult to ignore. EPA is currently in the process of revising the 1998 Interim Policy to be consistent with current air quality regulations, including the Exceptional Events Rule and changes to the PM2.5 and Ozone NAAQS. The revised policy will also be expanded to address agricultural burning and will provide guidance on smoke management programs. It is anticipated the revised policy will be released for public review in 2011.

The Regional Haze program was formally adapted in 1999 and specifically required that states and tribes develop and utilize smoke management programs to minimize the impacts of smoke on air quality. Further, the RHR program requires states and tribes to develop SIPs that create emission reduction programs for the major contributing sources to impaired visibility. These SIPs are only currently being completed.. However, they have already generated a large volume of regional air quality data, data analysis, regional air quality modelling and modelling results analysis. For the most part, fire has been recognized as a significant contributor to impaired visibility and smoke management programs are being implemented as a result. The Technical Support System, TSS, developed by the Western Regional Air Partnership (WRAP) is the best source for information about the status of all these analyses, especially in the western US (see: http://vista.cira.colostate.edu/TSS/). It is important to note only the WRAP (in western US) attributed prescribed fire as a significant contributor...hence enhanced smoke management programs are only being developed in the west. The other 4 Regional Planning Organizations addressing Regional Haze did not find prescribed fire a significant contributor to Regional Haze.

2.5 Smoke and Air Quality Regulations 2010-2020: There is continuing uncertainty for smoke managers. It is certain that National Ambient Air Quality Standards for ozone will be significantly reduced and a new secondary standard for ozone developed. The fine particulate 24-hour $PM_{2.5}$ standard was reduced from 65 to 35 micrograms per cubic meter in 2006 with the annual standard also being lowered, however, most states have not been able to issue SIPs to support it. As a result EPA has filed its intent to issue a "Federal Implementation Plan" unless the states and tribes are able to issue SIPs within the next two years. While there may be many reasons why states have not produced SIPs, 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. Some believe that significant contributions to these levels of particulate may be attributed to regional sources in adjacent states. Also in the opinion of some, wildland, managed and agricultural fire may prove to contribute enough to ambient PM 2.5 levels implementing these new standards will be extremely difficult for wildland fire managers to maintain their mission requirements. and comply with air quality regulatory requirements.

This is also true for the new ozone standard. Many sites are apparently impacted by ozone and fine particulate which have been transported long distances and across state lines. This represents a challenge to individual states taking actions without the support of regional actions. Thus, the combination of the Regional Haze Regulations and the new lowered ozone and fine particulate standards is will lead to significant changes in how air quality is managed in the US.

It is also clear that fire sources -- wildfire, prescribed fire and agricultural burning - are not going to be allowed the relative inattention of the past by these regulators. At the very least smoke will need to be accounted for and fire emissions recorded as carefully as other major sources have had to do since 1977, resulting in the need to develop a national smoke emissions inventory. State and tribal air regulators are not singling out fire as a pollution source; rather they are being forced to quantify all sources that are contributing to poor air quality at a time of ever-tightening standards. Smoke and fire emissions will need to be taken into account as regulators develop their next generation plans. The implications of this are that smoke management will need to become even more professional. It will need to have scientifically creditable data and this data will need to be analysed with scientifically validated models. Additionally, smoke will need to be monitored in a continuing manner using technologies that are approved by EPA and state regulators. Another important point to consider is the general conformity requirement of the CAA. Conformity provisions require that all Federal and Federally funded activities may not contribute to nonattainment of an ambient standard. The potential of a large number of areas being designated as nonattainment for new ozone and particulate standards, especially near National Forests, Parks and Wildlife refuges could result in overwhelming administrative and planning workloads for wildand fire management agencies.

EPA is under a Supreme Court mandate to regulate greenhouse gases as pollutants. Such emissions were determined to be a direct threat to public health and welfare. It is not clear at present what the specific outcomes of EPA deliberations will be. However, it is very likely that some form of carbon emissions accounting and tracking will be involved. Forest burning emissions are sometimes not considered in greenhouse gas inventories, however, because of their magnitude EPA has included them to some extent in their annual inventories. Some postulate that wildland fire is a necessary component of ecosystem health and thus will be included with the larger issue of ecosystem carbon sequestration to offset industrial emissions and be given special status under any US GHG regulatory program. Nevertheless it seems prudent for fire managers to ensure that they have the most accurate carbon emissions inventory from fire as is possible.

Two new wildland fire smoke issues should also be mentioned here. The first is black carbon. According to the United Nations Intergovernmental Panel on Climate Change (IPCC), “the presence of black carbon over highly reflective surfaces, such as snow, ice and clouds, may cause a significant positive radiative forcing”. Simply put, back carbon (and perhaps brown carbon, a slightly varied form) may cause the albedo of snow to change and thus capture more solar energy in the form of heat. The IPCC has stated “climate forcing due to snow/ice albedo change is of the order of 1.0 W/m^2 at middle- and high-latitude land areas in the Northern Hemisphere and over the Arctic Ocean". Dr Tami Bond of the University of Illinois, Urbana Champaign, estimates the sources of world-wide black carbon emissions as follows:

- 42% open biomass burning (forest and savanna burning)
- 18% residential biofuel burned with traditional technologies
- 14% diesel engines for transportation
- 10% diesel engines for industrial use
- 10% industrial processes and power generation, usually from smaller boilers
- 6% residential coal burned with traditional technologies

Although a resolution has been introduced in the House of Representatives (H.R. 1760), a long process must be followed before actual air quality regulations on black carbon would be enacted. Assuming legislation success, a period of regulation development would follow, providing careful consideration and negotiation before any changes in fire management practices are mandated. Additionally, questions remain as to whether black carbon emitted from prescribed fires in the continental US is of concern due to the fire intensities involved and transport trajectories to the arctic.

A final issue of concern is the increasing occurrence of megafires and their smoke potential to impact large urban areas (see Appendix E). Megafires are created when separate fires link and create a "super-front". For example, some of Australia's fires in the summer of 2009 had borders stretching thousands of kilometers. Such fires emit very large amounts of smoke which can be, have been, and will be, transported into large urban areas at concentrations that cause health impacts to populations. Moscow, Russia in 2002 and 2010 is an outstanding example of these phenomena. As climates change, megafires and resulting urban air quality concerns are likely to be a major issue in the US and worldwide.

3.0 Smoke Science Areas of Certainty and Uncertainty

3.1 Background: After more than 30 years of national attention to smoke and air quality, there are areas of scientific progress, but also areas where progress must be made. We believe four social "drivers" can describe the forces behind modern smoke management. Social drivers, as we define them here, are larger forces that place pressure for change on organised groups or sectors of society. These most often result in the need for increased knowledge and action. The four drivers we have chosen for the SSP are taken directly from synthesis of our web-based questionnaire and personal interviews. They are:

- ***Air quality standards -*** which are evolving and changing and will impact fire management as new standards are developed particularly for ozone and fine particulates and possibly course particles

- ***Air quality management -*** in response to new standards and increasing industrialization, air quality management is demanding higher levels of competency in modelling air pollutants.

- ***Ecosystem and human health -*** Wildland fire is necessary for ecosystem health. Prescribed and wildfire emissions have increasing potential to impact human health as the growth of the wildland urban interface continues and urban areas expand.

- ***Changes in large scale fire ecology -*** As the climate changes, fire ecology is changing on continental scales with resulting regional shifts; such changes in fire ecology will change fire emission rates, timing and perhaps even fire emissions constituents, with potential for changed feedbacks to the atmospheric system.

Here are listed areas of certainty and uncertainty which we believe are relevant to the Joint Fire Science Program. They are arranged under each of the four drivers listed above. It should be understood that the list presented is not exhaustive; rather designed to help the reader understand the need for the SSP themes and the projects suggested later in the plan.

3.2 Areas of certainty:

- ***Air quality standards -*** We know that the ozone standards will be significantly lowered and this lowering will cause many areas of the CONUS to be in non-compliance for ozone. We also know that fire smoke does contribute ozone precursors and the timing of large fires corresponds to the times of greatest concern for elevated ozone. We also know that the annual ambient standards for particulates will be lowered, causing many US counties to fail to meet standards for fine particulates. Wildland fires are a major source of particulates and will be considered under states' plans to achieve compliance with the new standards. Unfortunately, we also know that emissions calculations for fire are not accurate and reliable. This situation has direct implications for the sovereignty of fire managers (under the general conformity provisions of the CAA and other provisions) to apply prescribed fire.

- ***Air quality management -*** We know that air quality managers will employ greater levels of sophistication in air quality modelling analyses required by the Clean Air Act. We also know that smoke modelling systems, although advancing theoretically, are lagging behind the levels of technical/scientific complexity of state-of-the-art air quality forecasting models.

- ***Ecosystem and human health -*** We know urban populations and the wildland urban interface are expanding. We also know that smoke health risks are not well understood and that populations, in general, are becoming more sensitive to accepting health risks from environmental factors. We also know there is increasing pressure to increase prescribed fire acreages, and that such increases will increase the amount of smoke to which the public is exposed.

- ***Changes in large scale fire ecology -*** We know that the climate is changing, that these changes are in significant part due to increased greenhouse gas emissions, and that the changed climate will result in larger, more intense fires during a longer fire season. Such fires will emit more smoke, with different timings for release, with potential to impact the public and the climate system itself.

3.3 Areas of uncertainty:

- ***Air quality standards -*** Unfortunately, we do not know how to accurately conduct a US wildland fire emissions inventory. This is partly due to some lack in emissions factors, but in large part the result of a lack of information on areas burned, the amount of fuels consumed, rates of heat release, rates of fire spread and other factors. Without adequate information on fire emissions, there is great uncertainty as to how wildland fire will be managed under the new ozone and fine particulate standards.

- ***Air quality management -*** We have very little objective evidence that any wildland fire smoke model to date provides accurate and reliable results. We do not have much more than informed speculation as to the factors causing the large error-bars we must attach to model results.

- ***Ecosystem and human health -*** We do not know at what smoke concentration levels extreme risks to public health will occur, although we suspect from our discussions with scientists such levels may be near 350 ug/m^3 of fine particulate, levels that have been exceeded in several extreme urban wildland fire smoke episodes. We do not know what levels of smoke, either episodic or chronic, are acceptable to the public (and to maintain fire fighter health) and what factors make smoke levels acceptable. This is especially true for megafire smoke impacting large urban centers (Appendix E).

- ***Changes in large scale fire ecology -*** We do not know what large-scale changes to fire ecology climate change will bring at regional and sub-regional levels, and what the resulting fire smoke loadings in the atmosphere will be. We also don't know and have not quantified what the wildland fire smoke loadings under climate change will themselves contribute as feedback to greenhouse gas concentrations and radiative forcing of the atmosphere.

4.0 Four Themes for Future Smoke Research Investments

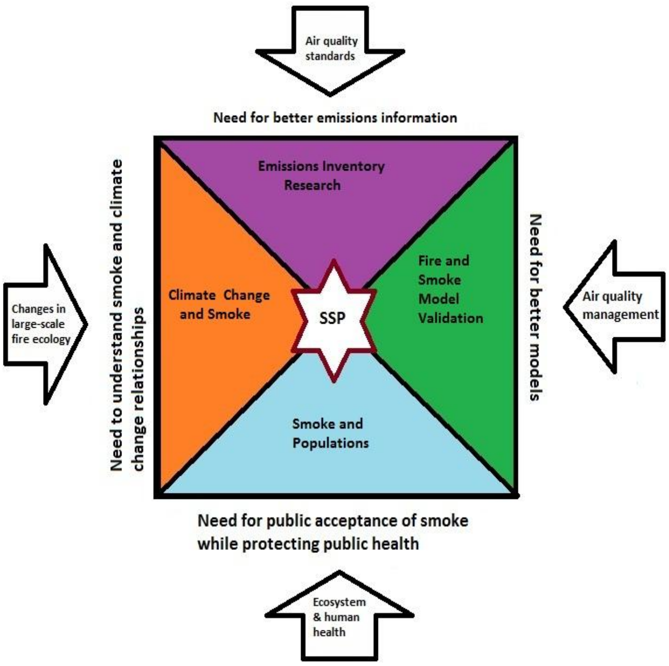

Figure 1: The Smoke Science Plan (SSP) unites four themes, each of them addressing a need, and each need resulting from a large 'driver' that has historically impacted and will continue to impact wildland fire management in the United States.

