A Compendium of Brief Summaries of Smoke Science Research In Support of the Joint Fire Science Program Smoke Science Plan

Summaries of key research findings and management implications of JFSP smoke science research projects, as of March 2017

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Introduction --- The Smoke Science Plan (SSP) and Brief Project Summaries

During the course of the Joint Fire Program Smoke Science Plan's five-year duration, 41 research projects came under its umbrella. Each of these projects whether funded under the plan or funded before it began, were managed to further the four themes of the plan and each theme's objectives. The SSP themes and their objectives are:

- The objective of the *Smoke Emissions Inventory Research Theme* is to develop science and knowledge needed to improve national wildland fire emissions inventories, paving the way for the design of a national consensus inventory system.
- The objective of the *Fire and Smoke Model Validation Theme* is to identify the scientific scope, techniques and partnerships needed to objectively validate smoke and fire models using field data.
- The objectives of the *Populations and Smoke Theme* are to quantify the impact of wildland fire smoke on population centers and on fire fighters, and to elucidate the mechanisms of public smoke acceptance in light of the needed balance between human smoke exposure risk and ecosystem health risk. Ultimately this is envisioned to help in the development of a national smoke hazard warning system/methodology based on best science.
- The objectives of the *Smoke and Climate Change Theme* are to better understand implications of climate change on wildland fire smoke and of wildland fire smoke on climate change using UN IPCC future climate scenarios for guidance (IPCC, 2013).

In this document readers will find concise summary statements for each of the projects under the SSP. These statements were prepared for the JFSP for use in guiding the program's '*smoke line of work'* or smoke research portfolio. They are not inclusive of everything that might be reported about each of the research projects, but they do provide the reader with a concise place to begin determining what research has been done and more importantly, what results may address their needs. This compendium of brief summaries is arranged by JFSP SSP theme. All are either summaries of project final reports (where available) or summaries of responses submitted (March 2017) by project principal investigators. All JFSP project final reports can be found at WWW.FIRESCIENCE.GOV.

SSP Theme I --- Emissions Inventory Research

The objective of the Smoke Emissions Inventory Research Theme is to develop science and knowledge needed to improve national wildland fire emissions inventories, paving the way for the design of a national consensus inventory system. A smoke emission inventory is an account of the contribution smoke makes to the loading of specific chemicals in the atmosphere. There might, for example, be an inventory of all smoke, of smoke from agricultural burning, of smoke from prescribed burning or of smoke from wildfires. And for each of these there might be an inventory of carbon dioxide, size segregated particulate material (PM10 or PM2.5), VOC (volatile organic carbon), and a host of other chemicals. Obviously there are both temporal and spatial dimensions for each of these accounts. An inventory might be associated with a specific event, e.g. a wildfire; with a period of time, a week, month or year; with a specific location, a National Forest, a county or a State and so forth. So, in general, an inventory may have a number of dimensions such as: time, space, emitted chemicals and fire type perhaps being the most common. Inventories are constructed from "emission factors" which are the amount of the specific chemical species emitted into the atmosphere divided by the amount of "fuel" consumed by the fire. Emission factors, obviously, are rather complex. They would be expected to be a function of the nature of the fuel, environmental factors and efficiency of fuel combustion as well as other things. Emission factors are measured quantities; they are determined from observations collected on many different burns and hence are statistically determined with a central value and an uncertainty distribution. The emission factor typically is a mass per unit mass number, e.g. x grams of an emitted species/kg of fuel burned. The inventory is then constructed by identifying the mass of fuel consumed by the fire over appropriate time and space dimensions then multiplying it by the emission factor. Building the inventory involves adding up all of the emissions for each chemical species for the times and locations of interest.

Table 1 --- Theme I: Emissions Inventory Research

JFSP Project Number PI	Project Title	Status of Project or Expected Completion Date	Benefits to Additional Themes	Benefiting User Communities
09-1-3-01 Jeff Collett	Experimental Determination of Secondary Organic Aerosol Production from Biomass Combustion.	Completed	II	Air quality modellers and managers
11-1-5-16 Brian Benscoter	Influence of Fuel Moisture and Density on Black Carbon Formation During Combustion of Boreal Peat Fuels	Completed	II	Fire, smoke and air quality managers
11-1-6-06 Tom Moore	Deterministic and Empirical Assessment of Smoke Contribution to Ozone	Completed	II, III	
12-1-7-01 Wei Min Hao	Critical Assessment of Wildland Fire Emissions Inventories: Methodology, Uncertainty, Effectiveness	2015 (unofficially extended until 2017)		
12-1-7-02 Sim Larkin	Assessment of Prescribed Fire Emissions and Inventories	2015-Extended		
12-1-8-31 Tom Moore	Particulate Matter Deterministic and Empirical Tagging and Assessment of Impacts on Levels	2015-Past Due	II, III	
14-1-03-44 Sonia Kreidenweis	Phase Dynamics of Wildland Fire Smoke Emissions and their Secondary Organic Aerosols	2017	II	Air quality managers and smoke scientists
14-1-04-16 Kelley Barsanti	Synthesis of Comprehensive Emissions Measurements and Multi-scale Modeling for Understanding Secondary Organic Aerosol Chemistry in Wildland Fire Smoke Plumes	2017	II, IV	Fire, smoke and air quality managers
15-1-01-1 Nancy French	Mapping Fuels for Regional Smoke Management and Emissions Inventories	2018	II, IV	
16-1-08-1 Talat Odman	Southern Integrated Prescribed Fire Information System for Air Quality and Health Impacts	2018	III	

JFSP 09-1-03-1: Experimental determination of secondary organic aerosol production from biomass combustion.
PI – Jeffery Collett

Why is this work important?

- Fine particulates in wildland fire smoke affect visibility, can conflict with PM2.5 standards, and affect health.
- These fine particles include both the direct emissions from combustion, and additional particulate matter from the chemical transformation of volatile organic compounds as the plume ages while moving downwind. The newly formed particulate is called secondary organic aerosol (SOA).
- Unraveling the contribution of smoke to both fine particulate and secondary organic aerosols will help assess the success of smoke management policies and facilitate air quality management to meet the goals of both the Regional Haze Rule (to protect and improve visibility) and the National Ambient Air Quality Standards.

What did we learn?

Key Findings

- The amount of SOA produced in downwind smoke plumes can be substantial but varies with fuel type.
- Both fresh and aged biomass-burning emissions exert important effects on climate; through the influence of small particles on cloud reflectance, and black and brown carbon on absorption of solar radiation. These findings have implications for global climate modeling.
- A commonly used chemical marker for smoke, levoglucosan, decays during plume aging. Therefore models that use this marker as a conservative tracer will underestimate the contribution of smoke to ambient fine particulate matter.
- A new marker for SOA production from biomass burning (nitrocatechols) was found and a simple, practical method was developed for routine analysis of particulate filter samples used in monitoring. This should allow better monitoring of biomass burning impacts on particulate concentrations and visibility.

Management Implications

- Since average increases in fine particle mass from plume aging were approximately 70% this added effect on human health and visibility will need to be weighed when considering the air quality impacts of fire management strategies.
- Emission inventories developed by this study will improve the ability of modelers to assess the impact of wild and prescribed fires on fine particulate concentrations since earlier inventories are likely to under predict impacts.
- Models from this project can be used for regional haze planning purposes and to better understand the contributions of biomass burning to reactive nitrogen deposition in sensitive ecosystems.

Publications

Desyaterik, Yury, Yele Sun, Xinhua Shen, Taehyoung Lee, Xinfeng Wang, Tao Wang, and Jeffrey L. Collett. 2013. "Speciation of Brwon Carbon in Cloud Water Impacted by Agricultural Biomass Burning in Eastern China." *Journal of Geophysical Research: Atmospheres* 118 (13): 7389–99.

Englehart, Garbriella J., Christopher J. Hennigan, Marissa A. Miracolo, and Spyros N. Pandis. 2012. "Cloud Condensation Nuclei Activity of Fresh Primary and Aged Biomass Burning Aerosol." *Atmspheric Chemistry and Physics* 12 (3): 7521–44. doi:10.5194/acpd-12-7521-2012.

Hennigan, C. J., M. A. Miracolo, G. J. Engelhart, A. A. May, A. A. Presto, T. Lee, A. P. Sullivan, et al. 2011. "Chemical and Physical Transformations of Organic Aerosol from the Photo-Oxidation of Open Biomass Burning Emissions in an Environmental Chamber." *Atmos. Chem. Phys.* 11 (15): 7669–86. doi:10.5194/acp-11-7669-2011.

Hennigan, Christopher J., Amy P. Sullivan, Jeffrey L. Collett, and Alan L. Robinson. 2010. "Levoglucosan Stability in Biomass Burnig Particles Exposed to Hydroxyl Radicals." *Geophysical Research Letters* 37 (L09806). doi:10.1029/201GL043088.

Hennigan, Christopher J., Daniel M. Westervelt, Ilona Riipinen, Garbriella J. Englehart, Taehyoung Lee, Jeffrey L. Collett, Spyros N. Pandis, Peter J. Adams, and Allen L. Robinson. 2012. "New Particle Formation and Growth in Biomass Burnig Plumes: An Important Source of Cloud Condensation Nuclei." *Geophysical Research Letters* 39 (9).

May, Andrew A., Ezra J. T. Levin, Christopher J. Hennigan, Ilona Riipinen, Taehyoung Lee, Jeffrey L. Collett, Jose L. Jimenez, Sonia M. Kreidenweis, and Allen L. Robinson. 2013. "Gas-Particle Partitioning of Primary Organic Aerosol Emissions: 3. Biomass Burning." *Journal of Geophysical Research: Atmospheres* 118 (19): 2013JD020286. doi:10.1002/jgrd.50828.

Saleh, R., C. J. Hennigan, G. R. McMeeking, W. K. Chuang, E. S. Robinson, H. Coe, N. M. Donahue, and A. L. Robinson. 2013. "Absorptivity of Brown Carbon in Fresh and Photo-Chemically Aged Biomass-Burning Emissions." *Atmospheric Chemistry & Physics* 13 (August): 7683–93. doi:10.5194/acp-13-7683-2013.

Schichtel, B. A., M. A. Rodriguez, M. G. Barna, K. A. Gebhart, M. L. Pitchford, and W. C. Malm. 2012. "A Semi-Empirical, Receptor-Oriented Lagrangian Model for Simulating Fine Particulate Carbon at Rural Sites." *Atmospheric Environment* 61: 361–70.

Sturtz, Timothy M., Sara D. Adar, Timothy Gould, and Timothy V. Larson. 2014. "Constrained Source Apportionment of Coarse Particulate Matter and Selected Trace Elements in Three Cities from the Multi-Ethnic Study of Atherosclerosis." *Atmospheric Environment* 84 (February): 65–77. doi:10.1016/j.atmosenv.2013.11.031.

JFSP 11-1-5-16: Influence of fuel moisture and density on black carbon formation during combustion of boreal peat fuels.
PI – Brian Benscoter

Why is this work important?
Smoke from burning peat emits black carbon (BC) and particulate organic matter (POM) emissions that contribute to global climate conditions, air quality and community health. Black carbon is important in soil carbon storage; atmospheric radiative forcing; and melting snow and ice. While the influence of fuel condition on peat combustion has been studied, the implications of fuel moisture and density on the formation and emission of BC and POM have been lacking. Process-level information regarding BC emissions during peat fires is needed.

What did we learn?
This study quantified production of fine particulate matter during smoldering combustion of organic peat soils common to boreal forested and non-forested ecosystems of the Great Lakes region, Northeast USA, Alaska, and Canada. Spectral reflectance-based methods for remotely sensing peatland water table position and surface peat moisture content were studied.
<u>Key Findings</u>

- Good agreement of water table depth and soil moisture with the narrow-band dynamic floating water band index (fWBI980) and broadband MODIS-derived SWIR.
- Both the lab and field burns exhibited organic carbon to elemental carbon ratio (OC: EC) signatures of low temperature smoldering combustion.
- Peat smoldering and its emissions exhibit a threshold response at 200% Gravimetric Water Content or GWC, with diminished smoldering extent and particulate organic carbon emissions above this tipping point.
- Within the low-moisture treatments, surface (top 6cm) fuels produced lower organic PM2.5 emissions than deeper (6-12cm), denser fuels.
- Black carbon (BC) emissions were constant across all fuel moistures and sources.

<u>Management Implications</u>

- Remote sensing applications can be used for estimating peatland water table position and surface soil fuel moisture, which can inform fire behavior assessment models.
- The threshold of 200% GWC can be used to structure prescribed or wildland fire decisions to minimize the likelihood of burning when direct measurements or indirect indices suggest a high smoldering risk due to low peat fuel moisture content.
- These research results expand our capacity to represent and accurately estimate $PM_{2.5}$ emissions during peatland fires for regional or national air quality and emissions inventories.

Publications

Meingast, K.M., Falkowski, M.J., Kane, E.S., Potvin, L.R., Benscoter, B.W., Smith, A.M.S., Bourgeau-Chavez, L.L., Miller, M.E., 2014. Spectral detection of near-surface moisture content and water-table position in northern peatland ecosystems. Remote Sensing of Environment 152, 536–546. doi:10.1016/j.rse.2014.07.014

JFSP 11-1-6-6: Deterministic and empirical assessment of smoke's contribution to ozone (DEASCO3) – An online technical resource to support federal land managers in air quality planning.
PI – Tom Moore

Why is this work important?

- Air regulators must periodically evaluate and revise air quality management plans to ensure that emissions from all combined sources are at levels that will meet the current national ambient air quality standards (NAAQS).
- As air quality standards become more stringent it is a fact that air regulators will need more detailed information on the spatial patterns and temporal frequency of smoke's contribution to elevated ozone episodes across the US.
- The DEASCO3 project developed an online, interactive set of tools and procedures that can be configured, and applied by fire and air quality managers to understand wildland fire contributions (both from individual fires and collections of fires) to ozone events.

What did we learn?

Key Findings

- Emissions inventories for wildfire, prescribed fire and agricultural fire were improved.
- Rules were developed to identify the contribution of individual fires, fire complexes, and coincident groups of different fire types to elevated ozone episodes.
- A unique and flexible set of tools were created in a web map browsing environment allowing managers a variety of spatially oriented ways to interrogate the various data bases, ozone monitoring data, fire emissions data and modeling results that are included in the system.
- Complex technical analyses of historic fire events were transformed into instructive tables, charts and maps that help describe how and to what extent fires contribute to ambient ozone concentrations.

Management Implications

- The DEASCO3 project has created a dynamic and accessible web-based tool that allows resource managers to participate more fully in ozone air quality planning efforts with state and federal air regulators.
- When coupled with a follow-on project on PM2.5, these tools will improve the ability of air and fire managers to communicate and develop coordinated plans.

Publications *(None reported as of March 2017))*

JFSP 12-1-07-1: Critical assessment of wildland fire emissions inventories: methodology, uncertainty and effectiveness.
Preliminary findings as of March 2017.
PI – Wei Min Hao

Why is this work important?
Emissions inventories are key to understanding the contribution of wildland fire to pollution in the atmosphere. Emissions inventories are used in both retrospective and predictive air quality modeling, and multiple inventories exist. To understand the accuracy and precision of model outputs, it is important to know how the emissions inventory is assembled and the uncertainties surrounding the inventory values. This study considered 4 different inventories including GFED (an international Global Fire Emissions Inventory), FiNN (NCAR's fire emissions inventory), WFEIS (Wildland Fire Emissions Information Inventory) and NEI (EPA's National Emissions Inventory). Finally this study has resulted in the development of a new Missoula Fire Laboratory Emissions Inventory (MFLEI) as described by Urbanski at the Second International Smoke Symposium in November 2016.

What did we learn?
Key Preliminary Findings

- Burned area based solely on MODIS active fire detections frequently underestimates actual burned area for fires occurring in rangelands, especially fires with rapid growth.
- Burned area mapped with the MODIS MCD64 product tends to identify regions mapped as "unburned to low severity" in the LANDSAT based MTBS (Monitoring Trends in Burn Severity, http://www.mtbs.gov) product as "burned".
- In forests there are large differences in fuel load consumed among the different inventories. Some are consistently biased low while some are consistently biased high. .
- Deviations of WFEIS fuel load consumed are often sufficient to outweigh differences in burned area and, pre-fire surface fuel loadings are inconsistent with FIA data.
- There is significant uncertainty in emission factors (EFs) for western wildfires due to the lack of field observations. EFs are estimated assuming an MCE = 0.88, based on limited field observations of western wildfires. The EFs used in FiNN and GFED are based on measurements from understory prescribed in the southeast US.
- The project team determined that most of the other data inputs served many purposes and would exist independent of FEIS needs. Uniquely, the CONSUME model seems to have been developed primarily to serve the WFEIS community. If CONSUME costs were not included in the WFEIS costs, assuming their existence independent of the WFEIS, the average WFEIS annual operating cost would be $59,025.

- Overall, fuel load consumed is the greatest source of uncertainty in the emission inventories, particularly for forest fires.

<u>Management Implications</u>

- Improved mapping of fuel loading, especially for forests is needed to reduce the uncertainty of the WFEIS (This is being done in JFSP Project 15-1-01-1, French).
- The surface fuel loading for forests developed for MFLEIS is based on over 28,000 FIA plots, and as such, provides the most rigorous modeling of surface fuel loading available. However, the WFLEIS simply uses a forest-type map to assign per-fire fuel load. While this classification approach does have skill in assigning fuel loads (see Keane et al., 2013), a spatially explicit map base would undoubtedly provide more accurate and less uncertain assignment of forest fuel loads for modeling emissions.
- It is recommended that FIA plot data and plot locations be used for differentiating forest-type map distributions to burned pixels.

Publications

Keane, Robert E., Jason M. Herynk, Chris Toney, Shawn P. Urbanski, Duncan C. Lutes, and Roger D. Ottmar. 2013. "Evaluating the Performance and Mapping of Three Fuel Classification Systems Using Forest Inventory and Analysis Surface Fuel Measurements." Forest Ecology and Management 305 (October): 248–63. doi:10.1016/j.foreco.2013.06.001.

Mallia, D. V., J. C. Lin, S. Urbanski, J. Ehleringer, and T. Nehrkorn. 2015. "Impacts of Upwind Wildfire Emissions on CO, CO2, and PM2.5 Concentrations in Salt Lake City, Utah." Journal of Geophysical Research (Atmospheres) 120 (January): 147–66. doi:10.1002/2014JD022472.

Urbanski, Shawn. 2014. "Wildland Fire Emissions, Carbon, and Climate: Emission Factors." Forest Ecology and Management, Wildland fire emissions, carbon, and climate: Science overview and knowledge needs, 317 (April): 51–60. doi:10.1016/j.foreco.2013.05.045.

JFSP 12-1-7-02: Assessment of prescribed fire emissions and inventories.
PI – Sim Larkin

No progress report or findings available as of March 2017.

JFSP 12-1-8-31: Particulate matter deterministic and empirical tagging and assessment of impact on levels. (PMDETAIL)
Preliminary Findings as of March 2017.
PI – Tom Moore

Why is this work important?
Air regulators must periodically evaluate and revise air quality management plans to ensure that emissions from all combined sources are at levels that will meet the current national ambient air quality standards (NAAQS) and make progress toward visibility goals of the Regional Haze program. As air quality standards become more stringent and we get closer to the visibility goals, air regulators will need more detailed information on the spatial patterns and temporal frequency of smoke's contribution to elevated pollution episodes across the US. The PMDETAIL project is developing an online, interactive set of tools and procedures that can be configured, and applied by fire and air quality managers to understand wildland fire contributions to fine particulate (PM2.5) events. PMDETAL will also enable comparative analysis of fire contributions to visibility impairment and the occurrence of Exceptional Events that influence NAAQS determinations.

What did we learn?
Key Preliminary Findings

- Emissions inventories for wildfire, prescribed fire and agricultural fire were improved.
- Rules were developed to identify the contribution of individual fires, fire complexes, and coincident groups of different fire types to elevated PM2.5 episodes.
- A unique and flexible set of tools were created in a web map browsing environment allowing managers a variety of spatially oriented ways to interrogate the various databases, PM2.5 monitoring data, fire emissions data and modeling results that are included in the system.
- Complex technical analyses of historic fire events are being transformed into instructive tables, charts and maps that help describe how and to what extent fires contribute to ambient PM2.5 concentrations.

Management Implications

- The PMDETAIL project is creating a dynamic and accessible web-based tool that can allow resource managers to participate more fully in PM2.5 and regional haze air quality planning efforts with state and federal air regulators. as well as support analyses for Exceptional Events determinations
- These tools will improve the ability of air and fire managers to communicate and develop coordinated plans.

Publications *(None reported as of March 2017))*

JFSP 14-1-03-26: Phase dynamics of wildland fire smoke emissions and their secondary organic aerosols.
***Preliminary findings as of March 2017*.**
PI – Sonia Kreidenweis

Why is this work important?
Wildland fires emit particle-phase organic aerosols (OA), which exert important influences on human health, visibility and climate. These emissions undergo further transformation in the atmosphere that lead to the formation of secondary organic aerosols (SOA). Recent work has shown that SOA mass concentrations could be several times larger than primary OA. It is important to improve the representation of SOA formation in air quality modeling to better predict the effects of wildland fire emissions on air quality.

What did we learn?
<u>Key Preliminary Findings</u>

- The losses of semi-volatile vapors to Teflon walls may contribute to significant primary-particle evaporation during wood-smoke aerosol experiments carried out in smog chambers. Modeling studies found that 35% of the total aerosol mass lost during a typical experiment could be attributed to losses of organic vapors to absorption into the Teflon walls, rather than simply to particle deposition.
- The vapor wall loss is likely to reduce secondary organic aerosol production in smog chamber experiments, implying that previous estimates derived from such lab studies of secondary organic aerosol formation from biomass combustion are too low. Using the best estimates of key parameters available to date, organic aerosol enhancement was estimated to increase by over a factor of 3 in the absence of vapor wall losses – that is, production of secondary aerosol in the atmosphere is a factor of three larger than that observed in the lab.
- Aerosol evolution in biomass-burning plumes is largely dependent on the nature of the fire and on the ambient conditions (i.e., key parameters are fire size, emission mass flux, and atmospheric stability). Emissions from large fires, such as intense wildfires, dilute slowly, which suppresses organic aerosol evaporation and subsequent secondary organic aerosol formation in the near field. In contrast, although small fires have a lower overall aerosol mass concentration, the production of secondary organic aerosol is enhanced because evaporation efficiently delivers precursors to the gas phase where they can be oxidized.
- Overall, this project's observationally-guided modeling studies suggest that the contribution of secondary organic aerosol may be underestimated by currently-recommended aerosol yields. However, in the atmosphere, much of this secondary organic aerosol may be compensating for evaporation of primary organic aerosol, and thus the effects on net aerosol mass from biomass burning activity may be small, although the composition of primary

and secondary aerosol is different and should be accounted for in studies of air quality and health impacts.

<u>Management Implications</u> –

- Modeling the impacts of fire on regional PM2.5 and ozone, especially for such regulatory applications as SIPs, must properly account for organic aerosol emissions and chemistry.

Publications

Bian, Q., A. A. May, S. M. Kreidenweis, and J. R. Pierce. 2015. “Investigation of Particle and Vapor Wall-Loss Effects on Controlled Wood-Smoke Smog-Chamber Experiments.” Atmos. Chem. Phys. 15 (19): 11027–45. doi:10.5194/acp-15-11027-2015.

JFSP 14-1-03-44: Synthesis of comprehensive emissions measurements and multi-scale modeling for understanding secondary organic aerosol chemistry in wildland smoke plumes.
Preliminary findings as of March 2017.
PI – Kelley Barsanti

Why is this work important?
Secondary organic aerosols (SOA) are an important component of wildland fire emissions, but they are not well characterized in emission sampling or air quality modeling. Improvements in SOA characterization will improve air quality modeling of wildland fire smoke.