4.1 Introduction: The Joint Fire Sciences Program Smoke Science Plan (SSP) aims to guide research investments for wildland fire smoke over the next five years. The SSP will be different from previous approaches in that it will employ several parallel themes to allow synergism in smoke research investments. These themes are based on a foundation of needs in smoke science which have been created by large "drivers" or forces effecting wildland fire management across the US (see figure 1). They developed as the result of four approaches used to gather information from the diverse community of smoke stakeholders. We propose using these themes as a means to integrate and organize the wide diversity of research that JFSP has already funded and, if our inquiries are correct, will continue to be asked to fund. The JFSP has already funded some 25 completed and 14 continuing projects and while this has resulted in significant contributions to fire smoke knowledge and management practices, many of the projects have been "stand alone" efforts that could benefit from closer integration. This is especially true as JFSP matures as a program and while resources continue to be constrained. In our opinion, JFSP's fire smoke research investment can be enhanced and improved with attention to such integration and to the thematic structures we are proposing.

Firstly, we reviewed the JFSP's 2007 invited participation smoke roundtables to help identify smoke research needs. The results of the roundtables were a separate set of eastern and western recommendations. These were used as our starting point for developing the SSP themes. We felt that some of the roundtable recommendations were not research issues, but rather proposals to modify agency practice. In these cases we attempted to identify research components within the general recommendations rather than ignore them altogether. However, we also felt that the 2007 roundtables had attracted only limited attention within the diverse communities that have a stake in smoke science research. As a result, one of our first priorities was to broaden the opportunity for interested parties to comment on the roundtable recommendations and to suggest other priorities for smoke science research.

Secondly, we reviewed past smoke science needs assessments. In particular, we reviewed what we had learned from our own past JFSP project (Technically Advanced Smoke Estimation Tools or TASET) and the 1997 Nebraska City smoke needs assessment. These efforts had influenced smoke science investments under the National Fire Plan and in turn significantly influenced JFSP investments and the smoke roundtables. A prime example of this influence is the development of the Pacific Northwest Station's Bluesky smoke modelling framework, a system which can be tracked directly back to a TASET-identified need and built upon ideas incorporated in the earlier smoke modelling systems SMISS (USFS Southern Research Station) and TSARS (by BLM). Additionally, two past-needs assessments undertaken by EPA on smoke emissions were extremely useful to our project, as were work and needs assessments by the Western States Air Resources Partnership (WRAP).

Thirdly, in October 2009 we met with smoke specialists from NASA, NOAA, EPA, universities, BLM and the Forest Service to discuss the results of the JFSP roundtables and our idea of using the thematic approach mentioned above. We found universal support for the concept of using themes in the SSP. We asked these specialists what they thought such themes might be. It was not surprising to us that most thought climate change, emissions inventory, public health and understanding of smoke, and smoke dispersion model evaluation and refinement should be on the list of potential themes. Such topics have been voiced as critical to smoke research since the JFSP TASET project and the 1997 Nebraska City meeting and before.

Finally, we developed a short web-based ***Smoke Roundtable and Research Needs Questionnaire*** for broad distribution to gain a better understanding of what the SSP research themes should be. The questionnaire focused on probing the importance of smoke as an issue, what research priority smoke should have and how the roundtable recommendations might be used in the plan. A total of 554 people, representing a broad spectrum of work duties and employers, responded to the questionnaire. From the feedback, it was clear that smoke is an important research topic which, in our respondents' opinions, possibly should attract up to 25 per cent of total fire research investment funding. The respondents felt that although smoke was not the only important fire research topic it was becoming more contentious and significant because of increasing air quality regulatory and management pressure. We believe that the questionnaire results validated and reinforced our thinking about the four research themes with which we propose to develop the SSP.

To summarize, the four proposed themes have been developed from the synthesis of:

- Recommendations from the JFSP 2007 smoke roundtables
- Past needs assessments
- Our face-to-face agency interviews in October 2009
- Results from our web-based questionnaire
- Our professional judgement gained from more than 30 years each working in wildland fire smoke science.

4.2 SSP Themes Use: The use of themes in the plan will allow the development of four parallel timelines for research projects. Discrete projects will be attached to each timeline. Each project will be designed to further progress toward an achievement or objective. The placement of projects along parallel timelines will allow the JFSP to view its smoke investments holistically and to build synergism among the themes. We chose this approach because wildland smoke is a complex and rapidly changing issue where an abundance of potential projects makes it easy to lose sight of long-term goals. If the themes themselves are too restrictive this approach will not allow the JFSP to use the plan with flexibility. If the themes are too broad, however, they will only lead to a piecemeal approach. We have chosen four themes which we believe will allow a flexible, holistic approach with potential for cooperation with programs such as the EPA Star Grants program and NOAA's air quality research programs.

The four themes are:

- ***Smoke Emissions Inventory Research***
- ***Fire and Smoke Model Validation***
- ***Smoke and Populations***
- ***Climate Change and Smoke***

Emissions Inventory Research: This theme will develop science and techniques that support work on the accompanying themes of *Smoke and Populations* and *Climate Change and Smoke*. Accurate knowledge of the spatial and temporal distribution of smoke emissions is the single most important need for air quality managers and regulators. Virtually all decision-making is based on this information. Without accurate emissions data, it is impossible to work credibly on smoke; we propose that emissions factors, the use of remote sensing, on-the-ground fire reporting and regional scale emissions be tackled as science problems under this theme. It is clear that new air quality regulations will require improved wildland fire emissions inventory at both regional and national levels, and we believe that such new regulations without better emissions science will result in greater contention and challenges nationwide over the use of prescribed fire and wildfire emissions thus hindering land management agencies and fire managers in their missions. The need for an improved inventory was certainly among the recommendations from the roundtables. However, because there are significant agency management issues involved in improving inventory, it is important to isolate research questions for JFSP to consider. JFSP research could help lead to agency procedural change and possibly improved data collection systems without JFSP needing to undertake any of this work.

Fire and Smoke Model Validation: While an accurate emissions inventory is vital for meeting air quality standards, a critical tool for air quality management is air quality modelling. Modelling is required by the Clean Air Act for air quality management. It is used to help identify which sources are responsible for ambient pollution and to evaluate the effectiveness of control strategies. Since wildland fire is among the potential contributors to degraded air quality, accurately assessing fire's contribution though modelling is indispensible. We have seen increasing attention to fire smoke as US states seek to improve visibility and reduce ozone and particulate concentrations. Existing models, however, lack objective field validation and ties to fire behavior, which means their findings are often questioned. The theme of *Fire and Smoke Model Validation* will help fire management in supporting ecosystem health needs by objectively demonstrating the strengths (and weaknesses) of existing smoke models while providing the data needed to develop better future models. This theme will support the three other themes by direct testing of new emissions factors, new generation smoke public health protocols under study by EPA, observation of fine scale meteorology, and observation of long-range smoke transport and plume chemistry. Without objective verification, fire smoke calculations and models will always remain suspect and controversial. Moreover, this theme directly supports work in Core Fire Science on fire behavior and provides for explicit linkages to smoke research; thus providing an opportunity for smoke and core fire science researchers to work cooperatively. One may also note that this theme is a direct recommendation of the

2007 JFSP smoke roundtables, albeit with elaboration from our work. We have had almost universal support for this theme from scientists we have spoken with from NOAA, NASA and EPA. We envision that as this theme progresses JFSP would not necessary lead the model evaluation but would collegially support the work financially and intellectually which might, in the end, be lead by a panel of experts.

Smoke and Populations: There remains a strong sense within the fire management community, as evidenced from our questionnaire, that the public does not understand the need for fire and its resulting smoke. This includes recognition that natural forest ecosystems have evolved with fire and that its elimination increases stresses on forests. Because of this it has been proposed, especially in the western US, that air pollution standards should recognize fire smoke as part of a natural background. Without going into detail about air quality legislation and regulation to justify our stance, we believe this issue is in need of further research. We need to improve our understanding of how people value their personal health and the health of their surrounding ecosystems, especially in circumstances where fire, climate change and increasing populations are interconnecting. This theme will directly support work in *Emissions Inventory Research* and *Climate Change and Smoke* through new science on the health effects of smoke and people's perception of smoke events that appear likely to increase under climate change. It will require the collaboration of fire ecologists, atmospheric scientists, health scientists and social scientists. It will also directly support climate change research concerning the increase in megafires and help the understanding of the air quality consequences of such events (see: Appendix E).

The IPCC is adopting new scenarios measured as > 8.5 W/m2, 6.5, 4 and 3 W/m2 of increased global radiative forcing. Modellers are developing the climates that result from such scenarios and ecosystem modellers worldwide will follow. Their results should be available by fall 2010.

Climate Change and Smoke: The climate change research community continues to develop future scenarios that drive climate models. The ecological community has used these future climates to project future ecosystems. Many forest ecosystems are likely to experience increased stress, especially increased flammability, as a result of a drier, hotter climate. We recommend that the JFSP enhance these studies to specifically address fire and smoke consequences. This theme will directly support *Emissions Inventory Research* and *Smoke and Populations* through helping to set the near future climatic background for US wildland fire emissions. It will also draw upon information gained through developing a large-scale field validation study for *Fire and Smoke Model Validation*, in particular information on plume injection and the chemistry of ageing plumes. Recognizing that the JFSP can only make available limited resources in this large scientific area, we recommend focusing on collaboration with the climate change science community by using new IPCC (Intergovernmental Panel on Climate Change, the UN scientific consensus forum) climate scenarios to ensure that work done by the JFSP is directly relatable to work that will be undertaken nationally and internationally by the US Global Change research program (including all federal government research agencies, the National Science Foundation and universities who will be compelled to incorporate the scenarios in their research). This will also allow for synergism to be built within JFSP on fuels management and fire ecology under climate change by having smoke research follow the larger global climate change research community.

4.3 The objectives of the four themes: Each theme has an objective(s) which we propose will further the state of wildland fire science in the US. Each of the objectives is parsed so that it can be realistically achieved during the five years covered by the plan. Thus they are not what might be considered JFSP's ultimate objectives but, by having such parsed objectives under each theme, it is possible to visualise how specific projects serve as incremental steps toward achieving each objective.

- **Objective for the Emissions Inventory Research Theme:** To develop new science and knowledge that would support and define an accurate national wildland fire emissions inventory system.
- **Objective for the Fire and Smoke Model Validation Theme:** To develop the scientific scope, techniques and partnerships needed to validate smoke and fire models objectively using field data.
- **Objective for the Smoke and Populations Theme:** To develop the science to objectively quantify the impact of wildland fire smoke on populations and fire fighters, elucidate the mechanisms of public smoke acceptance and increase understanding of the balance between ecosystem health and acceptable smoke exposure risks.

- **Objective for the Climate Change and Smoke Theme**: To gain understanding of the implications of wildland fire smoke to and from climate change using the IPCC scenarios as guidelines.

4.4 Four themes for future smoke research topical focus: The four themes address the need for increasing smoke information to meet the regulatory concerns of both air quality and fire managers. They also address the need to better understand smoke models and their performance. Additionally, they address the need for public information about smoke with a focus on public health, a suggestion that results from the concerns of a number of air quality managers. Finally, they address the complex yet pressing issue of climate change and smoke in a manner that leverages what we understand to be the near-term directions of the IPCC.