What did we learn?
<u>Key Preliminary Findings</u>

- Created the most comprehensive non-methane organic compound (NMOC) emission factor database to date by compiling data from multiple advanced, analytical approaches.
- Identified a large number of compounds that are likely SOA precursors and currently not represented in emissions inventories.
- Prioritized those SOA precursors for future laboratory study.
- Determined that some NMOCs (including SOA precursors) likely are partitioned between the gas and particle phases, and thus their gas-phase emission factors will vary with particle loading.
- In box models, predicted gas- and particle-phase pollutants and precursors are very sensitive to changes in the emissions inventories and subsequent changes in surrogate species profiles.
- In comprehensive air quality simulation models, ozone and SOA formation are also somewhat sensitive to changes in emissions inventories; in some cases, maximum predicted SOA concentrations doubled with changes to emissions inventories/surrogate profiles.

<u>Management Implications</u>

- Modeling the impacts of fire on regional PM2.5, especially for such regulatory applications as SIPs, must properly account for organic aerosol emissions and chemistry.

Publications

Barsanti, Kelley C., Jesse H. Kroll, and Joel A. Thornton. 2017. “Formation of Low-Volatility Organic Compounds in the Atmosphere: Recent Advancements and Insights.” The Journal of Physical Chemistry Letters 8 (7): 1503–11. doi:10.1021/acs.jpclett.6b02969.

Coggon, Matthew M., Patrick R. Veres, Bin Yuan, Abigail Koss, Carsten Warneke, Jessica B. Gilman, Brian M. Lerner, et al. 2016. “Emissions of Nitrogen-Containing Organic Compounds from the Burning of Herbaceous and Arboraceous Biomass: Fuel

Composition Dependence and the Variability of Commonly Used Nitrile Tracers." Geophysical Research Letters 43 (September): 9903–12. doi:10.1002/2016GL070562.

Hatch, L. E., R. J. Yokelson, C. E. Stockwell, P. R. Veres, I. J. Simpson, D. R. Blake, J. J. Orlando, and K. C. Barsanti. 2017. "Multi-Instrument Comparison and Compilation of Non-Methane Organic Gas Emissions from Biomass Burning and Implications for Smoke-Derived Secondary Organic Aerosol Precursors." Atmos. Chem. Phys. 17 (2): 1471–89. doi:10.5194/acp-17-1471-2017.

JFSP 15-1-01-1: Mapping fuels for regional smoke management and emissions inventories. *Preliminary findings as of March 2017*.
PI – Nancy French

Why is this work important?
Fire managers are more frequently depending on predictive smoke modeling and projected impacts to the pubic, and firefighters, to inform their fire management decisions. Having an accurate assessment of fuel types and fuel loads (fuel inventory) is important to the modeling outcome. Also, emissions inventories used in air quality modeling and regulation development also require fuel inventories. The validation exercise in this project will provide a way for managers to know the reliability of the data in specific forests or regions, and the statistical assessment will provide modelers of emissions and smoke a way to include an uncertainty metric in emissions data outputs.

What did we learn?
Key Preliminary Findings

- Completed the compilation of Fuel Characteristic Classification System (FCCS) fuel loading data and population of the FCCS database. FCCS fuel type aggregation decisions were made, and documented, to best represent and quantify fuel loadings for specific and general fuelbed types. Methods developed to compile and record data have been documented so new data sets can be efficiently integrated into the database as they are developed.
- Most of the largest and most appropriate data sets on fuel loads have been ingested into the system. Distribution functions for each type/strata are being created. Decisions related to how to group fuelbeds are on-going and will lead to a better understanding of the data available and the gaps in information for emissions modeling.
- The database will be used to work toward developing ways to map and validate fuel loadings and to assess the statistical characterization of fuel loadings by type.

Management Implications

- While fuels and fuel loading data collection methods have been somewhat standardized for FCCS, a standard way to hold these data in a single database format had not been devised. This work provides the guidance for documenting fuels data that can be easily integrated into the database and compared or pooled with other data for developing a broader perspective on fuel loading variability and consistency.
- By compiling fuel loadings and assessing the available data for fire emissions modeling, the management community will have a comprehensive view of available data, and gaps in information on loadings can be targeted so that reliability can be better judged.

Publications *(None reported as of March 2017))*

JFSP 16-1-08-1: Southern integrated prescribed fire information system for air quality and health impacts.
PI – Talat Odman

Project has not begun as of March 2017.

SSP THEME II --- FIRE AND SMOKE MODEL VALIDATION

The objective of the fire and smoke model validation theme is to identify the scientific scope, techniques and partnerships needed to objectively validate smoke and fire models using field data. Since the plan's implementation in 2011 and before the plan itself, 10 projects have been funded and completed in this area. Completed projects have addressed: A) weaknesses in existing smoke models and what data are needed to improve them, B) investigated the mechanisms of plume rise and super fog formation, C) developed data sets and a framework comparing existing smoke model performance, D) evaluated the smoke consequences from both low and high intensity burns, and E) laid the groundwork through the development of an interagency plan for a new research effort, the Fire and Smoke Model Evaluation Experiment (FASMEE), which will collect field data over a multi-year series of large multi-discipline multi-agency field experiments; this effort will be the largest and most complex set of smoke model validation field experiments which the JFSP has ever undertaken, but it will be done in partnership with DOD, NOAA, NASA, EPA, USDA Forest Service, and others. Under the SSP major new insights have been gained into areas of smoke modeling that are weakest, such as plume dynamics and combustion physics as influencing factors to emissions. Additionally, research has demonstrated that small, low-intensity fires and large, high-intensity fires generate different smoke chemistry regimes, generally not considered by most current models but which have different consequence for secondary organic aerosols (SOA), fine particulate emissions, and ozone creation. One area, which has been highlighted, is the growing need to recognize the differences which plume injection height estimates can make in smoke trajectories, an issue which has plagued smoke modeling accuracy for many years. JFSP funded work on model evaluation/validation has already resulted in changes in the EPA's National Emissions Inventory (EPA NEI) as it regards wild land fire. It has also resulted in improvements to the BlueSky smoke modeling framework (which was developed originally with JFSP support in partnership funding with others) and also NASA smoke satellite and modeling products. SSP research under this plan theme will have a lasting significant impact on how fire, especially prescribed fire, will be treated in future smoke/air quality model development.

Table 2 --- Theme II: Fire and Smoke Model Validation

JFSP Project Number PI	Project Title	Status of Project or Expected Completion Date	Benefits to Additional Themes	Benefiting User Communities
08-1-6-01 Roger Ottmar	Validation of Fuel Consumption Models for Smoke Management Planning in the Eastern Regions of the US	Completed	I	Fire and AQ modellers
08-1-6-04 Talat Odman	Evaluation of Smoke Models and Sensitivity Analysis for Determining their Emission Related Uncertainties	Completed	I	Smoke managers, AQ modellers
08-1-6-06 Yong Liu	Evaluation and Improvement of Smoke Plume Rise Modeling	Completed		
08-1-6-09 Shawn Urbanski	Airborne and Lidar Experiments for the Validation of Smoke Transport Models	Completed	I	Developers of emissions inventories and models
08-1-6-10 Sim Larkin	Creation of a Smoke and Emissions Model Intercomparison Project (SEMIP) and Evaluation of Current Models	Completed	I	AQ and smoke model developers
09-1-4-01 Warren Heilman	Development of Modeling Tools for Predicting Smoke Dispersion from Low-Intensity Fires	Completed	I	Fire research, smoke managers
09-1-4-02 Tara Strand	Sub-Canopy Transport and Dispersion of Smoke: A Unique Observation Dataset and Model Evaluation	Completed	I	
09-1-4-05 Marko Princevac	Superfog Formation: Laboratory Experiments and Model Development	Completed	I, III	Fire managers
11-2-1-11 Roger Ottmar	Data Set for Fuels, Fire Behavior, Smoke and Fire Effects Model Development and Evaluation (Rx Cadre)	Completed	I, IV	Research
12-3-1-06 Talat Odman	Sensitivity Analysis of Air Quality to Meteorological Changes in Fire Simulations	Completed		
13-S-01-01 Tim Brown	Fire and Smoke Model Validation Workshop	Completed	I, IV	
15-S-01-01 Roger Ottmar	Fire and Smoke Model Evaluation Experiment (FASMEE)	Ongoing	I, IV	

JFSP 08-1-6-01: Validation of fuel consumption models for smoke management planning in the eastern regions of the US.
PI – Roger Ottmar

Why is this work important?

- Both land managers and air regulators are interested in improving emissions estimates from wildland fire in order to make the best decisions that will allow prescribed burning while meeting air quality standards.
- Because many state smoke management programs require an emissions estimate prior to allowing prescribed burning to take place, it is critical to make an accurate estimation.
- Fuel consumption is a key element in predicting emissions generated from wildland fire and the associated air quality impacts. Models have been developed to estimate fuel consumption, however little research had been conducted on many eastern fuel types. Land managers were concerned that available techniques were over-predicting fuel consumption and emissions.
- Measured fuel consumption data were needed to improve consumption estimates and validate consumption models.

What did we learn?

Key Findings

- The studied models, Consume and FOFEM (First Order Fire Effects Model), predicted consumption accurately for shrub and herbaceous vegetation in the fuelbed types measured (mixed hardwoods, southern pine and sand pine scrub).
- Predictions of fine woody fuel, litter and duff consumption could be improved in Consume and FOFEM to better represent prescribed fire practices in the eastern US.

Management Implications

- The next version of Consume (4.1) will be improved to better predict fuel consumption in eastern mixed hardwood, southern pine and sand pine scrub fuelbeds.
- Fuel consumption datasets from around the US were compiled into one database that is available to all scientists, modelers, regulators and managers for testing and validating other fuel consumption systems.
- A new calibration method for airborne infrared fire temperature sensing is expected to be widely applicable and useful in evaluating heat release and rate of fuel consumption over a burn unit.

Publications

Prichard, Susan J., Eva C. Karau, Roger D. Ottmar, Maureen C. Kennedy, James B. Cronan, Clinton S. Wright, and Robert E. Keane. 2014. "Evaluation of the CONSUME and FOFEM Fuel Consumption Models in Pine and Mixed Hardwood Forests of the Eastern United States." Canadian Journal of Forest Research 44 (7): 784–95. doi:10.1139/cjfr-2013-0499.

JFSP 08-1-6-04: Evaluation of smoke models and sensitivity analysis for determining their emission related uncertainties
PI – Talat Odman

Why is this work important?

- Smoke predictions from models are most useful to fire and air quality managers when the associated uncertainty can be described. Existing models often lack objective field validation, which means the accuracy of the prediction is often unknown.
- This project monitored prescribed burns and wildfires in the southeastern US, and used three models to simulate fine particulate ($PM_{2.5}$) levels downwind of the burn units. Researchers compared monitored and modeled results to assess performance of each model.

What did we learn?

Key Findings

- DAYSMOKE successfully predicted $PM_{2.5}$ concentrations within 5-10 km of a single or relatively small number of distinct fires. It also predicted plume height correctly, injecting smoke into the correct vertical layer of the atmosphere, which is needed for regional-scale air quality models such as CMAQ that consider how emissions interact, transform, chemically react and are removed through deposition.
- The project was unable to determine whether CALPUFF is suitable for simulating air quality impacts of fire. All simulations with CALPUFF under-predicted ground level pollution levels.
- CMAQ was unable to provide good predictions of smoke concentrations but a specially constructed version, AG-CMAQ, improved performance for prescribed fires. AG-CMAQ might also be used effectively for wildfires if certain model parameters (grid adaptation) were readjusted for typical wildfire plumes.

Management Implications

- DAYSMOKE can be turned into a reliable smoke-impact prediction tool for land managers to use within short distances of a burn unit.
- Managers should be aware that CALPUFF, based on this study's results, might under predict smoke impacts.
- On a regional scale, fine particulate impacts can best be predicted with air quality models like CMAQ that can simulate the transport and chemistry of fire emissions. However these models are not perfect. Alternative versions, such as AG-CMAQ, are promising but need further development.
- Fire emissions can be estimated with 30-50% uncertainty using existing tools (e.g. fuel photo series, fuel consumption models, and emission factors).

Publications

Achtemeier, Gary L., Scott A. Goodrick, Yongqiang Liu, Fernando Garcia-Menendez, Yongtao Hu, and Mehmet Talat Odman. 2011. “Modeling Smoke Plume-Rise and Dispersion from Southern United States Prescribed Burns with Daysmoke.” Atmosphere 2 (3): 358–88. doi:10.3390/atmos2030358.

Garcia-Menendez, Fernando, and Mehmet Talat Odman. 2011. “Adaptive Grid Use in Air Quality Modeling.” Atmosphere 2 (3): 484–509. doi:10.3390/atmos2030484.

Garcia–Menendez, Fernando, Aika Yano, Yongtao Hu, and M. Talat Odman. 2010. “An Adaptive Grid Version of CMAQ for Improving the Resolution of Plumes.” Atmospheric Pollution Research 1 (4): 239–49. doi:10.5094/APR.2010.031.

JFSP 08-1-6-06: Evaluation and improvement of smoke plume-rise models.
PI – Yong Liu

Why is this work important?

- Smoke plume rise describes the height in the atmosphere that smoke particles reach after being emitted from wildland fires. It is an important parameter for local and regional air quality modeling, but one that has been difficult to evaluate due to lack of smoke measurements for model evaluation. If fire emissions are projected to be injected into the wrong layer of the atmosphere, dispersion model results will be incorrect. Since air quality models are important tools used by fire and air quality managers, improving smoke plume rise simulation will reduce uncertainty in the modeling results.
- This study focused on measuring and modeling smoke plumes from twenty different prescribed burns conducted in the piedmont and coastal plains of the southeastern U.S.

What did we learn?

Key Findings

- Overall, the field measurements revealed an average smoke plume height of 1000 meters.
- Measurements showed that fluctuations in the vertical structure of plumes occur over various timeframes, increasing the difficulty of both model simulation and satellite detection of plume height.
- Smoke plume height can be estimated simply and with a reasonable level of accuracy using three measurements typically collected by fire managers; fuel temperature, fuel moisture and wind speed.
- Evaluation of various models showed that Daysmoke held the most promise for simulating plume height correctly. Simpler plume rise simulations tended to overestimated smoke plume heights.
- Predictions in the Daysmoke model were improved by including a new smoke property, multiple updraft core number.
- Regional simulations of prescribed fire impacts on air quality using the Community Multi-scale Air Quality model (CMAQ) were improved when smoke plume rise information from Daysmoke was used and multiple updraft cores were included.

Management Implications

- Daysmoke has the potential to be a useful tool for prescribed fire managers if the user interface can be modified to retrieve meteorology data, fire spread can be incorporated, and multiple burns can be modeled simultaneously.
- A new empirical model was developed that could be used for making quick estimates of projected plume height by managers burning in the piedmont and coastal plains of the southeastern U.S.

- Current models widely used in smoke management were shown to overestimate plume rise for prescribed burns in the Southeast. More evaluation is needed to understand the limitations of WRAP, FEPS and Briggs plume rise models applied to burns in the southeastern US.

Publications

Achtemeier, Gary L., Scott A. Goodrick, and Yongqiang Liu. 2012. "Modeling Multiple-Core Updraft Plume Rise for an Aerial Ignition Prescribed Burn by Coupling Daysmoke with a Cellular Automata Fire Model." Atmosphere 3 (3): 352–76. doi:10.3390/atmos3030352.

Achtemeier, Gary L., Scott A. Goodrick, Yongqiang Liu, Fernando Garcia-Menendez, Yongtao Hu, and Mehmet Talat Odman. 2011. "Modeling Smoke Plume-Rise and Dispersion from Southern United States Prescribed Burns with Daysmoke." Atmosphere 2 (3): 358–88. doi:10.3390/atmos2030358.

Davis, Aika Y., Roger Ottmar, Yongqiang Liu, Scott Goodrick, Gary Achtemeier, Brian Gullett, Johanna Aurell, et al. 2015. "Fire Emission Uncertainties and Their Effect on Smoke Dispersion Predictions: A Case Study at Eglin Air Force Base, Florida, USA." International Journal of Wildland Fire 24 (2): 276–85. doi:10.1071/WF13071.

Goodrick, Scott L., Gary L. Achtemeier, Narasimhan K. Larkin, Yongqiang Liu, and Tara M. Strand. 2013. "Modeling Smoke Transport from Wildland Fires: A Review." International Journal of Wildland Fire 22 (1): 83–94. doi:10.1071/WF11116.

Liu, Yongqiang. 2014. "A Regression Model for Smoke Plume Rise of Prescribed Fires Using Meteorological Conditions." Journal of Applied Meteorology and Climatology 53 (8): 1961–75. doi:10.1175/JAMC-D-13-0114.1.

Liu, Yongqiang, Gary L. Achtemeier, Scott L. Goodrick, and William A. Jackson. 2010. "Important Parameters for Smoke Plume Rise Simulation with Daysmoke." Atmospheric Pollution Research 1 (4): 250–59. doi:10.5094/APR.2010.032.

Liu, Yongqiang, Scott Goodrick, and Warren Heilman. 2014. "Wildland Fire Emissions, Carbon, and Climate: Wildfire–climate Interactions." Forest Ecology and Management, Wildland fire emissions, carbon, and climate: Science overview and knowledge needs, 317 (April): 80–96. doi:10.1016/j.foreco.2013.02.020.

Liu, Yongqiang, Scott L. Goodrick, Gary L. Achtemeier, Ken Forbus, and David Combs. 2013. "Smoke Plume Height Measurement of Prescribed Burns in the South-Eastern United States." International Journal of Wildland Fire 22 (2): 130–47. doi:10.1071/WF11072.

Liu, Yongqiang, Scott L. Goodrick, and John A. Stanturf. 2013. "Future U.S. Wildfire Potential Trends Projected Using a Dynamically Downscaled Climate Change Scenario." Forest Ecology and Management, The Mega-fire reality, 294 (April): 120–35. doi:10.1016/j.foreco.2012.06.049.

Mitchell, Robert J., Yongqiang Liu, Joseph J. O'Brien, Katherine J. Elliott, Gregory Starr, Chelcy Ford Miniat, and J. Kevin Hiers. 2014. "Future Climate and Fire Interactions in the Southeastern Region of the United States." Forest Ecology and Management 327 (September): 316–26. doi:10.1016/j.foreco.2013.12.003.

JFSP 08-1-6-9: Validation of smoke transport models with airborne and Lidar experiments.
PI – Shawn Urbanski

Why is this work important?

- Detailed information on fire emissions, smoke dispersion and smoke plume rise are needed to validate emissions estimates and smoke dispersion models, but this type of information is difficult and costly to collect.
- The project collected data from 11 separate incidents, representing both prescribed fires and wildfires. It is particularly significant that the data were collected downwind of the fire by aircraft and Lidar remote sensing. Data are supplemented by ground-based measurements of burned area and fuels.
- These data are important for two reasons. First, the emissions data measurements are useful to compare with modeled emissions used to generate emissions inventories and related regulatory activities. The smoke dispersion and plume height data will be used for model validation studies as the SSP Theme on validation progresses.

What did we learn?

Key Findings

- The fire and emissions measurements done by this project provide new information about the magnitude of carbon dioxide (CO_2) fine particulate ($PM_{2.5}$) and ozone (O_3) precursors emitted from western wildfires and prescribed fires. These data suggest estimates of regional and national fire emissions currently used for regulatory purposes may need to be modified.
- The data suggest the important role that combustion efficiency plays in determining fire emissions.
- The smoke dispersion and plume rise measurements made in this project represent the most comprehensive set of such measurements for western wildfires yet developed. They will be used to evaluate smoke models and to quantify uncertainties associated with a satellite remote sensing tool used globally to estimate fire impacts.

Management Implications

- Managers will benefit from having more accurate assessments of the contribution fires make to ambient air quality and, in future, better smoke models.

Publications

Kovalev, Vladimir A., Alexander Petkov, Cyle Wold, and Wei Min Hao. 2011. "Lidar Monitoring of Regions of Intense Backscatter with Poorly Defined Boundaries." Applied Optics 50 (1): 103–9. doi:10.1364/AO.50.000103.

Kovalev, Vladimir A., Alexander Petkov, Cyle Wold, Shawn Urbanski, and Wei Min Hao. 2009. "Determination of Smoke Plume and Layer Heights Using Scanning Lidar Data." Applied Optics 48 (28): 5287–94. doi:10.1364/AO.48.005287.

Urbanski, S. P. 2013. "Combustion Efficiency and Emission Factors for Wildfire-Season Fires in Mixed Conifer Forests of the Northern Rocky Mountains, US." Atmospheric Chemistry and Physics 13 (14): 7241–7262.

JFSP 08-1-6-10: Creation of a Smoke and Emissions Model Intercomparison Project (SEMIP) and evaluation of current models.
PI– Sim Larkin

Why is this work important?

- Fire and air quality managers increasingly rely upon various emissions and smoke dispersion models to make decisions about planned burning and air quality. In order to estimate emissions and downwind smoke impacts several models and datasets must be linked into a chain consisting of information on fire location, fuel type, fuel loading, fuel consumption and fire intensity over time, emissions factors, and smoke plume height and chemistry. Understanding the limitations of these tools is necessary to guide managers on appropriate model use and on how to interpret modeling results.
- SEMIP created a structure to facilitate model intercomparison that includes a sequence of model steps necessary to estimate emissions and downwind concentrations, model output levels where different model pathway results can be directly compared, test cases designed to evaluate one or more models, and an infrastructure for supporting model and data comparison including a data warehouse and metadata catalog.

What did we learn?

Key Findings

Evaluations conducted as part of this project showed that:

- Errors in fire activity information have a critical impact on fire and emissions modeling.
- The diurnal emission profile has huge, non-linear effects on the magnitude and location of emissions but it is not well represented in emissions and smoke transport modeling. This is primarily because improvements are needed in fire behavior models to adequately represent fire spread and consumption over a 24-hour period. Without this, smoke scientists cannot estimate the diurnal pattern of smoke correctly.
- Plume rise calculations were found to be important in smoke dispersion and downwind concentrations. Differences in plume rise can lead to vastly different patterns and magnitudes of ground level smoke.

Management Implications

- New observation campaigns targeted toward developing test cases in areas of limited understanding could lead to improvement in emissions and smoke dispersion estimates, if the correct parameters are measured.
- Continued model comparisons and evaluations will be needed, especially when new models or model versions are created and when new test cases become available.
- An open-access platform for collaborative modeling and evaluation (such as SEMIP) would maintain baseline comparison test cases and ensure that standard comparisons between models and model validation can be performed.

Publications

Raffuse, Sean M., Kenneth J. Craig, Narasimhan K. Larkin, Tara T. Strand, Dana Coe Sullivan, Neil J. M. Wheeler, and Robert Solomon. 2012. "An Evaluation of Modeled Plume Injection Height with Satellite-Derived Observed Plume Height." Atmosphere 3 (1): 103–23. doi:10.3390/atmos3010103.

Strand, Tara M., Narasimhan K. Larkin, Kenneth J. Craig, Sean M. Raffuse, D Sullivan, Robert Solomon, Miriam Rorig, N Wheeler, and D Pryden. n.d. "Analyses of BlueSky Gateway PM2.5 Predicitions during the 2007 Southern and 2008 Northern California Fires." Journal of Geophysical Research: Atmospheres 117 (D17).

JFSP 09-1-04-1: Development of modeling tools for predicting smoke dispersion from low-intensity fires.
PI – Warren Heilman

Why is this work important?

- The impacts of emissions from low-intensity fires used in fuels management are of concern because these prescribed fires often occur in the wildland-urban interface (WUI) where smoke can have adverse impacts on human health and safety.
- Of particular concern is the effect of local fire-vegetation-atmosphere interactions on smoke transport and dispersion within a forest canopy, and the potential for this smoke to linger for extended periods of time.
- This study focused on evaluating and adapting existing modeling systems specifically for predicting the meteorological and air quality impacts of low-intensity wildland fires in forested environments.