Smoke Emissions Inventory Research Topical Focus:
We propose that the JFSP provide research support projects to support the development of an annual national wildland fire emissions inventory. Research topics will include:

- Understanding smoke emissions, especially as they contribute to new ozone and PM standards
- Emissions factors improvement and development especially for organic aerosols
- Precursor emissions for ozone, regional haze and black carbon
- Fuel consumption measurement research for emissions calculations
- Remote sensing tools for emissions calculation
- Fine scale meteorology and turbulence influence on smoke emissions
- Plume dynamics and emissions chemistry
- Trade-offs between wildfire and prescribed fire emissions
- National wildland fire smoke emissions inventory proof of concept
- Design needs for a national interagency smoke emissions inventory system

Fire and Smoke Model Validation Topical Focus:
We propose that the JFSP provide research support projects to ensure that efforts be made to develop an interagency supported Fire and Smoke Model Validation field study(s). Research topics will include:

- Understanding current smoke model performance by intercomparison study
- Data-needs definition for model validation; emissions, dispersion, plume dynamics
- Data-needs definition for model validation; meso/micro scale meteorology, fire fuels consumption, fire intensity, fire spread, smoke chemistry

- Field data collection proof of concept (two trials in two ecosystems)
- Fire and Smoke Model Validation interagency research plan development
- Fire and Smoke Model Validation interagency field research

Smoke and Populations Topical Focus:

We propose that the JFSP provide research support projects that develop an improved science foundation for assessing health risks from smoke and understanding people's perception of the balance between smoke exposure risk and ecosystem health. Research topics will include:

- The health effects of high concentrations of smoke on individuals, especially to identify “evacuation-levels” of exposure (including fire fighter smoke exposure implications)
- The public perception and acceptability of smoke at high concentrations for extended durations
- Research into the best means for communication about smoke to the public and generating and distributing smoke information, especially smoke hazards, among responsible agencies
- Advancing understanding of how to incorporate smoke events in large urban centers into air quality forecasting (such as is now being undertaken by NOAA and EPA)
- Deepen understanding of public perceptions of the dangers from smoke and improved scientific basis for public health smoke warnings during large fire events

Since large-scale smoke exposure events appear to be increasing around the world, in equal parts driven by climate change and development (eg, expansion of cities and the urban wildland interface) greater understanding of this issue is critical. Fortunately, work on such large-scale phenomena will be translatable to small-scale events. For example, work on exposure guidelines from high-concentration, long-duration smoke events will be useful for the much smaller smoke concentrations of prescribed fires. Therefore, this work will be useful across the spectrum of fires and will complement (and utilise as is appropriate) work previously done on fire fighter smoke exposure.

Climate Change and Smoke Topical Focus:

We propose that the JFSP provide research support for projects to develop new knowledge of climate change and fire utilizing the new IPCC radiative forcing scenarios. Research topics will include:

- Climates generated under the new IPCC scenarios; a white paper for use by JFSP researchers that will explain what the scenarios mean in terms of future ecosystem changes in specific regions of the United States

- Regional CONUS smoke loading assessments under the IPCC scenarios; Northwest, Southwest, Southeast and Northeast
- Black and brown carbon emissions and consequences under the IPCC scenarios
- Projections of fire greenhouse gas emissions and feedbacks from those emissions in the climate system under the IPCC scenarios
- Information sharing on climate change and smoke; workshop(s) for fire managers

Again, to determine the future for fire emissions we propose using new IPCC scenarios which include high, medium and low radiative forcing to guide research (http://www.ipcc.ch/popup_scenarios.htm). From these forcing scenarios, which are a direct result of projected shifts in atmospheric gas concentrations with forcing calculated from the radiative trapping coefficients of the gases, IPCC will model future climates. Using these, the JFSP would research US fire smoke consequences of the projected climate and ecosystems resulting from each of the three scenarios. Inherent to the process researchers will be encouraged to employ of assemblages of models and not just one specific model or modelling system in hope to achieve a better sense of both certainties and uncertainties in the simulated climates and smoke outcomes. Such work will focus research on climate change event drivers of large-scale fire (multi-week burn durations) and smoke emissions (100-1000km) and the climate system implications of increased smoke emissions and their long-range transport (continental to global scales). By using the IPCC scenarios, JFSP research for climate change and smoke will be naturally harmonized with the larger international body of research. This approach is technically and scientifically feasible, yet challenging. If done properly it will potentially go beyond merely acknowledging that emissions may increase and provide a quantitative foundation and context for work beyond the SSP scope.

5.0 Smoke Science Plan Future Smoke Research Investments

5.1 Suggested research investments background: The SSP research themes can be truly valuable to the Joint Fire Science Program only if they are supported by a set of specific incremental projects that provide a tangible means to make progress on smoke. We present here in tabular form the plan's incremental projects. They are accompanied by a description of each potential project or theme work foci, as they are better termed at this stage of development, suitable for use in developing JFSP calls for proposals, included in *Appendix B - Example or Suggested Theme Foci RFA Narratives and Funding Targets by Year*. For each project, we have given an estimate of cost and duration.

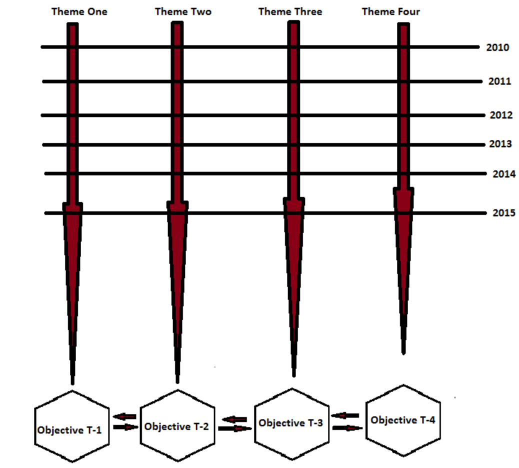

Figure 2: The four themes of the SSP are linked and complementary. Each year, each theme's progress towards meeting its objective will be evaluated and the opportunities for cross-theme research synergisms evaluated and fostered.

We are projecting that the implementation of the SSP will cost approximately $10 million to $11 million over a six-year period (this includes our earlier recommendations to the JFSP board of directors for the 2010 solicitation). This figure of approximately $2M per year of JFSP research funds is below the consensus opinion of the 554 respondents to our web-based questionnaire (who were predominately fire managers). They indicated that about 25 per cent of total wildland fire research funding should be spent on smoke. Additionally, much of the proposed thematic research would not be solely applicable to smoke issues. It would also provide social science, core fire science (eg, fire behaviour, fuel consumption, etc.), basic fire ecology, health science and climate change information. We believe that the SSP program of research would also allow participation of researchers from a broad spectrum of scientific backgrounds, many of whom may not have been involved in past smoke research. It is our opinion that the SSP will provide added value to the JFSP research portfolio, in general, by providing information, data and techniques to non-smokecentric fire research.

5.2 Past foundation: As we have discussed above, we have defined four drivers for SSP research: air quality standards; air quality management; ecosystem and human health, and climate and fire ecology. From within these drivers, we have selected specific themes, which can be addressed through specific research projects. Previous and current JFSP research has already begun to address many of the issues under these themes (see: Appendix A). We identified ten projects that we classified as fitting the Emissions Inventory Research theme, twenty two projects fitting the Fire and Smoke Model Validation theme, six projects that fit equally well under both of these themes, two current projects that we consider fit the Smoke and Populations theme and seven projects that fit the Climate Change and Smoke theme.

Obviously, these projects represent a very significant research investment by the JFSP toward smoke management research. And while we propose a structured program of future research projects, we feel very strongly that the proposed Smoke Science Plan must be built upon the accomplishments of these 41 previous and existing projects. For this reason, we include a number of proposed projects designed to build upon these past efforts by ensuring that the researchers are fully aware of recent research and are able, where possible, to build upon it rather than take a totally new direction. Thus, our proposed work includes a number of workshops and reviews designed to build a sense of cohesion within the smoke research community, a sense which is sorely lacking at present.

The objectives of the four themes: Each theme of the Smoke Science Plan has an objective(s) which we propose will further the state of wildland fire science in the US. The objectives are parsed so that they can be realistically achieved during the five years covered by the plan. Thus they are not what might be considered JFSP's ultimate objectives but, by having such parsed objectives under each theme, it becomes possible to visualise projects as incremental steps towards achieving each objective. The following projects are designed to further each of the theme objectives and allow them to be realistically met under the Smoke Science Plan.

- **Objective for the Emissions Inventory Research Theme:** To develop new science and knowledge that would support and define an accurate national and regional wildland fire emissions inventory system.
- **Objective for the Fire and Smoke Model Validation Theme:** To develop the scientific scope, techniques and partnerships needed to validate smoke and fire models objectively using field data.
- **Objective for the Smoke and Populations Theme:** To develop the science to objectively quantify the impact of wildland fire smoke on populations, elucidate the mechanisms of public smoke acceptance and increase understanding of the balance between ecosystem health and acceptable smoke exposure risks.
- **Objective for the Climate Change and Smoke Theme**: To gain understanding of the implications of wildland fire smoke to and from climate change using the IPCC scenarios as guidelines.

5.3 The linkages and synergies of the four themes that increase investment value: The objectives of each of the themes are complementary (Table 5-1). For example, progress in Emissions Inventory Research will provide new tools and information to help calculate smoke emissions for Climate Change and Smoke research. During each year of the research program, progress in achievement of each theme objective will be evaluated and, by looking across the theme work, opportunities to enhance cooperation, share results and insights and for serendipitous findings can be used the inform the entire program of research (Figure 1). This will require active and thoughtful management, and in this way the plan and its resulting research portfolio cannot be viewed as mere guidance; rather it is a path forward that must be actively pursued.

Table: 5-1 JFSP Smoke Science Plan Themes and Theme Linkages

Themes and Theme Linkages	Emissions Inventory Research	Fire and Smoke Model Validation	Smoke and Populations	Climate Change and Smoke
Emissions Inventory Research supports the other themes through...	Supports its own objective: To develop new science and knowledge that would support and define an accurate national wildland fire emissions inventory system.	Provides insight, techniques and science to support emissions calculations for smoke modelling including assessing compliance with new PM and ozone standards.	Provides science to understand what the constituents of wildland fire are and thus aids in quantification of potential impacts and also public information.	Delivers evolving and improving wild land fire emissions calculations and inventory tools to assess the amounts of smoke released from climate shifts and also to quantify greenhouse gases emitted to the atmosphere.
Fire and Smoke Model Validation supports the other themes through...	Providing ground truth of emissions calculations, and thus future inventories, with real-world data.	Supports its own objective: To develop the scientific scope, techniques and partnerships needed to validate smoke and fire models objectively using field data.	Provides field information on smoke transport and atmospheric transformations of smoke to assess potential of smoke exposure of populations.	Develops a systematic framework to evaluate models used in assessing climate change influences on fire ecology and fire smoke scenarios.
Smoke and Populations supports the other themes through...	Provides context for the need for emissions inventory and also will provide information on how accurate inventories need to be for regulatory, public health and public information purposes.	Provides information and insight as to what levels of accuracy models need to achieve for public acceptance of wildland fire and public/fire fighter risk from smoke exposure.	Supports its own objective: To develop the science to objectively quantify the impact of wildland fire smoke on populations, elucidate the mechanisms of public smoke acceptance and increase understanding of the balance between ecosystem health and acceptable smoke exposure risks.	Develops understanding of the social dimension of wildland fire smoke under changing fire ecologies resulting from climate change.
Climate Change and Smoke supports the other themes through...	Provides basic information on how fire emissions regimes may change under changing climate, allowing better understanding of scope of future emissions inventory needs.	Provides a basic foundation for designing field studies as to the most important current and near-future geographic areas, fuel types and fire behaviour conditions.	Allows public concerns over climate change and smoke to be discussed cogently by providing framework fire emissions scenarios that will result from projected fire ecology shifts under the IPCC scenarios.	Supports its own objective: To gain understanding of the implications of wildland fire smoke to and from climate change using the IPCC scenarios as guidelines.

5.4 Program of research under the four themes: Presented in Table 5-2 are specific incremental foci. Each of these foci or steps could be realized as a specific project or a set of related projects. Such projects would initiate through requests for proposals through the yearly JFSP RFA process. As each foci progresses or reaches completion, the information gained will provide the foundation for the next focus activity. An absolute necessity for this approach to work is communication between researchers engaged in the four theme research portfolio of the Smoke Science Plan. This is proposed to be accomplished though active management of the portfolio by the JFSP, as has been its business model and management hallmark to date. Several questions may arise from reading the foci under each theme. These include:

- **Do the suggested foci build logically upon each other?** Careful thought was put into each foci to move each thematic line of research and activity towards achievement of the theme's five-year objective. The key to designing a cohesive program of research has always been establishing clear and achievable objectives.