What did we learn?

<u>Key Findings</u>

- The presence of forest overstory vegetation and its typical heterogeneous qualities can alter the atmospheric turbulence environment throughout the vegetation layer, which in turn, affects how smoke plumes behave as they are transported away from low-intensity fires. Forest overstory tends to enhance mixing of smoke plumes immediately above the canopy, mostly in the horizontal direction, thus increasing the potential for impacting air quality in areas surrounding low-intensity fires.
- Plume heights associated with low-intensity fires beneath forest canopies can be highly variable and with increased resultant variability of downwind plume heights.
- The ARPS-CANOPY (a complex forest canopy flow simulation modeling system) coupled with the FLEXPART Lagrangian particle dispersion model is a potential predictive smoke modeling tool option for fire managers requiring detailed smoke dispersion information.
- Enhancement of the RAFLES modeling system are making it a viable research tool for studying local small-scale atmospheric responses to surface fires in forested environments.

<u>Management Implications</u>

- ARPS-CANOPY/FLEXPART prototype system will be available (September 2013) within a suite of predictive tools on the FCAMMS-Eastern Area Modeling Consortium (EAMS) website: http://www.nrs.fs.fed.us/eamc/products/.
- The observational datasets generated by the project are available for uploading to the SEMIP data warehouse.
- Additional prescribed fire experiments using on-site instrumentation are needed to improve understanding of forest vegetation, terrain, fire intensity,

and atmospheric conditions affecting the fire-fuel-atmosphere interactions and resulting smoke dispersion within and in the vicinity of the fire environment.

- Recent advances in the application of LIDAR technology for characterizing forest vegetation structure/architecture need to be incorporated into future fire-fuel-atmosphere interaction monitoring studies in order to improve parameterizations of canopy effects on atmospheric circulations in coupled fire-atmosphere and smoke prediction models.

Publications

Garrity, Steven R., Kevin Meyer, Kyle D. Maurer, Brady Hardiman, and Gil Bohrer. 2012. "Estimating Plot-Level Tree Structure in a Deciduous Forest by Combining Allometric Equations, Spatial Wavelet Analysis and Airborne LiDAR." Remote Sensing Letters 3 (5): 443–51. doi:10.1080/01431161.2011.618814.

Kiefer, M. T., S. Zhong, W. E. Heilman, J. J. Charney, and X. Bian. 2013. "Evaluation of an ARPS-Based Canopy Flow Modeling System for Use in Future Operational Smoke Prediction Efforts." Journal of Geophysical Research. Atmospheres 118 (12): 6175–88.

Kiefer, Michael T., Warren E. Heilman, Shiyuan Zhong, Joseph J. Charney, Xindi Bian, Nicholas S. Skowronski, John L. Hom, Kenneth L. Clark, Matthew Patterson, and Michael R. Gallagher. 2014. "Multiscale Simulation of a Prescribed Fire Event in the New Jersey Pine Barrens Using ARPS-CANOPY." Journal of Applied Meteorology and Climatology 53 (4): 793–812. doi:10.1175/JAMC-D-13-0131.1.

JFSP 09-1-4-02: Sub-canopy transport and dispersion of smoke: a unique observation dataset and model evaluation.
PI – Tara Strand

Why is this work important?

- Fire managers need to be able to accurately predict potential smoke dispersion from low-intensity prescribed burning operations in order to manage the potential smoke impacts to air quality that affect human health and safety.
- The BlueSky Modeling Framework links models and data sets together to make smoke dispersion predictions, and recent advancements have resulted in improved predictions for large wildfire events. However less attention had been paid to understanding the underlying capabilities of the Framework to predict smoke emissions, transport and surface concentrations from small low-intensity fires that often characterize prescribed burning operations.
- This project was designed to collect information that could be used to develop new modeling pathways within the BlueSky Framework and improve smoke predictions for low intensity prescribed fires.

What did we learn?

Key Findings

- Identified the best modeling pathway within the BlueSky Framework to operationally predict smoke concentrations from low intensity burns.
- Found that emission and smoke dispersion predictions can be easily improved by updating emission factor algorithms used in the BlueSky Framework.
- BlueSky modeling significantly under predicted measured smoke concentrations no matter how fuels and consumption data were used to tune model results.
- Using observed fuel loads would not improve predictions enough to warrant the expense and time to measure fuel loading.
- A simple Gaussian line source model shows promise as a viable option for predicting smoke concentrations near the burn.

Management Implications

- Fire managers could reduce the potential for unwanted smoke impacts by ending ignition earlier in the day. This would allow for more mixing and movement of smoke away from the forest floor and mitigate the amount of smoke trapped under the forest canopy.
- BlueSky predictions for low intensity burns could be improved by incorporating planned start and end times for burns and flame length limitations.

Publications

Seto, Daisuke, Craig B. Clements, and Warren E. Heilman. 2013. “Turbulence Spectra Measured during Fire Front Passage.” Agricultural and Forest Meteorology 169 (February): 195–210. doi:10.1016/j.agrformet.2012.09.015.

JFSP 09-1-04-5: Superfog formation and laboratory experiments and model development
PI – Marko Princevac

Why is this work important?

- Major multiple-vehicle accidents have occurred in the Southeastern US as a consequence of the formation of a dense smoke cloud or Superfog. A driver entering Superfog immediately experiences loss of visibility (to less than feet), which can result in chain reaction crashes. When this occurs on highways it can be especially tragic with injuries and loss of lives.
- This intense fog results from the combination of fine particulates and moisture under certain weather and terrain conditions. Superfog events generally occur in the early morning hours.
- Smoldering emissions from wildland fire can set up conditions that contribute to Superfog events, and therefore fire managers need to consider the likelihood of residual emissions contributing to Superfog when making decisions to burn.

What did we learn?

Key Findings

- Theoretical investigation using thermodynamic and visibility models confirmed the factors that most affect the development of Superfog and severely reduced visibility conditions.
- Experimental testing in specially designed fog and wind chambers showed that both small particles and water vapor must be present for Superfog to form. These experiments also found that Superfog is highly sensitive to small changes in environmental conditions such as wind, temperature, fuel moisture content and humidity. Conditions most conducive to Superfog were quantified and then used to develop a predictive model.
- The Superfog Assessment Model (SAM) is a two-dimensional boundary layer model that predicts the likelihood of Superfog forming at a burn site. Model inputs include temperature, relative humidity, atmospheric stability, heat and water vapor produced by a smoldering fuel bed, and fuel bed height. The model has been validated by laboratory experiments and is capable of predicting historic Superfog events.

Management Implications

- The Superfog Assessment Model (SAM) is designed to assess situations as favorable or unfavorable to Superfog formation, however it does not predict the spread of Superfog. SAM must be coupled with another model, such as PB-Piedmont, to identify where Superfog is most likely to occur.
- Although SAM requires a number of inputs that are not always readily available to fire managers, recommendations for approximations are provided in the User's Manual.
- SAM is ready for testing by fire managers under field conditions.

Publications *(None reported as of March 2017))*

JFSP 11-2-1-11: Data set for fuels, fire behavior, smoke and fire effects model development and evaluation.
PI – Roger Ottmar

Why is this work important?

- Outputs from fire models play a critical role in fire management decision-making and yet most models currently in use have not been objectively evaluated nor have their outputs been verified because of a lack of quality assured data. The lack of integrated, quality-assured datasets across key fire related disciplines reduces the ability to evaluate fire and smoke models and to answer fundamental fire questions.

What did we learn?

Key Findings

- The Prescribed Fire Combustion and Atmospheric Dynamics Research Experiment (RxCADRE) collected fire data on large and small operational burns and successfully developed synergies between fuel, atmospheric conditions, fire behavior, radiative power and energy, smoke and fire effects measurements; all critical inputs to fire model development and evaluation.
- Proved that it is possible to bring together many scientists and successfully and efficiently complete large research data collection campaigns. Strong leadership is a necessary component for success.
- These data are at the low end of fire intensity spectrum and represent a first step in building a comprehensive dataset to support evaluation and development of fir behavior, effects and emissions models.
- Many new tools and platforms were deployed and tested which will be of used in future studies.

Management Implications

- Quality assured datasets now exist in the Forest Service Research Data Archive and are accessible to all for development and evaluation of fire models.
- These datasets represent only a fraction of the fuel types and burn scenarios that managers deal with. Longer-term, more intense burns in complex and heavy fuels will be required to successfully validate and improve smoke and air quality models.
- RxCADRE produced a model upon which future interagency data collection efforts could be built.

Publications

Hudak, Andrew T., Roger D. Ottmar, Robert E. Vihnanek, and Clinton Wright. 2014. "Relationship of Post-Fire Ground Cover to Surface Fuel Loads and Consumption in Longleaf Pine Ecosystems." In Proceedings of 4th Fire Behavior and Fuels Conference, 235–40. Raleigh, NC. https://www.fs.usda.gov/treesearch-beta/pubs/46780.

Ottmar, Roger D., Robert E. Vihnanek, Clinton Wright, and Andrew T. Hudak. 2014. “Ground Measurements of Fuel and Fuel Consumption from Experimental and Operational Prescribed Fires at Eglin Air Force Base, Florida.” In Proceedings of 4th Fire Behavior and Fuels Conference, 227–34. Raleigh, NC. https://www.fs.usda.gov/treesearch-beta/pubs/46782.

Strand, Tara, Brian Gullett, Shawn Urbanski, Susan O’Neill, Brian Potter, Johanna Aurell, Amara Holder, Narasimhan Larkin, Mark Moore, and Miriam Rorig. 2016. “Grassland and Forest Understorey Biomass Emissions from Prescribed Fires in the South-Eastern United States – RxCADRE 2012.” International Journal of Wildland Fire 25 (1): 102–13. doi:10.1071/WF14166.

JFSP 12-3-1-06: Sensitivity analysis of air quality to meteorological changes in fire simulations.
PI – Talat Odman

Why is this work important?
Air quality models use meteorology and fire emissions data to quantify exposure to fire-related pollution and provide important information to fire and land managers. But the limitations inherent to these models must be identified and well understood to adequately interpret results and further improve the model's predictive skills. This project explored the implications of uncertain meteorological inputs on model predictions.

What did we learn?
Key Findings

- The Community Multi-scale Air Quality Modeling system (CMAQ) was reasonably accurate when predicting the local impact of a single fire, but performance was inferior in an extended regional-scale simulation or when modeling multiple fires.
- Simulations attempting to replicate the impact of fires on fine particulate ($PM_{2.5}$) concentrations are very sensitive to wind direction and wind speed in meteorological fields.
- The sensitivity of predicted $PM_{2.5}$ concentrations to wind fields increases as the grid resolution is refined in regional-scale models.
- There are significant uncertainties associated with meteorological fields produced by numerical weather prediction models used to drive air quality models.
- The errors typically associated with wind fields in meteorological inputs propagate into the results of air quality models and may considerably constrain their performance in fire-related simulations.

Management Implications

- Air quality forecasts predicting the impact of fires on air quality produced by atmospheric chemistry and transport models must be considered substantially uncertain.
- The performance of regional-scale chemical transport models in fire-related air quality forecasting largely depends on the accuracy of the meteorological inputs.
- The ability of current air quality models to replicate the impacts of wildland fires may be limited by the capability of existing numerical weather prediction systems.
- Improvements in meteorological modeling should be considered as one of the goals in any strategy designed to improve fire-related air quality simulations. The limitations in fire-related air quality simulations cannot be overcome solely by improving emission rates.

Publications

Garcia-Menendez, Fernando, Yongtao Hu, and Mehmet Talat Odman. 2013. "Simulating Smoke Transport from Wildland Fires with a Regional-Scale Air Quality Model: Sensitivity to Uncertain Wind Fields." Journal of Geophysical Research (Atmospheres) 118 (June): 6493–6504. doi:10.1002/jgrd.50524.

Odman, Mehmet Talat, Yongtao Hu, Fernando Garcia-Menendez, Aika Y. Davis, and Armistead Russell. 2013. "Fire and Air Quality Forecasts: Past, Present and Future." Environmental Management 1 (November): 12–21.

JFSP 13-S-01-01: Validating the next generation of wildland fire and smoke models for operational and research use – a national plan.
PI – Tim Brown

Why is this work important?

- A lack of comprehensive field measurements from heavy fuels, that define much of the observed smoke production, has inhibited needed detailed quantitative validation of smoke models that are used by fire, smoke and air quality managers.
- This plan organizes what is needed to facilitate inter-agency funding and support for a field campaign to collect appropriate and complete datasets for model validation and improvement.

What did we learn?

Key Findings

- Current smoke models are limited in their operational and research utility.
- Addressing the shortcomings in smoke models requires additional field observations.
- Field data are critical to scientific understanding and having an accurate predictive model.
- A wide range of wildland fire conditions, terrain and fuels would need to be observed to gather the necessary quantitative data for model evaluation and modification.
- Experts and specialized equipment across a wide range of disciplines are needed to measure the fire and smoke plume.
- Careful management of safety, logistic, and cost challenges is critical to success.

Management Implications

- A large-scale, multi-year campaign with three specific phases (project planning and sensitivity analyses, observations, and data analysis and archiving) is recommended.
- A collaborative, multi-agency, multi-university, multi-disciplinary approach is necessary.
- The total budget for this project, estimated over a five-year period, is roughly $20 million dollars.

Publications *(None reported as of March 2017))*

JFSP 15-S-01-01: Fire and Smoke Model Evaluation Experiment (FASMEE) - Phase I.
***Preliminary findings as of March 2017*.**
PI – Roger Ottmar

Why is this work important?

Advanced field measurements are necessary to evaluate and improve operationally-used fire and smoke modeling systems and the underlying scientific models. This field campaign will be conducted on large operational prescribed fires targeting heavy fuel loads and burned to produce high-intensity fires with developed plumes. (from the FASMEE website: https://www.fasmee.net)

What did we learn?

Key Preliminary Findings

- The Phase I study plan is under development and leads have been designated for each section of the experiment.
- Four candidate study areas have been selected with enthusiastic support from potential host agencies. Depending on funding, FASMEE will conduct at least one large operational burn in the southeastern U.S. and one in the western U.S.

Management Implications

- Data provided by this experiment will allow evaluation and improvement of fire and smoke modeling systems used by managers.

Publications *(None reported as of March 2017))*

SSP THEME III – SMOKE AND POPULATIONS

The SSP objective for the smoke and populations research theme is 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. In recent years it has become clear that smoke from fires, especially from "megafires", can impact not only the wildland urban interface but also large urban areas some distance removed from the fire itself. With more people exposed to wildland fire smoke comes the need to better understand how smoke affects human health, the levels of smoke that create different public health concerns, and how we can best warn the public when smoke events are imminent. Also, as fires become more frequent and larger, and the demands on firefighting resources increase, there is a need to understand the effects of extended exposure for firefighter health. The Smoke Science Plan envisioned research to 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 included:

1. The health effects of high concentrations of smoke on individuals, especially to identify "evacuation-levels" of exposure (including fire fighter smoke exposure implications).
2. The public perception and acceptability of smoke at high concentrations for extended durations.
3. Research into the best means for communication about smoke to the public and generating and distributing smoke information, especially smoke hazards, among responsible agencies.
4. 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).
5. Deepen understanding of public perceptions of the dangers from smoke and improved scientific basis for public health smoke warnings during large fire events.

Table 3 --- Theme III: Smoke and Populations

JFSP Project Number PI	Project Title	Status of Project or Expected Completion Date	Benefits to Additional Themes	Benefiting User Communities
10-1-3-02 Troy Hall	Examining the Influence of Communication Programs and Partnerships on Perceptions of Smoke Management	Completed		Social scientists, health officials
10-1-3-07 Eric Toman	Public Perceptions of Smoke: Contrasting Tolerance Amongst WUI and Urban Communities in the Interior West and the SE US	Completed		Fire managers
12-3-01-21 Christine Olsen	Public Perceptions of Smoke and Agency Communication: A Longitudinal Analysis	Completed		Social scientists, fire managers
13-1-02-14 Joe Domitrovich	Wildland Fire Smoke Health Effects on Wildland Fire Fighters and the Public	2016-Past Due		Fire, smoke and air quality managers; health officials
13-C-01-01 Bill Malm	Visual Range and Particulate Matter Data Analysis and Literature Review	Completed		Smoke and air quality managers
14-1-04-5 Michael Jerrett	Health Effects from Wildfire Air Pollution: a Spatiotemporal Modeling Approach	2017	I, II	Fire, smoke and air quality managers; health officials
14-1-04-9 Brian Reich	Estimating Fire Smoke Related Health Burden and Novel Tools to Manage Impacts on Urban Populations	2017	I, II	
14-1-04-16 Ian Gilmour	The Role of Composition and Particle Size on the Toxicity of Wildfire Emissions	2017	I, IV	
15-1-02-2 Joseph Vaughn	AIRPACT – Fire enhanced communication of human health risk with improved wildfire smoke modeling	2018	II	
15-1-02-4 Sim Larkin	US Smoke Hazard Warning System: Prototype and Enhancements to Operational Systems	2018	II	

JFSP 10-1-03-2: Public perceptions of smoke: contrasting tolerance amongst WUI and urban communities in the interior west and the south-central US. PI – Troy Hall

Why is this work important?

- As the need for prescribed fire increases, smoke impacts on communities are likely to increase. Thus, we need to better understand diverse public opinions toward forest fire smoke and society's willingness to tolerate short-term smoke in order to obtain long-term forest benefits.
- Results from this research provide a framework to develop effective public communication strategies that align with local and regional perspectives.

What did we learn?

Key Findings

- The two strongest predictors of public tolerance of smoke from wildland fires were being aware of prescribed fire's benefits and trust in fire managers. The same factors that have been shown to shape public acceptance of prescribed fire.
- People with previous adverse health experiences with smoke had a significantly lower tolerance for smoke.
- The lowest competency and credibility ratings, although still positive values, were for fire manager's ability to manage smoke and provide timely information regarding smoke.

Management Implications

- Although the public is generally tolerant of wildland fire smoke, it can be a significant concern for individuals who have had negative health experiences with smoke in the past.
- There is room for improvement regarding communication with the public about smoke management issues, and specifically the timing at which communication takes place. Results imply that the public desires advanced warning about potential smoke impacts and issues.
- The results of this project provide managers with a framework from which to shape public engagement strategies based on building and maintaining agency trust and reinforcing beliefs about ecological and community protection benefits of prescribed fire practices, while also being sensitive and proactive about regional and community perceptions of smoke impacts, especially those related to health impacts.
- Online tools from this project include a four-part series of YouTube videos presenting research results on smoke perception and a photo guide for communicating smoke impacts (https://www.frames.gov/partner-sites/emissions-and-smoke/research/perceptions/).

Publications

Blades, Jarod J., Steven R. Shook, and Troy E. Hall. 2014. "Smoke Management of Wildland and Prescribed Fire: Understanding Public Preferences and Trade-Offs." Canadian Journal of Forest Research 44 (11): 1344–55. doi:10.1139/cjfr-2014-0110.

JFSP 10-1-03-7: Examining the influence and effectiveness of communication programs and community partnerships on public perceptions of smoke management: a multi-regional analysis.
PI - Eric Toman

Why is this work important?

- Public tolerance of wildland fire smoke can affect the ability of managers to use prescribed burning as part of a fuels management program. Fire managers may be able to develop communications programs that increase acceptance of prescribed fire when they have a better understanding of the social acceptability of smoke management practices, factors influencing acceptability, and the effectiveness of different communication approaches on acceptability and beliefs.

What did we learn?

Key Findings

- A survey found that most communication efforts regarding smoke lacked strategic focus and were not coordinated across agencies. At the local level communication efforts were underfunded and understaffed and usually treated as "add-on" responsibilities to staff with a full suite of other duties.
- For the majority of the public surveyed, smoke from many types of fuel reduction fires was at least somewhat acceptable. Residents who perceive fewer risks from smoke as well as those who recognize more benefits of prescribed fire are more likely to have a higher acceptability of smoke.
- Informational messages can influence smoke acceptance. Each of the messages used in the communication experiment resulted in a significant decrease in participant concerns about smoke. Participants felt their level of knowledge regarding smoke emissions increased, as did their appreciation of the complexity of smoke management. They were also more likely to indicate they had a greater ability to control their own exposure to smoke.
- Participants were more positive towards agency managers, more likely to agree that managers could effectively manage smoke and were more confident in their ability to do so after receiving informational messages regarding wildland fire and smoke.

Management Implications

- Communication efforts appear likely to be able to increase citizen's understanding and acceptance of smoke.
- Some portion of the population will be sensitive to smoke and it is important to communicate strategies to help improve their ability to control their exposure to emissions.
- Enhance interagency coordination in communication efforts to develop clear, unified and consistent messages.

Publications

Engebretson, Jesse M., Troy E. Hall, Jarod J. Blades, Christine S. Olsen, Eric Toman, and Stacey S. Frederick. 2016. "Characterizing Public Tolerance of Smoke from Wildland Fires in Communities across the United States." Journal of Forestry 114 (6): 601–9. doi:10.5849/jof.14-142.

Olsen, Christine S., Danielle K. Mazzotta, Eric Toman, and A. Paige Fischer. 2014. "Communicating About Smoke from Wildland Fire: Challenges and Opportunities for Managers." Environmental Management 54 (3): 571–82. doi:10.1007/s00267-014-0312-0.

JFSP 12-3-01-21: Public perceptions of smoke and agency communication: a longitudinal analysis.
PI – Christine Olsen

Why is this work important?
Wildfires are increasing in size and intensity and the number of people living in communities affected by smoke are also increasing, resulting in more people being exposed to smoke. A big part of a successful prescribed fire program is community acceptance and support. Understanding the factors that influence citizen acceptance of smoke, and the impacts of fire and smoke experiences on public perceptions of smoke and fire management agencies, will enable managers to improve their communication methods related to wildland fire and smoke.

What did we learn?
Key Findings

- Overall perceptions about the agencies and smoke remained similar before and after a year of moderate fire activity that included an escaped prescribed fire near the Shasta-Trinity National Forest in California.
- Most respondents to this survey study agreed that smoke was acceptable from all types of fire including wildfire, prescribed fire, pile burns, agricultural burns, and private refuse burns.
- The only measured increase in perceived risk associated with smoke (and it was considered minimal) was confined to recreation-related impacts such as reduced recreation and tourism visits, and reduced opportunities for outdoor activities.
- A survey of 11 types of smoke information revealed an increase in the usefulness of television and radio messages and a decrease in usefulness of informational brochures and flyers. The most useful sources of information were interactive situations (educational workshops with agency staff) and websites. Social media ranked low, but this was likely a function of the older age of most respondents.

Management Implications

- Most people accept wildland fire smoke and this acceptance is resilient to smoke events. This may suggest that efforts to help the public understand that fire is a common and beneficial process have been effective and that a social culture of living with fire may be emerging in some areas. Continuing to promote messages of beneficial fire is a positive course of action for management agencies.
- A third of respondents in this study do not accept smoke and most of the reasons were health related. Understanding the background of people who object to smoke can help in the development of smoke management strategies and communication and outreach messages that best address their concerns.

Publications *(None reported as of March 2017))*

JFSP 13-1-02-14: Wildland fire smoke health effects on wildland fire fighters and the public.
PI – Joe Domitrovich

No progress report or findings available as of March 2017.

JFSP 13-C-01-01: Visual range and particulate matter data analysis and literature review.
PI – William Malm

Why is this work important?

- In situations where wildland fire has the potential to affect public health and air quality monitoring data is not available, some officials are turning to human observed visual range estimates (and associated particulate matter concentrations) to inform their public health warnings. However this method may not provide reliable results when used in conditions different from the unique environment it was originally designed for.

What did we learn?