- **Is this structure too rigid?** We believe that the foci will be useful as signposts and guidelines that will allow the JFSP to progress, but also to add innovative ideas beyond the foci on a case-by-case basis in each yearly proposal cycle. Because the plan and the foci will be published by the JFSP, researchers will be better able to anticipate what research will be requested and thus improve their responsiveness and innovation within the themes.

- **Is this structure responsive to changing air quality regulations?** Air quality regulations by law progress at a measured pace. A five- or six-year program of research, we believe, aligns well with current development of air quality regulations and their implementation. The history of air quality regulation influence on fire management supports this contention.

- **Do the themes, their objectives and the foci match the JFSP research charter?** We believe that the themes, their objectives and the foci fit the JFSP well. This is supported by the JFSP's past smoke research and its on-going management directions. It has also been overwhelmingly supported by respondents to our web-based questionnaires with input from fire managers, air quality managers, researchers and many others knowledgeable of wildland fire smoke issues.

5.5 Science Communication under the four themes: The program of research under the SSP will develop interim results and products under the four themes. There will be a continuing need to monitor progress and report results. We envision this to occur throughout the life of the SSP. One mechanism that will be employed is the JFSP sponsored science delivery consortia (e.g., the Consortia of Appalachian Fire Managers and Scientists (CAFMS)) and similar JFSP efforts. Additionally, the SSP envisions using periodic workshops under each of the themes to share knowledge among scientists and between scientists and managers. We also believe that articles in fire management periodicals, such as *Fire Management Today,* should be employed during the course of the program of research. Researchers will be encouraged to present interim results and progress on issues at professional and agency meetings. Managers and researchers will be encouraged to discuss research findings and new results specifically to identify existing and new training opportunities and mechanisms that might be appropriate. Finally, JFSP will develop a management strategy for the SSP that will include allocation of resources for oversight of the SSP. The management strategy will address appropriate attention to science communication and technology transfer. It will also address how JFSP science can be applied to issues identified in the JFSP Smoke Roundtables such as developing guidance on smoke modelling.

Table: 5-2 JFSP Smoke Science Foci 2010-2015

Themes and Foci by Year	***Emissions Inventory Research (SSP T1)***	***Fire and Smoke Model Validation (SSP T2)***	***Smoke and Populations (SSP T3)***	***Climate Change and Smoke (SSP T4)***
2010	(SSP T1-1): Fire smoke and ozone standards analysis	(SSP T2-1): Current and past JFSP smoke project investigators brought together in a focused meeting(s) to improve technical coordination, integration and marketing of project accomplishments (SSP T2-2): Smoke models and data providers to participate in the PNW Smoke and Emissions Model Intercomparison Project (SEMIP)	(SSP T3-1): Megafire smoke and population impacts trajectory analysis.	
2011	(SSP T-2): Critical assessment of fire inventory tools (satellite and ground based) (SSP T1-3): Interagency workshop on wildland fire emissions inventory research: Improving emissions factors for ozone, particulates, hazardous air pollutants and greenhouse gases (SSP T1-4): Assessment catalogue of existing US and EU wildland fire emissions inventory systems (SSP T1-5): Assessment of new ambient and 24 fine particulate matter standards and year 2010 wildland fire emissions in the USA	(SSP T2-3): Interagency workshop on fire and smoke model validation Phase I: State of the science of fire emissions, fire plumes and smoke dispersion models; this will also include discussions on wildlfire management strategies (e.g., full suppression vs multiple use objectives) and emissions consequences and improving links to Federal Fire Policy and emissions	(SSP T3 -2): Epidemiological research/literature review to determine human health risk from high PM loadings (SSP T3 -3): Identify public perceptions of high smoke concentrations and public health (SSP T3-4) Fire fighter smoke health hazards: trends in health and exposures	(SSP T4 -1): White paper to scope US fire smoke consequences of projected climate and ecosystems that result from each of the IPCC's projected future scenarios

Themes and Foci by Year	*Emissions Inventory Research (SSP T1)*	*Fire and Smoke Model Validation (SSP T2)*	*Smoke and Populations (SSP T3)*	*Climate Change and Smoke (SSP T4)*
2012	(SSP T1-6): Project to reconcile national fuel mapping tools with emission models	(SSP T2-4): Interagency workshop on fire and smoke model validation Phase 2: State of the science of fire-scale and meso-scale fire meteorology, fire fuels consumption and smoke chemistry/ atmospheric transformations in ageing plumes (SSP T2 -5): Field trial of fire behavior and smoke dispersion as a proof of concept on a small scale prescribed fire in the Midwest	(SSP T3-5): Review of epidemiological research to determine human health risk from high PM, high ozone and high aromatic hydrocarbon loadings with a focus on synergisms between pollutants (SSP T3 -6): Identify public perceptions of smoke risks and ecosystems health tradeoffs in the Southwestern states	(SSP T4-2): Determine US fire smoke consequences of projected climate and ecosystems that result from each of the IPCC's three projected future scenarios in the Western states
2013	(SSP T1-7): 2012 US Wildland Fire Emissions Inventory to determine total fire emissions contributions to atmospheric aerosol, (both primary and secondary), fine particulates and ozone precursors with consideration of the trade-offs between prescribed fire and wildfire managed for multiple use objectives or full suppression	(SSP T2-6): Interagency workshop on fire and smoke model validation Phase 3: Developing an Interagency Research Plan for Fire and Smoke Model Validation (SSP T2-7): Field trial of fire behaviour and smoke dispersion as a proof of concept on a small scale prescribed fire in the Southwest	(SSP T3-7): Risk assessment of wildland fire smoke to US large urban centers with emphasis on high potential locations for smoke evacuations (SSP T3-8): Identify public perceptions of smoke risks and ecosystems health tradeoffs in the Pacific Northwest	(SSP T4-3): Determine US fire smoke consequences of projected climate and ecosystems that result from each of the IPCC's three projected future scenarios in the Southern states (SSP T4-4): Determine changes in black and brown carbon emissions resulting from enhanced fire activity due to climate change, following the IPCC projections (SSP T4-5): Determine US fire smoke consequences of projected climate and ecosystems that result from each of the IPCC's three projected future scenarios in the Pacific Northwest states

Themes and Foci by Year	Emissions Inventory Research (SSP T1)	Fire and Smoke Model Validation (SSP T2)	Smoke and Populations (SSP T3)	Climate Change and Smoke (SSP T4)
2014	(SSP T1-8): Development of next generation emissions model or modelling system (including next generation emissions factors)	(SSP T2-8): Interagency workshop on fire and smoke model validation Phase 4: Field program initiation meeting (SSP T2-9): Funding of first interagency Fire and Smoke Model Validation Field Experiments	(SSP T3-9): Project to assess public understanding of smoke health risk and acceptance of smoke warning systems and actions for public safety (SSP T3-10): Development of next generation smoke transport model or modelling system to assess air quality standards maintenance and public health impacts	(SSP T4-6): Determine US fire smoke consequences of projected climate and ecosystems that result from each of the IPCC's three projected future scenarios in the North eastern states (SSP T4-7): Eastern and western workshops for fire and air quality managers to share research results on the influence of climate change and variability on US fire and fire smoke seasons under the IPCC scenarios
2015	(SSP T1-9): 2014 US Wildland Fire Emissions Inventory to determine total fire emissions contributions to atmospheric aerosol (both primary and secondary), fine particulates, and ozone precursors (SSP T1-10): Interagency workshop on developing a national wildland fire smoke emissions inventory system with system design document development	(SSP T2-10): Interagency workshop on fire and smoke model validation Phase 4: Field program coordination meeting (SSP T2-11): Funding of second interagency Fire and Smoke Model Validation Field Experiments	(SSP T3-11): Implementation of a research smoke warning system with NOAA/EPA air pollution forecasting system (SSP T3-12): Identify public perceptions of smoke risks and ecosystems health tradeoffs in the Southern states	(SSP T4 -8): Assessment of the contribution of US prescribed and wildfires to atmospheric greenhouse gases and their potential for warming or changes to radiative forcing for 2011-2015

5.6 Suggested directions for JFSP smoke research 2016-2019: In this section we present a series of ideas that would support the research work trajectories of the four themes beyond 2015. None of the ideas presented here are complete. However, we believe the JFSP can use these as a starting point for requests for proposals beyond the period of the Smoke Science Plan. These ideas could also serve as initial thoughts for development of the next plan for smoke research (eg, a smoke science plan for 2016-2020).

2016

Theme 1: Developing a “proof of concept” emissions inventory system.
Theme 2: Funding of second interagency Fire and Smoke Model Validation Field Experiments.
Theme 3: Workshop on determining levels of smoke concentration appropriate public safety responses.
Theme 4: Synthesis of smoke trends, 1990 -2015: What the data show concerning smoke emissions, pollutant concentrations, satellite trajectories and fire seasons.

2017

Theme 1: Workshop on improving fire data pertinent to smoke emissions calculations targeted to fire managers.
Theme 2: Funding of third interagency Fire and Smoke Model Validation Field Experiments.
Theme 3: Communicating smoke health hazards to the public: an assessment of techniques appropriate to actions and threats.
Theme 4: Trans-boreal wildland fire and smoke, 1990-2015: What the data show concerning smoke emissions, pollutant concentrations, satellite trajectories and fire seasons.

2018

Theme 1: Emissions data management; developing a common smoke data pre-processor for input to regulatory, science assessment, and research atmospheric chemistry and smoke dispersions models.
Theme 2: Funding of fourth interagency Fire and Smoke Model Validation Field Experiments.
Theme 3: Fire fighter smoke health hazards: trends in health and exposures - round two.
Theme 4: Trans-temperate wildland fire and smoke, 1990-2015: What the data show concerning smoke emissions, pollutant concentrations, satellite trajectories and fire seasons in the middle latitudes of the Northern Hemisphere.

2019

Theme 1: Emissions data management; developing a common smoke data pre-processor for input to regulatory, science assessment, and research atmospheric chemistry and smoke dispersions models.
Theme 2: Workshop on implementation of the results of the interagency Fire and Smoke Model Validation Field Experiments.
Theme 3: Developing smoke exposure biomarkers for humans,
Theme 4: Trans-tropical wildland fire and smoke, 1990-2015: What the data show concerning smoke emissions, pollutant concentrations, satellite trajectories and fire seasons in the sub-tropics and tropics of the Northern and Southern Hemispheres.

6.0 Conclusions

Wildland fire smoke in the US has been a controversial issue for air quality and fire management since the 1970s. Air quality regulations have gone through a significant evolution some would even say revolution, in the past 40 years. Historically, air quality standards which have influenced wildland fire management have been concerned with particulates: total suspended particulates (TSP); particulate matter ten microns or less in diameter (PM_{10}), and particulate matter two and one half microns in diameter ($PM_{2.5}$). Other issues, such as visibility for traffic safety and regional haze, have also been concerns. More recently, concerns have also included fire smoke and ozone; fire smoke's potential to harm public health; its long-term impact on fire worker health, and smoke and climate change (including, but not limited to, black carbon concerns).

As regulations and regulatory pressures have changed, smoke research needs have had to be re-examined through a series of research needs assessments. While this has led to improved smoke research, it has not resulted in a truly interagency national program of smoke research. The assessments have helped inform agencies and research organizations how their work might be better focussed, but they have not necessarily coordinated research across agency lines.

In the course of developing the JFSP Smoke Science Plan, we have gathered advice and input on smoke research needs from more than 900 responses to a series of web-based questionnaires. Our plan is organized under four themes which have had great resonance with the respondents, particularly fire managers and smoke researchers. These themes have been assigned objectives for the six explicitly defined years of the plan's duration. This approach embodies a number of perhaps unique concepts, which are explained in the plan itself.

Collecting together a series of individual projects, which have resulted from needs identified on a yearly basis, has not resulted in an optimal portfolio of research. Our plan and its themes are designed to move the JFSP into a higher level of visionary interagency activity on smoke research. By following the themes, the JFSP will be able to manage smoke research as a designed, rather than a collective, portfolio. This coordinated approach to research should lead the JSFP toward even greater accomplishments in the next six years.

Appendix A - JFSP Smoke Science Recent Advances and Shortfalls

<u>Background:</u> In our discussion of the state of smoke science, we use the term "drivers": major social, political and physical forces driving the needs for modern smoke science and management. Drivers, as we define them here, apply significant external pressure for change on organized groups or sectors of society. We have chosen four drivers for the SSP, developed directly from past research work, synthesis of our web-based questionnaire(s) and recent personal interviews. They are:

- ***Air quality standards -*** which are evolving and will impact fire management.
- ***Air quality management -*** is demanding higher levels of quantification and accuracy in modelling, monitoring and managing air pollutants.
- ***Ecosystem and human health -*** Prescribed and wildfire emissions have increasing potential to impact human health.
- ***Climate and fire ecology -*** As fire ecology changes on continental scales, regional shifts in fire frequency, intensity and emission rates are probable.

We reviewed some recent JFSP research activities, including areas of science progress, using the four drivers as a starting point:

<u>Areas of JFSP Progress and Major Science Gaps by Driver:</u>

Air quality standards - Wildland fires are a major source of particulates and ozone precursors; unfortunately, emissions calculations for fire are not as accurate and reliable as they could be. The JFSP has addressed this in ten projects. Certain JFSP efforts, completed and on-going, help to address these needs. Specifically, projects 05-2-1-45, 05-3-1-04, 07-2-1-60, 09-1-03-1 and 10-S-02-1 could make some contribution to the further research we propose. But although these projects have certainly advanced smoke science, none has satisfied the need for annual reliable emissions data to address new air quality standards. We believe that under the air quality standards driver, the most important research need is to produce a reliable and accurate national inventory of fire smoke emissions.

Air quality management - Air quality managers will require greater levels of sophistication in air quality modelling analyses while smoke modelling systems are lagging behind current state-of-the-art air quality forecasting models. Existing smoke models are judged to be adequate (on-going web questionnaire results and personal interviews) but there is little objective data to evaluate them. JFSP has directed 21 projects addressing these concerns. Particularly notable are efforts already underway to evaluate models and to establish their performance characteristics in a variety of circumstances. Projects 08-1-6-10, 08-1-6-09, 08-1-6-06, 08-1-6-04, 08-1-6-01, 06-2-1-33 and 05-3-1-04 should be evaluated for their specific contribution toward model evaluation and validation. We believe that under the air quality management driver, the most important research work remaining is to develop a database of field measurements in order to evaluate the performance of smoke models.

Ecosystem and human health – We know that urban populations are growing and the wildland urban interface is expanding. We also know that fires are needed for most forest ecosystem health. We suggest that the JFSP focus on the smoke and human health components of this issue. Areas of research we feel need to be funded under this theme include health effects of high concentrations of smoke on individuals, public perception and acceptability of smoke at high concentrations for extended durations, how to incorporate smoke events in large urban centers into air quality forecasting and understanding public perceptions of the dangers from smoke. JFSP has recently initiated two projects, 10-2-03-2 and 10-1-03-7, which begin to address these concerns. They will need to be monitored and, depending upon results, included with proposed studies under this smoke research plan.

Climate and fire ecology - The climate is changing due, at least in part, to increased greenhouse gases, and the changed climate will result in larger, more intense fires during a longer fire season. The JFSP has directed some of its work in this area with seven projects addressing these concerns (projects 01-1-6-1, 01-1-6-05, 03-1-1-06, 03-1-1-07, 03-1-1-22, 03-1-1-37 and 08-S-02.) However, most have been focused on single-region responses to general climate change. They have not been designed in accord with IPCC scenarios nor have they necessarily used IPCC modelling projections of future ecosystems. Areas of research we feel need to be further funded include identifying the likely fire climates that will result from new IPCC scenarios; regional smoke loading assessments under these scenarios for the US; black and brown carbon emissions and consequences under the scenarios; projections of fire greenhouse gas emissions and feedbacks from those emissions in the climate system, and climate change and smoke workshops for fire managers. By using the IPCC scenarios, the JFSP will become naturally harmonized with the work of the larger climate science community and will avoid redundancy while creating greater opportunities for collaboration.

Table: A-1 JFSP Smoke Science Research Projects Mapped to SSP Drivers

JFSP Project Number	Year Awarded	Project Title	Active (A) or Completed (C)	Driver: Air quality standards	Driver: Air quality management	Driver: Ecosystem and human health	Driver: Climate and fire ecology
98-1-9-01	1998	**Smoke Produced from Residual Combustion**	C		**Yes**		
98-1-9-03	1999	**Technically Advanced Smoke Evaluation Tools (TASET): Needs Assessment and Feasibility Investigation**	C	**Yes**	**Yes**		
98-1-9-05	1998	**Implementation of an Improved Emission Production Model**	C		**Yes**		
		Number of Projects by driver for 1998 --		**1**	**3**	**0**	**0**
N/A							
		Number of Projects by driver for 1999 --		**0**	**0**	**0**	**0**
N/A							
		Number of Projects by driver for 2000 --		**0**	**0**	**0**	**0**
01-1-5-03	2001	**Automated Forecasting of Smoke Dispersion and Air Quality Using NASA Terra and Aqua Satellite Data**	C	**Yes**	**Yes**		
01-1-5-06	2001	**Improving Model Estimates of Smoke Contributions to Regional Haze Using Low-cost Sampler Systems**	C		**Yes**		
01-1 -6-01	2001	**Fire and Climate Variability in the Inland Pacific Northwest Integrating Science and Management**	C				**Yes**
01-1-6-05	2001	**Climatic Controls of Fire in the Western US: From Atmospheres to Ecosystems**	C				**Yes**
		Number of Projects by driver for 2001 --		**1**	**2**	**0**	**2**

JFSP Project Number	Year Awarded	Project Title	Active (A) or Completed (C)	Driver: Air quality standards	Driver: Air quality manage-ment	Driver: Ecosystem and human health	Driver: Climate and fire ecology
01-1-5-01	2002	**Fire Effects on Regional Air Quality Including Visibility**	C	**Yes**			
		Number of Projects by driver for 2002 --		**1**	**0**	**0**	**0**
03-1-3 -02	2003	**Forecasting of Fire Weather and Smoke Using Vegetation-Atmosphere Interactions**	C		**Yes**		
03-1-3-08	2003	**Forest Floor Consumption and Smoke Characterization in Boreal Forested Fuelbed Types of Alaska**	C		**Yes**		
03-1-1-06	2003	**Carbon Cycling at the Landscape Scale: The Effect of Changes in Climate and Fire Frequency on Age Distribution, Stand Structure, and Net Ecosystem Production**	C				**Yes**
03-1-1-07	2003	**Climate Drivers of Fire and Fuel in the Northern Rockies: Past, Present and Future**	C				**Yes**
03-1-1-22	2003	**Fire-Climate Interactions and Predicting Fire Season Severity in the Mediterranean Climate Areas of California, Southern Oregon and Western Nevada**	C				**Yes**
03-1-1-37	2003	**Atmospheric Fire Risk in a Changed Climate**	C				**Yes**
		Number of Projects by driver for 2003 --		**0**	**2**	**0**	**4**

JFSP Project Number	Year Awarded	Project Title	Active (A) or Completed (C)	Driver: Air quality standards	Driver: Air quality manage-ment	Driver: Ecosystem and human health	Driver: Climate and fire ecology
[04-2-1-80](04-2-1-80)	2004	**Development and Demonstration of Smoke Plume, Fire Emissions and Pre-and Post-Prescribed Fire Fuel Models on North Carolina Coastal Plain Forest Ecosystems**	C		**Yes**		
		Number of Projects by driver for 2004 --		**0**	**1**	**0**	**0**
[05-3-1-04](05-3-1-04)	2005	**Hybrid Source Apportionment Model: An Operational Tool to Distinguish Wildfires Emissions from Prescribed Fire Emissions to Measurements of PM 2.5 for Use in Visibility and PM Regulatory Programs**	C	**Yes**	**Yes**		
[05-2-1-45](05-2-1-45)	2005	**Does Prescribed Burning in Southern Forests Release Significant Amounts of Mercury to the Atmosphere?**	C	**Yes**			
		Number of Projects by driver for 2005 --		**2**	**1**	**0**	**0**
[05-3-1-03](05-3-1-03)	2006	**Tools for Estimating Contributions of Wildland and Prescribed Fires to Air Quality in the Southern Sierra Nevada, California**	C	**Yes**			
[05-3-1-06](05-3-1-06)	2006	**Characterizing Particulate Matter Emissions by Wildland Fires Relevant to Visibility Impairment and PM Non-Attainment**	C	**Yes**	**Yes**		

JFSP Project Number	Year Awarded	Project Title	Active (A) or Completed (C)	Driver: Air quality standards	Driver: Air quality manage-ment	Driver: Ecosystem and human health	Driver: Climate and fire ecology
06-1-1-12	2006	**Rapid Response Field Observations to Calibrate the BlueSky Smoke Prediction Model**	C		**Yes**		
06-2-1-33	2006	**Fuel Consumption and Smoke Emissions From Landscape-Scale Burns in Eastern Hardwoods**	**A**		**Yes**		
		Number of Projects by driver for 2006 --		**2**	**3**	**0**	**0**
07-2-1-60	2007	**Wildfire Inputs to Regional Air Quality: Remote Spatial-Temporal Measures for Improved Inventory Assessments**	**A**	**Yes**			
		Number of Projects by driver for 2007 --		**1**	**0**	**0**	**0**
08-S-02	2008	**Fire in the Southwest: Integrating Fire and Management into Changing Ecosystems**	**A**				**Yes**
08-1-6-01	2008	**Validation of Fuel Consumption Models for Smoke Management Planning in the Eastern Regions of the US**	**A**		**Yes**		
08-1-6-04	2008	**Evaluation of Smoke Models and Sensitivity Analysis for Determining their Emission Related Uncertainties**	**A**		**Yes**		
08-1-6-06	2008	**Evaluation and Improvement of Smoke Plume Rise Modelling**	**A**		**Yes**		
08-1-6-09	2008	**Airborne and Lidar Experiments for the Validation of Smoke Transport Models**	**A**		**Yes**		

JFSP Project Number	Year Awarded	Project Title	Active (A) or Completed (C)	Driver: Air quality standards	Driver: Air quality manage-ment	Driver: Ecosystem and human health	Driver: Climate and fire ecology
08-1-6-10	2008	**Creation of a Smoke and Emissions Model Intercomparison Project (SEMIP) and Evaluation of Current Models**	A		**Yes**		
		Number of Projects by driver for 2008 --		**0**	**5**	**0**	**0**
09-1-04-1	2009	**Development of Modelling Tools for Predicting Smoke Dispersion from Low-Intensity Fires**	A		**Yes**		
09-1-04-2	2009	**Sub-canopy transport and dispersion of smoke: A unique observation dataset and model evaluation**	A		**Yes**		
09-1-03-1	2009	**Experimental determination of secondary organic aerosol production from biomass combustion**	A	**Yes**	**Yes**		
		Number of Projects by driver for 2009 --		**1**	**3**	**0**	**0**
10-S-02-1	2010	**Identification of Necessary Conditions for Arctic Transport of Smoke from US Fires**	A	**Yes**	**Yes**		
10-1-03-2	2010	**Public Perceptions of Smoke: Contrasting Tolerance amongst WUI and Urban Communities in the Interior West and the Southeastern US**	A			**Yes**	

JFSP Project Number	*Year Awarded*	*Project Title*	*Active (A) or Completed (C)*	*Driver: Air quality standards*	*Driver: Air quality manage-ment*	*Driver: Ecosystem and human health*	*Driver: Climate and fire ecology*
10-1-03-7	2010	**Examining the influence of communication programs and partnerships on perceptions of smoke management**	**A**			**Yes**	
		Number of Projects by driver for 2010--		**1**	**1**	**2**	**0**
		Number of Projects by driver for 1999 through 2010--		**10**	**21**	**2**	**6**

Appendix B - Example or Suggested Theme Foci Descriptive Narratives and Funding Targets by Year

This appendix has been removed in this version of the Smoke Science Plan. Please contact the Joint Fire Science Program office for more information concerning this appendix.