Key Findings

- There are five uncertainties that come into play when trying to estimate a visual range and the associated particulate matter (PM) level. When all of these are added together particulate matter estimates could be off by a factor of 2.
- Visual range/particulate concentration relationships could be improved by including location, and; PM estimates could be improved by incorporating a measure of relative humidity.
- If observed visual range is going to be used to estimate the short-term (1-3 hour) average PM concentration, the air quality warning system should consist of no more than two levels of warning instead of the five currently used.
- Visual range should not be estimated by a human observer. There are more scientifically defensible procedures that could be used/developed.

Management Implications

- A simple alternative to the current method would be to develop "contrast cards" that can be visually compared to landscape features allowing for a better visibility estimate and in turn a better particulate estimate.
- A smart phone app could be developed to directly measure landscape feature contrast, which would allow calculation of visual range and therefore more accurate assessment of particulate concentration.

Publications *(None reported as of March 2017))*

JFSP 14-1-04-05: Health effects from wildfire air pollution: a spatiotemporal modeling approach.
Preliminary findings as of March 2017.
PIs – Michael Jerrett

Why is this work important?
Wildland fire emissions sometimes impact population centers and can have negative human health effects. More information is needed on the relationship between smoke exposure and health impacts, so that appropriate actions can be taken to protect public health.

What did we learn?
<u>Key Preliminary Findings</u>

- Created fine particulate ($PM_{2.5}$) prediction models that proved to be highly accurate within a single region, but these models did not extrapolate well to non-overlapping regions.
- After evaluating nine machine learning prediction algorithms for predicting ozone concentrations, two models, the randomized forest and generalized boosting models, provided the first good demonstrations of ozone concentration predictions related to wildfires.

<u>Management Implications</u>

- Fine particulate concentration predictive modeling based on statistical analysis of monitored data will need to be done for specific regions, making this type of smoke hazard warning systems more cumbersome.

Publications *(None reported as of March 2017))*

JFSP 14-1-04-9: Estimating fire smoke related health burden and novel tools to manage impacts on urban populations.
PI – Brian Reich

No progress report or findings available as of March 2017.

JFSP 14-1-04-16: The role of composition and particle size on the toxicity of wildfire emissions. *Preliminary findings as of March 2017.*
PIs – Ian Gilmour and Yong Ho Kim

Why is this work important?
Emissions from wildland fire contain a complex mixture of gases and particles. Very little is known about the toxicity of the particulate matter (PM) in smoke. This is the first study to specifically examine the toxicity and mutagenicity of emissions from different fuel types and combustion stages.

What did we learn?
Key Preliminary Findings

- Developed a novel combustion and smoke-collection system that features an automated tube furnace to control combustion phases (smoldering and flaming) and a multi-stage cryo-trap system to efficiently collect PM and semi-volatile phases of smoke emissions.
- Combusted five different fuels (red oak, peat, pine needles, pine and eucalyptus) under flaming and smoldering phase to represent contrasting fuel types, and assessed resulting PM for lung toxicity in mice and for mutagenicity in *Salmonella* bacteria.
- Determined biological outcomes in two ways: (1) as a potency expressed as toxicity per mass of PM, which is a unit used for regulatory decision-making, and (2) as an emission factor (EF) expressed as toxicity per mass of fuel burned, which is a unit used to express real-world exposures.
- Lung toxicity and mutagenic potencies of flaming emissions from biomass fuels were found to be greater than those of smoldering emissions (on a mass basis), whereas these toxicological endpoints resulted in greater responses for smoldering than flaming conditions on an EF basis.
- Eucalyptus and pine smoke emissions induced higher, but not statistically significant, toxicological outcomes compared to other biomass fuel emissions, suggesting that forests composed largely of eucalyptus and pine produced emissions that could cause greater health effects than comparable fires from forests composed of the other types of biomass fuels.
- A comparison of the mutagenicity data with published data for various combustion emissions indicated that the mutagenicity of the smoldering biomass emissions (on an EF basis) was greater than that of traffic emissions.

Management Implications

- Both ways of expressing toxicological outcomes (based on a potency and EF) should be considered in assessing the health effects of wildland fires.
- Researchers plan to provide guidance for firefighter and public health responses to wildland fires.

Publications *(None reported as of March 2017))*

JFSP 15-1-02-2: AIRPACT-Fire for enhanced communication of human health risk with improved wildfire smoke modeling.
Preliminary findings as of March 2017.
PI – Joseph Vaughn

Why is this work important?
A key component of hazard warning systems is the ability to predict air quality in order to communicate potential associated human health risks to the public. This holds true for forecasting the effects of wildland fire smoke events. This project plans to deliver enhanced wildfire-related air quality forecasts and "nowcasts" with associated health care demands by improving the modeling system, AIRPACT-Fire.

What did we learn?
Key Preliminary Findings

- Coupled atmosphere and fire behavior modeling experiments performed using WRF-SFire to model the Cougar Creek Fire (WA, 2015) show a significant sensitivity to initial fuel moisture conditions.
- High Resolution Rapid Refresh (HRRR) meteorology data, available from the NOAA National Center for Environmental Prediction (NCEP), initially appeared promising for use in now-casting fine particulate ($PM_{2.5}$) for the project. However researchers found that the data is not readily available in file formats most suitable for the air-quality modeling component of the system; Community Multi-scale Air Quality Model (CMAQ). The team is working to overcome this technical obstacle.
- A systematic literature search found information quantifying the sensitivity of human health for several respiratory or cardiovascular conditions in response to $PM_{2.5}$ associated with episodes of wildfire smoke. Generally, this literature seems adequate to inform development of a tool for projecting $PM_{2.5}$ forecasting into anticipatable health care demand.

Management Implications

- Because of WRF-SFire's sensitivity to initial fuel moisture, a product that can provide regularly updated estimates of 1 hr, 10 hr, 100 hr, and live fuel moisture classes at fire-model resolutions of ~30m would help model application.

Publications *(None reported as of March 2017))*

JFSP 15-1-02-4: US Smoke Hazard Warning System-prototype and enhancements to operational systems.
PI – Sim Larkin

No progress report or findings available as of March 2017.

SSP THEME IV– CLIMATE CHANGE AND SMOKE

The objective for the climate change and smoke research theme is to develop an understanding of the implications of wildfire smoke to and from climate change using IPCC scenarios as guidelines. One of the most important issues facing forest management, and perhaps still one somewhat controversial, is climate change. But the global climate is changing and the change is increasingly well documented. On a national basis, it is difficult to discern any climate change pattern because there is strong regional variability. Relationships between the global climate and regional climates are very complex and highly non-linear. As a result trying to determine how the changing global climate might affect fire and resultant air quality in the United States is a challenging multistep process. It involves a cascade of different simulation models. Firstly it requires models of the changing global climate and models capable of downscaling their results to simulate regional and sub-regional scale climates. Secondly, models capable of simulating ecological responses to the changing climate are needed. Thirdly, models able to simulate the effects of the altered ecology and climate on forests, and, especially on fuel buildup and fire regimes, are needed. Then finally, models to simulate fire occurrence, fuel consumption and smoke production are required. Because there are so many different models involved and models that in some cases are built upon completely different intellectual constructs and utilize different data in different ways, results may be vastly different and quite uncertain. In order to make progress on such a complex issue we felt it appropriate to utilize, to the extent possible, the efforts of the very large and significant climate research community. For this reason we suggested use of IPCC climate scenarios. In this way, any results from this research will be relevant to the broader climate change community.

Table 4 --- Theme IV: Smoke and Climate Change

JFSP Project Number PI	Project Title	Status of Project or Expected Completion Date	Benefits to Additional Themes	Benefiting User Communities
10-S-2-01 Sim Larkin	Identification of Necessary Conditions for Arctic Transport of Smoke from US Fires	Completed	I	Fire managers
11-1-5-12 Sonia Kreidenweis	Measuring the Optical Properties and Climate Impacts of Aerosol from Wild and Prescribed Fires in the US	Completed	I, II	Air quality modeling, emissions inventory and research
11-1-5-13 Serena Chung	Modeling Study of the Contribution of Fire Emissions on Black Carbon Concentrations and Deposition Rates	Completed	I	Fire, smoke and air quality managers; health officials
11-1-7-02 Yong Liu	Impacts of Mega-Fires on Large US Urban Area Air Quality Under Changing Climate and Fuels	Completed	III	Fire, smoke and air quality managers
11-1-7-04 Sim Larkin	Future Mega-Fires and Smoke Impacts	Completed	III	
12-S-1-02 Don McKenzie	Smoke Consequences of IPCC's Scenarios Projected Climate and Ecosystems Changes in the US - Review Paper	Completed	III	Fire and climate change researchers, fire planners
13-1-01-4 Jeffrey Pierce	Estimating the Effects of Changing Climate on Fires and Consequences for US Air Quality Using a Set of Global and Regional Climate Models	2017	I, II	
13-1-01-16 Uma Shankar	Assessing the Impacts on Smoke, Fire and Air Quality Due to Changes in Climate, Fuel Loads, and Wildfire Activity over the SE United States	2017	I, II	
16-S-01-2 Richard Birdsey	Potential Climate Feedbacks of Changing Fire Regimes in the US: A Review	Completed	I, II	

JFSP 10-S-02-1: Identification of necessary conditions for arctic transport of smoke from US fires.
PI – Sim Larkin

Why is this work important?

- Black carbon (BC) has been identified as a significant contributor to observed warming trends in the Arctic. Biomass burning, including wildland prescribed fires, is potentially a major source of BC reaching that area.
- The US is involved in international efforts to reduce BC emissions affecting the Arctic and is assessing potential emissions-reduction strategies; which may include limiting prescribed burning.
- There are large uncertainties in the current estimates of the sources, source regions, and transformation and transport of BC to the Artic region. This study provides the first comprehensive study of the meteorological conditions required for fire emissions to travel from the continental Unites States (CONUS) to the Arctic.

What did we learn?

Key Findings

- Results of forward-trajectory analyses simulating air parcel transport from 13,482 source points within the CONUS to the Arctic Circle showed that the potential for transport was highest from northern tier of states. And the region with the highest transport potential is within the northeastern U.S.
- Transport to the Arctic was also more likely during the winter and early spring months than late spring and summer.
- Although the southeast region has the most prescribed fire emissions, there is relatively low transport potential to the Arctic during the spring burning season.
- Plume injection height is key to whether or not emissions reach the Arctic. When smoke plumes rise to over 3000 meters, transport to the Arctic is likely all of the time from everywhere. Conversely, plumes less than 1000 meters are unlikely to contribute emissions to the Arctic.
- Even within seasons and regions with high levels of Arctic transport potential, there are a significant number of days when no Arctic transport is possible.

Management Implications

- Managers interested in mitigating Arctic BC effects can use the tools developed from this study to identify preferable months for burn activities, and get daily predictions for Arctic transport potential that can be used to inform decisions on the day of the burn: http://www.airfire.org/projects/arctic-transport/

Publications *(None reported as of March 2017)*

JFSP 11-1-5-12: Measuring optical properties and climate impacts of aerosol from wildfire and prescribed fire in the US.
PI – Sonia Kreidenweis

Why is this work important?

- Fire emissions evolve chemically and physically upon exposure to sunlight, other pollutants, and oxidants such as ozone (O3), hydroxyl radicals (OH), and nitrate (NO3) radicals. An improved understanding of the contributions of biomass burning emissions to local and regional photochemistry is required to quantify the impacts of prescribed and wild fires on fine particulate and ozone air quality standards, regional visibility and human health.
- Unraveling the contribution of wildland fire smoke to both fine particulate and secondary organic aerosols will help assess the success of smoke management policies and facilitate meeting air quality management goals.
- Findings from this project provided observational evidence of postulated chemical mechanisms in biomass burning plumes. They also provided observational tests of the applicability of emission factors developed using data from laboratory studies.

What did we learn?