Appendix C - Historical Regulatory Drivers for Smoke

Introduction

Smoke management is unique amongst other natural resource management issues. Smoke is a pollutant yet a natural part of the environment. It contains a mixture of gases, carbon monoxide (CO), sulphur and nitrogen oxides (SO2 and NOx) and volatile organic compounds (VOC) that are either directly affect human health or are precursors for other chemicals that do so, particularly ozone (O3) and secondary organic aerosols (SOA). Smoke also contains fine particles, particulate material smaller than 10 micrometers in diameter (PM_{10}) and smaller than 2.5 micrometers in diameter ($PM_{2.5}$) that have also been proven to degrade human health. The primary purpose for managing smoke is to protect human populations from breathing in these chemicals in amounts that would have a detrimental impact on their health. Additionally the small particles making up smoke are effective in scattering light, which obscures visibility, the ability to see through the smoke. This is also a major reason for managing smoke from wildland fires.

The Foundations of the Clean Air Act

With the emergence of the industrial age, people concentrated in ever-growing numbers in cities experiencing worsening air pollution. Since the middle of the 19^{th} century, use of solid fuels, coal, peat and wood, was recognized as the cause of air pollution. In the US, from the turn of the 20^{th} century, urban air pollution has been regulated through constraints on the visible smoke emissions from chimneys. Ever taller stacks at industrial facilities and power plants were designed to lower surface concentrations of pollutants, primarily SO2. However, by the middle of the past century, public health officials began to realize this practice was of only limited value. Under certain atmospheric conditions the smoke plumes from the tall stacks could be transported down to the ground with very limited mixing, and when such conditions occurred in mountain valleys with poor mixing and strong inversions, it resulted in lethal pollution concentrations. Most famous in the US was an incident in autumn of 1947 in Donora, PA that led to a number of fatalities and critical illnesses.

Air pollution was thus associated with two primary sources: cooking and heating, primarily in big cities; and large industrial and power plants. Outside the urban environment, smoke from wildland fire, especially wood fires in rural areas used for heating, was never considered an important contributor to air pollution. The US Congress addressed air pollution for the first time in 1955, funding a federal research program within the US Public Health Service. In 1963 Congress passed the Clean Air Act authorizing further research on monitoring techniques and air pollution control. Legislation in 1967 (the Air Quality Act) authorized the Public Health Service to initiate federal enforcement of air quality to reduce interstate transport pollution, conduct ambient air quality monitoring. develop air pollutant emissions inventories and carry out inspections of major pollution sources.

The Clean Air Act of 1970

However, it was the Clean Air Act of 1970 that really established the air quality management program that we follow today. At about the same time, the National Environmental Policy Act (NEPA) established the Environmental Protection Agency, in part, to implement the Clean Air Act. The 1970 Act authorized states to protect public health by limiting emissions from both stationary (industrial) and mobile sources, thus assuring air quality above federally set levels. The act mandated that EPA establish National Ambient Air Quality Standards (NAAQS) and states develop State Implementation Plans (SIP) to enforce these Standards. SIPs are legal documents that identify air pollution sources, authorize the monitoring of ambient air, require states to analyse the monitoring data to determine if the standards are being met (attainment areas) or not (non-attainment areas) and generate a plan to ensure the attainment areas remain in attainment and the non-attainment areas come into compliance within a set period of time.

National Ambient Air Quality Standards are set through a scientific and political process. Firstly, science is used to develop a Criteria Document, a report that reviews all the available published scientific information in order to identify the concentration and dosage of each “criteria pollutant” that will protect the health of the most vulnerable members of the public (primary standard) and the public welfare (secondary standard). Since Criteria Documents are scientific reports they must be regularly updated to reflect the latest scientific results, thus either raising or lowering the protection level. Once the Criteria Document is completed, it is submitted to the EPA Administrator through the Clean Air Scientific Advisory Committee (CASAC), which makes a policy recommendation on the standard level, including consideration of economic and other factors. The Administrator makes the final decision and sets the standard.

Since 1970, six criteria pollutants have been identified: carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, ozone and lead (added in 1977). Each standard is expressed as an ambient concentration level of the pollutant not to be exceeded for a selected averaging time. All the criteria pollutants have the same primary and secondary standards except carbon monoxide which has none, sulfur dioxide and, currently under consideration, ozone which have different values.

Three of the NAAQS have been changed significantly since they were first promulgated –those for ozone, particulate matter and lead - with PM and ozone strongly related to wildland fire emissions. Ozone, alone among the NAAQS in that it is not directly emitted from sources but produced in the atmosphere from photochemical reactions between nitrogen oxides and volatile organic compounds (VOC), remains controversial. A lowered value was set in 2008 and this is being revised lower in 2010. The particulate matter standard has also been refined, as evidence has accumulated that only PM smaller than 10 and 2.5 micrometers in diameter impacts on health.

A note here on procedure: each state is responsible for monitoring the criteria pollutants following EPA’s detailed guidance. They submit their data to EPA which reviews it to identify “non-attainment” areas – locations where one or more of the NAAQS are not being met. Then the state develops a State Implementation Plan, which considers all sources in the state that contribute to the ambient pollutant levels and introduces emissions reductions and limitations to both bring the non-attainment areas into compliance and ensure that attainment areas remain within compliance over a prescribed time frame, say ten years. The SIP process is most important in that it identifies specific sources and regulatory programs the state will enforce. Forest fires come into consideration for emissions limitations in this SIP process.

Naturally, exceedences of air quality standards have occurred from prescribed burning and more often by wildfires. EPA allowed wildfires and prescribed fires to be dealt with on a case-by-case basis through its “exceptional event” policy and a closely related PM policy for "natural events" that specifically was designed for wildland fire, volcanic eruptions, and high wind episodes. An “exceptional event” is defined as “an event that affects air quality but is not reasonably controllable or preventable; is an event caused by human activity that is unlikely to recur at a particular location or is a natural event” and is determined as an "exceptional event" by EPA through a process established in regulations. States successfully used this policy to eliminate episodes of high particulate caused by wildfire from the state’s air quality database. However, visibility continued to be a concern as did the effects of fire on fine particulates, especially when EPA revised the NAAQS to include PM_{10} (particles less than 10 micrometers in diameter) in 1987 and to an even greater extent again in 1997 when EPA promulgated NAAQS for $PM_{2.5}$ (particles less than 2.5 micrometers).

The Clean Air Act Amendments of 1977 and 1990

The Clean Air Act Amendments of 1977 added a new concept to the management of air quality. This was the Prevention of Significant Deterioration (PSD) provisions, implemented through a New Source Review (NSR) permit process. PSD introduced the idea that allowing air quality to deteriorate to the level of the NAAQS was not acceptable, especially for Class I areas: areas of special national significance such as National Parks and wilderness. The law established a permitting process for new sources that required them to show that they would not significantly pollute Class I areas. Specifically, the law stated that the air quality related values of Class I areas, including visibility, be protected. For visibility, the law set the goal that no human-caused visibility impairment should be allowed. The 1977 amendments mandated a proactive role for federal land managers to protect air quality related values and visibility in the lands they managed.

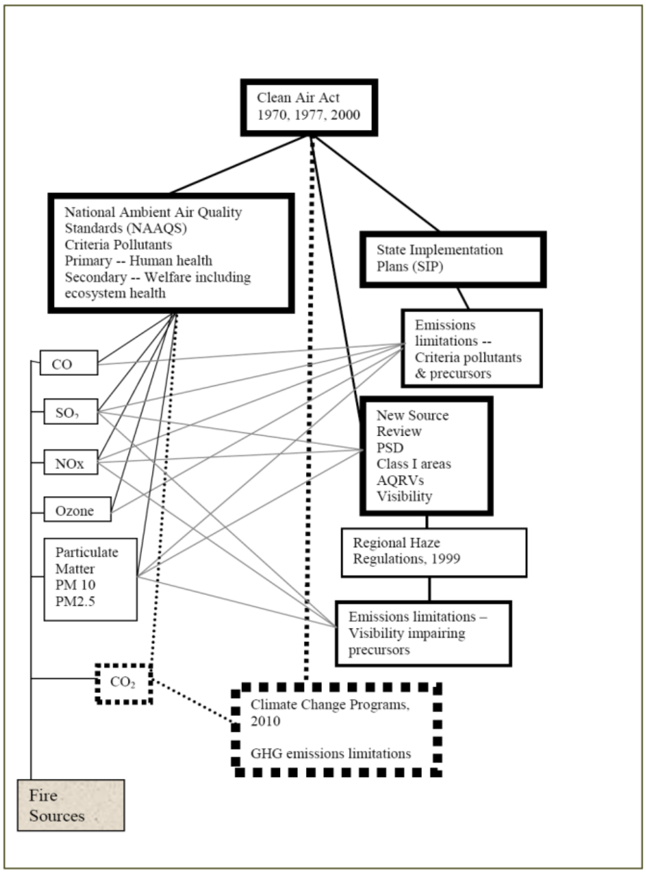

Figure C-1: Aspects of the Clean Air Act and how they relate to wildland fire emissions sources

The 1990 Clean Air Act Amendments further increased the authority and responsibility of the federal government. A new regulatory program was authorized to help control acid deposition (acid rain) through a stationary source operating permit program. And the law authorized a program to control 189 toxic pollutants, including those previously regulated by the National Emission Standards for Hazardous Air Pollutants.

States and EPA struggled with the visibility provisions of the Clean Air Act, especially after the goal of no human impairment was sustained in the 1990 amendments. Visibility degradation caused by individual stationary sources (both newly proposed and established) was controllable through the NSR permit program. But visibility in Class I areas did not materially improve and research established that degradation was largely attributable to a mix of regional sources often long distances from the Class I area, not subject to NSR. In 1999, EPA introduced a Regional Haze Regulatory (RHR) program. This program called for a national monitoring program for $PM_{2.5}$ in rural (Class I) areas, the cause of visibility impairment and for the states to establish visibility SIPs to impose emissions limitations on sources of the $PM_{2.5}$ that degraded visibility.

Wildland Fire Smoke and the Clean Air Act

Figure C-1 illustrates aspects of the Clean Air Act and how they relate to wildland fire emission sources. Fire is a source of all of the criteria pollutants (since lead is primarily associated with mobile sources it is not considered here). Fire is a particularly significant source of both PM_{10} and $PM_{2.5}$ on local, regional, national and even global scales. It contributes to a lesser extent to SO_2 and NOx and to ozone precursors. It is a local source of CO. Figure C-1 shows that the Clean Air Act establishes a process to determine the NAAQS, which include CO, SO_2, NOX, Ozone, PM_{10} and $PM_{2.5}$. It also creates the requirement that states promulgate State Implementation Plans to define emission limitations for all the significant sources that contribute to NAAQS concentrations. Depending on the state, these SIPs can lead to emissions limitations for the criteria pollutants as shown in the figure. If prescribed fire is deemed a significant source by the state, its emissions of these criteria pollutants can be so limited. Experience has shown that in selected states where burning on both public and private land has been determined to be for agricultural purposes, fire has attracted regulatory attention. Historically, in the Northwest states of Oregon and Washington and in Florida smoke management programs with the capability of limiting, or at least altering, prescribed fire emissions have had a long history.

The figure also illustrates that the Amendments of 1977 added the Prevention of Significant Deterioration (PSD) provisions and its associated New Source Review (NSR) which introduced Class I areas, areas where air quality was to be maintained well above the ambient standard levels. Besides designating the Class I areas, the Act required the Federal Land Managers of those areas to protect the air quality related values (AQRV), including visibility, of the Class I areas. The protection is provided by participation in the review of new pollution source permits, conducting modelling and other assessments to be sure AQRVs are not adversely affected. The pollution sources in question here do not include fire, so there is little relevance to smoke management except with regard to visibility.

In 1999, after 20 years of efforts to improve visibility by the NSR program, EPA issued a new set of regulations to protect visibility from regional haze. Regional haze, reckoned to be a significant cause of degraded visibility in Class I areas, is caused by a wide array of sources located in the region of the Class I areas, although not necessarily in their immediate vicinity. The regional haze program requires states to develop SIPs to limit emissions of regional haze-causing pollutants. As a result of extensive analysis, fire has been shown to be a significant cause of regional haze in the western states. The regulations encouraged states where smoke was an issue to establish, at the very least, smoke management programs that may even result in limiting certain burning activities (see section 308 of the EPA Regional Haze Rule)). The regional haze SIPs are just now being finalized. A significant concern for the future, illustrated in the dashed boxes in the figure C-1, is climate change. At this time (August 2010) the direction of EPA's regulatory program is not set, however, at a minimum, there will be limitations on CO_2 and other greenhouse gas emissions. There are likely to be implications for fire programs as a result.

Climate Change Potential Programs

At this time (August 2010), EPA has not fully formulated its climate change regulatory program. That there will be a regulatory program is assured by a 2007 Supreme Court decision. EPA reports:

"On April 2, 2007, in Massachusetts v. EPA*, 549 U.S. 497 (2007), the Supreme Court found that greenhouse gases are air pollutants covered by the Clean Air Act. The Court held that the Administrator must determine whether or not emissions of greenhouse gases from new motor vehicles cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, or whether the science is too uncertain to make a reasoned decision. In making these decisions, the Administrator is required to follow the language of section 202(a) of the Clean Air Act."*

On December 7, 2009, the Administrator signed two distinct findings regarding greenhouse gases under section 202(a) of the Clean Air Act:

- **Endangerment Finding:** The Administrator finds that the current and projected concentrations of the six key well-mixed greenhouse gases - carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) - in the atmosphere threaten the public health and welfare of current and future generations.

- **Cause or Contribute Finding:** The Administrator finds that the combined emissions of these well-mixed greenhouse gases from new motor vehicles and new motor vehicle engines contribute to the greenhouse gas pollution which threatens public health and welfare.

These findings do not themselves impose any requirements on industry or other entities. However, this action is a prerequisite to finalizing EPA's proposed greenhouse gas emission standards for light-duty vehicles, which were jointly proposed by EPA and the Department of Transportation's National Highway Safety Administration on September 15, 2009. At this time EPA has also issued an Advanced Notice of Proposed Rulemaking (ANPR) to consider greenhouse gas emissions from major emitting facilities under the New Source Performance Rule. Other efforts to consider limitations on greenhouse gas emissions are being formulated.

The concern for fire emissions from efforts to reduce greenhouse gases is that a wildfire can emit very large amounts of these greenhouse gases. Recent estimate suggest that the total emissions of GHG from wildfire are between 2 and 4 Pg C/yr (Pg is 10^{15} grams) which can be compared to approximately 7.2 PgC/yr of total anthropogenic CO_2 emissions, as much as 50 per cent of the global emissions. In general, fire has not been included in global greenhouse gas emissions reckoning because it has been recognized as a natural activity and while it can be manipulated by human activity (ie, forestry, agriculture and land use alterations), it really cannot be completely avoided. However, as costly international programs develop to limit global emissions, wildland fire, representing nearly 50 per cent of global greenhouse gas emissions by some estimates, will come under increasing scrutiny.

Black Carbon and Soot

A second reason for attention to fire is the issue of black carbon and soot, most of which emanates from open burning, proposed as exacerbating the melting of snow and ice in high latitudes. A recent study (Hegg, DA et Al, 2009) concluded that better than 90 per cent of arctic soot originated from biomass combustion. The environmental community has suggested that: "The task of reducing black carbon's impact on the Arctic demands a concerted, region-specific, approach to agricultural fires — one that combines economically viable innovation, with increased monitoring and regulation" (Pettus, 2009). A 2007 hearing on Black Carbon and Climate Change, before the House Committee on Oversight and Government Reform, US House of Representatives, further summarized the state of knowledge and suggestions for regulatory actions. A bill has been introduced in the US House of Representatives (HR 1760: Black Carbon Emissions Reduction Act of 2009) that would require the EPA Administrator to develop science and then policy to regulate black carbon emissions. Although, the bill specifically mentions agricultural fires as a source of black carbon, other forms of wildland fires would also likely be considered. Of course, this bill may not pass, and if it does there will be a process of some years before regulations come into play. However, this remains an issue that fire managers will need to consider in the future.

Voluntary GHG emissions activities

There has been growing interest in voluntary emissions limitations in the US. An enabling organization, the Climate Registry, has developed in response to this as an outgrowth of interstate air quality planning activities. The Climate Registry is a non-profit collaboration among states, provinces, territories and tribes that sets consistent and transparent standards to calculate, verify and publicly report greenhouse gas emissions into a single registry. The Climate Registry helps organizations reduce greenhouse gas emissions by establishing consistent, transparent standards for both business and government to calculate, verify and publicly report their carbon footprints to a single, unified registry. Quoting from their website (http://www.theclimateregistry.org/):

"The Registry is committed to:

- Utilizing best practices in greenhouse gas emissions reporting;
- Establishing a common data infrastructure for voluntary and mandatory reporting and emissions reduction programs;
- Minimizing the burden on Members, Directors and Native Sovereign Nations;
- Providing an opportunity for Members to establish an emissions baseline and document early action;
- Developing a recognized platform for credible and consistent greenhouse gas emissions reporting;
- Promoting full and public disclosure of greenhouse gas emissions while respecting business confidentiality."

To date, membership of the Climate Registry has focused on manufacturing, government bodies (ie, states, cities, counties and regional districts), and a wide variety of consulting and public interest organizations. There has been little involvement with agriculture or forestry. However, it seems as though pursuit of a generally agreed set of monitoring principles as well as developing an active, independently verifiable fire emissions protocol, could represent a proactive approach for the fire community in anticipation of climate change attention.

References

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Pettus, A. Agricultural Fires and Arctic Climate Change: A Special CATF Report, May 2009, Clean Air Task Force, Boston, MA.

Appendix D - Past Smoke Research Needs Assessments in the United States

Smoke as an air quality management issue in the US first arose in the late 1970s, and many of the people who worked in agencies concerned with forest and range fire impacts to air quality have either retired or are about do so. During these past decades there have been a number of efforts to determine smoke research needs. For those now involved in smoke and air quality issues, the history of smoke research needs assessments provides a useful context for future planning. Here, we briefly outline this history and explain what we believe were some of the major advancements as a result of these past needs assessments.

Peering Through the Haze 23 years ago: In 1987 we presented a paper wistfully entitled *Smoke and Air Resource Management - Peering Through the Haze*, which was published by the US Forest Service Pacific Southwest Station (Riebau and Fox, 1987). In that paper we speculated that air quality regulations would drive a number of science and technology needs for fire smoke. We also stated that we thought climate change and greenhouse gas concerns would be future concerns for smoke. Much has, of course, changed since 1987 but some smoke fundamentals have remained the same. Indeed, air quality regulations are still changing and require that more and improved information be supplied by fire managers to air quality managers and the public. We still do not have the all the information we need concerning fires worldwide and in the US in regard to potential climate change. As was speculated in our 1987 paper, computer and atmospheric modelling technologies have advanced to an extent no one had envisioned.

Smoke doomsayers gloomily have predicted the demise of prescribed fire as a forestry tool, and to a lesser extent as a rangeland management tool, since the late 1970s because of a perception that an unavoidable conflict between developing air quality regulations and smoke would end the practice. Air quality managers have also been concerned about this issue. Since the 1980s, federal land managers have worried that climate change, an issue that appeared very esoteric then, would lead to policies that banned prescribed burning. But none of this has happened. We believe this is because of the partnerships formed between fire and air quality managers and also because of the advances made in science and technology. Meetings between fire managers, an emerging cadre of smoke management specialists and air quality managers achieved much to improve information exchange and quantitative assessment. Formal smoke research needs assessments were also conducted, which resulted in funding for smoke science work. We believe that much of the science and technology developments for smoke in the US advanced through a series of thoughtful and well-timed smoke needs assessments. In the following paragraphs we highlight only a few of these and some of the outcomes that have moved the US forward on smoke.

Southern Forestry Smoke Management Guidebook: In 1976 Hugh E Mobley and others compiled *The Southern Forestry Smoke Management Guidebook* (Gen. Tech. Rep. SE-10. Asheville, NC: US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 140p). This guidebook was the first of its kind, and developed a basis for smoke management in the US. Not only did it provide immediate and practical answers for smoke management, it also set foundations for future smoke research. In 1989 the US Department of Agriculture, Forest Service Southern Region, published Technical Publication R8-TP 11, which supplemented *The Southern Forestry Smoke Management Guideline*. Much of what these guidelines advise is still very useful, a testament to insightfulness of the work done. Both documents were developed as a result of a series of meetings in the Southern Region between fire managers, air quality managers and Forest Service research scientists. In 2001 this guideline was updated by Colin Hardy and others for the National Wildfire Coordination Group, Fire Use Working Team (Hardy, et.al, 2001).

SASEM workshops: In 1986 the Wyoming State Office of the USDOI Bureau of Land Management was approached by the Wyoming Department of Environmental Quality, Air Quality Division with a request to demonstrate that prescribed fires conducted in the state would not exceed ambient standards for particulates (then TSP) or cause public nuisance. A number of needs-assessment workshops then followed between the Forest Service, BLM, the National Park Service and the state air agency. BLM proposed to develop an air quality model specifically tailored for prescribed fire smoke. This proposal was accepted by the state and the federal agencies, albeit with some scepticism that it could be done, and BLM took leadership on the development. The model that was developed used ideas presented in *The Southern Smoke Management Guideline* for smoke dispersion, used emissions factors developed by Darrel Ward of the Pacific Northwest Research Station and addressed the issue of public nuisance by calculating local visibility impairment. In 1987 the model was accepted by Wyoming and provisionally by EPA as a recommended model for smoke and air quality. As such, it was the first successful smoke model in the US (Riebau et al, 1988) and was soon adopted by Colorado, Arizona, New Mexico and Montana as a guideline model. It was also used in other states on a provisional basis. The use of SASEM resulted in a great number of workshops and presentations on the model. It could be argued that SASEM set the stage for future smoke modelling needs in the US.

Nebraska City Smoke Needs Assessments: In 1996 an extremely profitable meeting to assess smoke research needs was conducted in Nebraska City, Nebraska. This meeting was primarily organized by David (Sam) Sandberg and Sue Ferguson, two people who have had great impact on smoke management science in the US and internationally. The meeting resulted in the publication of the *The Forest Service National Strategic Plan: Modelling and Data Systems for Wildland Fire and Air Quality* (Sandberg et al,1999). This plan recommended nine specific strategies: 1. Fuels and Fire Characterization 2. Emission modelling systems 3. Transport, dispersion, and secondary pollutant formation 4. Air quality impact assessment 5. Emissions tradeoffs and determinations of natural visibility 6. Impact and risk assessment of emissions from fires 7. Monitoring guidelines and protocols 8. National fire and air quality information database 9. Public information and protection. Although this plan is 11 years old, it still provides much useful information. It has also helped to inform the research themes of the JFSP Smoke Science Plan, for example.

Technically Advance Smoke Evaluation Tools (TASET): The TASET project took the approach of identifying specific tools needed to accomplish the job of smoke management. These tools were classified according to how they supported one of four smoke management jobs, namely strategic planning, tactical planning, operational activities and monitoring and evaluation. TASET produced nine recommendations: R1: Fire community participation in Regional Air Quality Modelling Consortia; R2: National Smoke and Visibility Conference; R3:

National Smoke Emissions Data Structure or Database System; R4: Remote Sensing for Fuels and Fire Area Emissions Inventories; R5: Fire Gaming System; R6: CalMet/CalPuff Smoke Management Version; R7: Nationalized Screening Model; R8: On-Site Fire Emissions Verification; R9: Back-Trajectory Modelling and Filter Analysis for Fire Smoke Contributions for Non-Attainment Areas. TASET greatly influenced smoke research work by the US Forest Service, funded under the US National Fire Plan. It was especially influential in development of the Fire Consortia for Advance Modelling of Meteorology and Smoke (FCAMMS) and the Pacific Northwest Station BlueSky Smoke Modelling Framework.

Fire Consortia for Advanced Modelling of Meteorology and Smoke (FCAMMS): Under the National Fire Plan, USDA Forest Service established five cooperative modelling centers or consortia to lead the development and application of advanced meteorological, fire and smoke management tools. The FCAMMS, located so as to serve all areas of the continental US, shared a common objective of providing real-time, higher resolution weather simulations for use by the fire intelligence, fire fighting and smoke management communities. FCAMMS provided regional simulations of current conditions and up to 48 hours of simulated future conditions of such weather and weather-dependent phenomena as fire danger, fire behavior indices and smoke distributions at resolutions of 12km (many areas at 4km). Unique features of the FCAMMS were their blending of research and operational partnerships while demonstrating the development of a new pattern for collaborative fire management. As a business model for implementing high technology into fire management, the FCAMMS approach was selected for many reasons, but the complexity and costs of obtaining input data for weather simulations and the complexity of the models themselves were strong motivating factors. Thus, FCAMMS were designed to build broad partnerships among the fire weather, fire research and air quality regulatory communities while ultimately transferring better technologies to fire managers at fire sites. FCAMMS can be credited with advancing not only the state of smoke science but also with advancing smoke research needs assessments through regional meetings, conference presentations and regulatory implementation discussions. At present, the future of FCAMMS is uncertain. However, the Wildland Fire Decision Support System (WFDSS) Air Quality portal which is a product of the FCAMMS and the WFDSS is mainstreaming the air quality impacts of fire into wildland fire management.

Joint Fire Science Program Smoke Roundtables: In June 2007, the JFSP convened two roundtables – one in Arlington, Virginia and another in Seattle, Washington – on smoke management and air quality issues. The roundtables brought together incident commanders, wildland fire use managers, prescribed burn practitioners, air quality regulators and specialists, and non-governmental organizations interested in smoke management and air quality. Participants worked to articulate problems, develop possible solutions and prioritize the most useful research needs. These initial discussions focused on the following broad areas:

- Emissions tracking
- Accuracy of tools and validation of data
- Compatibility of models and tools
- Measuring impacts and tradeoffs
- Weather information
- Fire, carbon and climate change
- Outreach and communication with the public

- Contingency planning and mitigation
- Policy and process

One result of these roundtables was the development of this Smoke Science Plan, in which we have attempted to incorporate and clarify the roundtable recommendations.

Riverside IUFRO Smoke and Air Quality Workshop: The 22nd meeting for Specialists in Air Pollution Effects on Forest Ecosystems was held from September 10 to 16, 2006, in Riverside CA,, hosted by USDA Forest Service, Pacific Southwest Research Station, on behalf of the IUFRO Research Group 7.01.00 "Impacts of Air Pollution and Climate Change on Forest Ecosystems". A satellite Symposium on Forest Fires and Air Pollution Issues was held on 11th September at the Riverside Convention Center and was co-sponsored by the USDA Forest Service, Pacific Southwest Research Station; USDA Region 5 Air Quality Program; and the Joint Fire Science Program. The symposium was attended by about 80 people. Selected papers were published as a special volume in highly rated peer-reviewed international journal Environmental Pollution and also compiled into a Elsevier Press book Wildland Fires and Air Pollution: Developments in Environmental Science 8. This conference raised consciousness on the need for smoke research internationally. It is resulting in new smoke research initiatives being proposed in Australia and the European Union.

NOAA Office of the Federal Coordinator for Meteorological Services: Recently the Office of the Federal Coordinator for Meteorological services published the results of a survey of users and providers to the fire weather program, including smoke management issues (OFCM 2007). The OFCM report was focused on fire weather but included consideration of selected aspects of smoke. For example, the OFCM survey suggested:

- “A better understanding of wildland fire smoke is needed, and smoke prediction tools need to be refined and perfected”
- “Wildland fire and climate change/climate variability is an issue of high concern, for which more scientific understanding is a priority”
- “There is a specific need for improved smoke dispersion products”
- “Users overwhelmingly need higher resolution meteorological model fields in complex terrain and the tools and input data to understand fire behavior and smoke dispersion.” (This was deemed an urgent need)
- “The fire community needs better modelling of fire potential, threat, and impacts associated with climate and climate change”

NOAA Science Advisory Board: In 2008, the NOAA Science Advisory Board prepared a report “Fire Weather Research: A burning agenda for NOAA” (NOAA SAB 2008). The report also focused on fire weather and its associated research, but also recognised a need to develop better tools and science for smoke. NOAA SAB also acknowledges the contribution made by the Forest Service FCAMMS and suggested more formal cooperation with them and EPA to develop improved smoke models and, especially, to conduct the field measurements needed to gather sufficient data to evaluate models. Their specific recommendation dealing with smoke, number 10, is as follows:

“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, eg, a smoke website or a smoke information portal.”
The NOAA SAB report also made the following recommendation with regard to fire and climate change, which is also relevant to smoke:
NOAA should…
“16.1 … Use its climate modelling 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.”

The NOAA SAB report represents a clear signal from NOAA that it is serious about supporting the fire community and willing to support research in appropriate areas.

Peering Through the Haze 23 years later: This appendix is not designed to be a complete history of smoke needs assessments in the US. We hope it does, however, provide some context to a unique story of environmental and natural resources management. Readers may wonder what we might experience in the next 23 years. They are advised to check our prognostications for accuracy in 2033 when we hope to again review our findings and compare them to the advances that have been made.

Firstly, smoke emissions inventory will become increasingly important due to changes in air quality regulations, particularly changes in regulatory standards for ozone and PM. Smoke emissions will be increasingly of concern for climate change mitigation, especially as a source of carbon dioxide and other trace greenhouse gases. We believe that large megafires (multi-week extreme intensity fires over large geographic areas) will draw much concern for impacts to public exposure from smoke, especially in large urban areas such as the mega-cities. In our view, prescribed fire will continue to be applied for forest and rangeland management until an autonomous energy efficient technology is developed that can remove fire fuels in rough terrain mechanically. Recent autonomous vehicle advancements would make some aspects of this appear to be achievable in the next two decades (see:http://www.darpa.mil/grandchallenge/overview.asp).

Secondly, computers and computer simulation of the atmosphere will continue to advance. The complexity of models will increase, as will the skill-levels required to use then and interpret their results. Although implementation of some sophisticated applications such as the USDA Forest Service Pacific Northwest Station's Bluesky Modelling Framework would appear to belie this conjecture, the state of the science of atmospheric modelling required by the Clean Air Act and NEPA will not allow the application of such tools by non-expert modellers in sensitive circumstances. It is our belief that future successful smoke models will be tied to, or incorporate, spatially explicit physics-based fire behaviour simulations, without which accurate estimates of emissions and plume dynamics are not possible.

Finally, global change and wildland fire will continue to evolve as related issues. If the 2050 predictions of regional temperature increase and rainfall decreases for the US are accurate, there will very simply be very different natural forest regeneration. It would appear that rangelands and savannahs could increase, and thus the amount of prescribed fire and wildfire may also increase. Populations may likely view smoke not as a hallmark of good ecosystem stewardship or even as a necessary evil; but as a health threat piled onto an ever increasing list of health threats and worries. Concerns, and perhaps public critiques, about smoke's synergisms with other pollutants could surely grow.

Although it may not appear so from what is written above, we remain optimistic about wildland fire smoke, air quality and the future. The US, both in universities and in federal land management agencies such as the USDA Forest Service, has a huge intellectual capital to bring to this issue. Serious attempts to discuss research and technology needs for smoke are certainly on-going. There are many remarkable projects now funded by the JFSP and international groups such as the Australian Bushfire Cooperative Research Centre. These will continue to be guided by smoke research needs evaluations as part of the history and culture of fire management both in the US and worldwide.

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Appendix E - Climate, Megafires and MegaCity Air Quality

Introduction

There are few natural disturbances more dramatic than wildfire in mountain forests. Climate change could potentially increase the frequency and magnitude of extreme wildland fires for three reasons. Firstly, mountain climates in many locations are becoming warmer and dryer. Secondly, climate change may well be associated with increased climate variability, altering established fire seasons and creating extremes in fire weather conditions. Thirdly, perhaps most significantly, projected trajectories of climate change will alter the ecological equilibrium of alpine systems, creating more dead fuel build-up. Fire managers worldwide have begun to experience examples of such weather and fuel condition-enhanced fire and have coined the term “megafire” to characterize them. Such fires are created when extreme fire weather conditions coincide with heavy forest fuel loading of extraordinary flammability; factors that have been recognized as stemming from changing climate. In and near mountain and foothill environments around the world, populations are growing. In increasing numbers humans are living in urban environments, leading to the phenomenon of the "megacity" - cities with populations of 10 million or more. In the 21st century, the world is likely to see more large fire and smoke events impact human health and welfare in megacities. Such events have already occurred in the US, Russia, Greece and Indonesia.

Megafire and Climate

Megafires are created when extreme fire weather conditions coincide with heavy fuel loading of extraordinary flammability. In June 2002 in the western US such conditions resulted in the Hayman Fire in Colorado and the Rodeo-Chediski fire in Arizona. The 2003 Cedar fire in urbanized Southern California burned more than 111,000 hectares, consumed some 2,500 buildings and cost 15 fire fighter lives. During the European heatwave of 2003, the Moscow megafire burned for almost three months and reduced visibility in Moscow to less than 60 meters (Cubarava et al, 2009).

A recent forest health survey found that about 24 million hectares of mostly mountain forest in the US are at risk from wildfire. The survey defined at-risk areas as those where more than 25 per cent of the standing live volume of trees greater than 1in diameter are likely to die over the next 15 years. Moreover, background forest mortality rates due to climate change have increased rapidly in recent decades, with doubling periods ranging from 17 to 29 years among regions (van Mantgen et al, 2009). In the western US large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations and longer wildfire seasons (Westerling et al, 2006). Some projections of western US fire response to climate change propose that annual mean area burned in the western US to increase by 54 per cent by the 2050s relative to the present day (Spracklen et al, 2009). Although these studies are from the US, similar experiences are to be expected wherever the climate change trajectory is toward warmer and dryer conditions.

Megacities and Air Pollution

A recent review (Molina & Molina 2004) presents that for megacity air quality, current challenges are ozone and fine particulates. Ozone remains a major pollutant of concern in urban areas because its health impacts are being documented at ever lower concentrations. EPA is proposing (by September 2010) to strengthen the eight-hour ambient ozone standard to a level within 0.060-0.070 parts per million (ppm), roughly half the US standard of 15 years ago. Background ozone levels range from about 0.020-0.045ppm around the world. A forest fire can easily add 15-20ppb to this background. In addition, recent research demonstrates significant health impacts from fine aerosol particles smaller than 2.5 micrometers in diameter, at very low concentrations. Climate change exacerbated wildfires are proposed to increase summertime organic carbon (OC) aerosol concentrations over the western states by 40 per cent and elemental carbon (EC) concentrations by 20 per cent from 2000 to 2050, with most of this increase (75 per cent for OC and 95 per cent for EC) from large or megafires (Spracklen et al, 2009).

Conclusions

Cities and megacities located near (and sometimes far from) forest ecosystems are vulnerable to increased threats from air pollution caused by fire smoke emissions. North American west coast cities (Guadalajara, Los Angles, San Diego, San Francisco, Seattle and Vancouver) and within inland mountains (Denver, Salt Lake City, Phoenix and Mexico City) all have significant fire contributions to ambient levels of ozone and fine particulates. South American cities such as Rio de Janeiro, San Palo, La Paz and Buenos Aires are potentially susceptible to smoke pollution episodes. In Europe, Athens, Barcelona, Lisbon, Moscow, Rome and Budapest are potentially threatened. In Australasia, Jakarta, Manila, Karachi, Sydney, Melbourne, New Delhi, Mumbai and Bangkok are also vulnerable.

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