Key Findings

- Sophisticated, state-of-the-science, aircraft-based measurements of the evolution of fire emissions from prescribed burns at Fort Jackson, South Carolina allowed quantification of emissions estimates for an unprecedented 97 trace gases, including a suite of monoterpenes emitted during pre-combustion heating of the fuels. Since monoterpenes are known to react quickly in the atmosphere with ozone to produce secondary organic aerosols, this work enabled the first data based estimates of their impacts on both net ozone formation and secondary organic aerosol formation.
- Aerosol species emission factors estimated from both lab and fieldwork are in reasonable agreement, except for organic carbon. Estimated organic carbon emission factors based on field observations are consistently and significantly lower than those derived from laboratory data.
- Emission factors for black carbon are higher based on real-time measurement methods, relative to existing filter-based estimates.

Management Implications

- This study allows for the refinement of emission inventories, especially for black carbon and secondary particle precursors, which will improve the ability of air quality modelers to assess the overall impacts of wildland fires on fine particle concentrations.
- The observational data showed that a large portion of the organic matter present in fine particles in a highly concentrated plume near the source would volatilize and repartition to the gas phase as the plume dilutes.

Therefore, air quality models attempting to represent near-field concentrations of fine particles in a diluting plume need to actively treat gas-particle partitioning.

- The ability to routinely monitor for smoke tracer compounds offers the air quality and fire management communities capabilities for identifying the total effect of wild and prescribed fires on regional fine particle concentrations. This work showed that at least one set of tracer ratios was conserved for several hours after emission, and thus may be useful for identifying the contribution of smoke to overall pollution loading.

Publications

Akagi, S. K., R. J. Yokelson, I. R. Burling, S. Meinardi, I. Simpson, D. R. Blake, G. R. McMeeking, et al. 2013. "Measurements of Reactive Trace Gases and Variable O3 Formation Rates in Some South Carolina Biomass Burning Plumes." Atmos. Chem. Phys. 13 (3): 1141–65. doi:10.5194/acp-13-1141-2013.

May, A. A., G. R. McMeeking, T. Lee, J. W. Taylor, J. S. Craven, I. Burling, A. P. Sullivan, et al. 2014. "Aerosol Emissions from Prescribed Fires in the United States: A Synthesis of Laboratory and Aircraft Measurements." Journal of Geophysical Research (Atmospheres) 119 (October): 11. doi:10.1002/2014JD021848.

Sullivan, A. P., A. A. May, T. Lee, G. R. McMeeking, S. M. Kreidenweis, S. K. Akagi, R. J. Yokelson, S. P. Urbanski, and J. L. Collett Jr. 2014. "Airborne Characterization of Smoke Marker Ratios from Prescribed Burning." Atmospheric Chemistry & Physics 14 (October): 10535–45. doi:10.5194/acp-14-10535-2014.

JFSP 11-1-05-13: Modeling the contribution of fire emissions on black carbon concentrations and deposition rates.
PI – Serena Chung

Why is this work important.

- Black carbon (BC) is recognized as an important contributor to global warming and climate change, particularly when deposited on snowfields and glaciers. Wildland fires are a major source of particulate emissions, including black carbon.
- The contribution of fire emissions to BC is expected to increase in the future due to the combination of expected reduction in non-biomass burning anthropogenic emissions and an increase in wildfire activity due to a warmer climate.
- Understanding the locations, time periods and impacts of BC from wildfires and prescribed burning may be useful should BC mitigation become a policy priority.

What did we learn?

<u>Key Findings</u>

- BC concentrations were significantly elevated by wildland fires in the western US during the 1997-2005 study period.
- Wildland fires contributed to greater than 50% of the monthly mean BC concentrations in ID, MT and northern WY during August and September.
- Wildland fire emissions contributed significantly to the inter-annual variations in August-mean BC concentrations in ID, MT, northern WY, UT, CO and the eastern Dakotas.
- Non-wildland fire sources dominated 2011 annual BC deposition rates to glacial areas in the US, though monthly contributions during summer from wildfires and during fall and winter from prescribed fires can be significant.
- Contributions of prescribed fires to annual BC deposition to glacier areas were greater than those of wildfires in 2011.
- Contributions of wildfires to BC deposition onto snow-covered surfaces were generally negligible because of smaller snowpack in the summer months when wildfires are more likely to occur.
- Prescribed fires can be significant contributors to BC deposition onto snow-covered surfaces when prescribed burning coincides with snow season.

<u>Management Implications</u>

- Both wildfire and prescribed fire make significant contributions to BC loadings at limited locations and times. Although a detailed analysis was done for 2011, extending to multiple years using new emission inventory tools would help quantify these conclusions. .
- A detailed, continuous, long-term fire emissions inventory built with new emission inventory tools and incorporating both wildfires and prescribed

burns is needed for climate change policy and other fire emissions related issues.

Publications *(None reported as of March 2017)*

JFSP 11-1-7-02: Impacts of Mega-Fire on Large US Urban Area Air Quality under Changing Climate and Fuels.
PI – Yong Liu

Why is this work important?

- Mega-fires, generally those over 200,000 acres in size with associated high environmental and human health impacts and expensive control efforts, have increased in number over the past twenty years and are predicted to continue to increase into the future. However making these predictions is a complex task.
- This project utilized statistical tools specific to extreme events, and several other innovative techniques, to make improvements on predictions of mega-fire occurrence and air quality impacts. Refining the predictions of where, when and why these extreme fire events occur is important to planning future fire management and emergency response efforts, as well as air quality planning.

What did we learn?

Key Findings

- Changes in the projected Keetch-Byram Drought Index (KBDI), an important fire weather index, show that the number of months with high to extreme fire potential will increase by 1-3 months in the future (2041-2070). Results also show that future fire potential will increase by one grade (i.e. moderate risk to high risk) in many regions.
- Mega-fires are projected to increase by nearly 60% by the middle of this century, despite large variability among regional climate change scenarios.
- An algorithm was developed to improve ecosystem modeling of fuel load in regional climate change models. Results using this algorithm project an increase in fuel load for the future, mainly in the western U.S. Results using a gap filling climate simulation that allowed a gradual change in climate produced less dramatic increases.
- The fine particulate emissions from mega-fires increased several times from the relatively inactive fire period of 1980-1996 to the active fire period of 1997-2013 and are expected to increase nearly 80% in the future. Cities predicted to be most affected are those in the Southwest and southern Pacific coast due to increased mega-fires and fuel loading. For Southeastern cities where fires are expected to increase but fuel loading is expected to decrease (at least under some regional climate change scenarios) the picture is more complex.
- Mega-fires are so rare that extreme value statistics are needed to estimate their potential response to changing climates. Coupled with the climate, fuel loading and fire occurrence uncertainties attempts at prediction are confounded.

- New models used downscaled regional climate change simulations to dynamically estimate vegetation response, resulting fuel loadings and even fire potential between the present and the 2070's.

Management Implications

- Prescribed burn windows are expected mostly to become shorter in the future in the eastern U.S., the Pacific coast and southwestern border areas due to increasing risks of fire escaping.
- Air quality will be more impacted by mega-fires in some regions, e.g. the Southwest and Pacific coast, under anticipated 21st century climate change.
- A new model was developed to project mega-fire occurrence that better accounts for the extreme weather conditions associated with such fires.
- A single-day burn detection scheme was developed that has the potential for monitoring and tracking the spatial development of burned areas in rapid response applications.

Publications

Liu, Yongqiang. 2014. "A Regression Model for Smoke Plume Rise of Prescribed Fires Using Meteorological Conditions." Journal of Applied Meteorology and Climatology 53 (8): 1961–75. doi:10.1175/JAMC-D-13-0114.1.

Liu, Yongqiang, Scott Goodrick, and Warren Heilman. 2014. "Wildland Fire Emissions, Carbon, and Climate: Wildfire–climate Interactions." Forest Ecology and Management, Wildland fire emissions, carbon, and climate: Science overview and knowledge needs, 317 (April): 80–96. doi:10.1016/j.foreco.2013.02.020.

Liu, Yongqiang, Scott L. Goodrick, and John A. Stanturf. 2013. "Future U.S. Wildfire Potential Trends Projected Using a Dynamically Downscaled Climate Change Scenario." Forest Ecology and Management, The Mega-fire reality, 294 (April): 120–35. doi:10.1016/j.foreco.2012.06.049.

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Yang, Jia, Hanqin Tian, Bo Tao, Wei Ren, John Kush, Yongqiang Liu, and Yuhang Wang. 2014. "Spatial and Temporal Patterns of Global Burned Area in Response to Anthropogenic and Environmental Factors: Reconstructing Global Fire History for the 20th and Early 21st Centuries." Journal of Geophysical Research (Biogeosciences) 119 (3): 249–63. doi:10.1002/2013JG002532.

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JFSP 11-1-7-04: Future mega-fires and smoke impacts.
PI – Sim Larkin

Why is this work important?

- Megafire events, in which large high-intensity fires propagate over extended periods, can cause both immediate damage to the local environment and affect the air quality and health of those living downwind.
- Climate change research is projecting more frequent and extensive megafire events. Predicting the areas where megafires are likely to occur in the future and prioritizing potential air quality impacts can inform management actions that may be able to mitigate risks and human health impacts.

What did we learn?

Key Findings

- Overall megafire risk during the mid-century (2046-2065) is predicted to increase and be greatest in the western US and in limited areas along the east coast and upper Midwest. The highest-ranking areas for likelihood of Very Large Fires (VLF) are found in the west and include the Rockies, Cascades, Sierra Nevadas, and Great Basin regions. For the east, the areas with the highest likelihood of VLF are the upper Minnesota/Wisconsin and Upper Peninsula region and the southeastern seaboard (including the Carolinas, Georgia and Florida).
- The seasonal window of VLF is projected to lengthen across many regions of the US, mainly due to earlier onset of spring fires.
- *Smoke Risk* is a measure of how smoke from the source location might impact human populations in the future, due to both the probability of a megafire at that location and the ability of that smoke to be transported into human population centers.
- *Smoke Risk* is projected to be most heavily concentrated in California and areas upwind from population centers in Nevada. Minnesota ranks high due to potential for very large emissions from peat fires. The Ozarks are elevated in rank for smoke risk due to the potential to transport to both Midwest and eastern population centers. Although the eastern seaboard retains areas of significant overall risk, the rankings for this region - particularly those with potential for significant peat fires - are tempered due to the prevailing westerly winds that tend to move smoke into the Atlantic.

Management Implications

- *Smoke Impact Potential* (SIP) metric was developed using fire emissions and smoke transport patterns to smoke sensitive areas such as population centers, non-attainment areas and Class I wilderness areas.
- The climatological maps of Smoke Impact Potential (SIP) could easily be converted into an assessment tool for regional commands (or GACCs) seeking a simple system to rank fires based on smoke impact potential.

Publications

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Barbero, R., J. T. Abatzoglou, E. A. Steel, and Narasimhan K. Larkin. 2014. "Modeling Very Large-Fire Occurrences over the Continental United States from Weather and Climate Forcing." Environmental Research Letters 9 (12): 124009. doi:10.1088/1748-9326/9/12/124009.

Barbero, Renaud, John T. Abatzoglou, Crystal A. Kolden, Katherine C. Hegewisch, Narasimhan K. Larkin, and Harry Podschwit. 2015. "Multi-Scalar Influence of Weather and Climate on Very Large-Fires in the Eastern United States." International Journal of Climatology 35 (June): 2180–86. doi:10.1002/joc.4090.

Stavros, E. Natasha, John Abatzoglou, Narasimhan K. Larkin, Donald McKenzie, and E. Ashley Steel. 2014. "Climate and Very Large Wildland Fires in the Contiguous Western USA." International Journal of Wildland Fire 23 (7): 899–914. doi:10.1071/WF13169.

Stavros, E. Natasha, John T. Abatzoglou, Donald McKenzie, and Narasimhan K. Larkin. 2014. "Regional Projections of the Likelihood of Very Large Wildland Fires under a Changing Climate in the Contiguous Western United States." Climatic Change 126 (3–4): 455–68. doi:10.1007/s10584-014-1229-6.

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JFSP 12-S-01-2: Smoke consequences of IPCC's scenarios projected climate and ecosystem changes in the U.S. – Review paper.
PI – Don McKenzie

Why is this work important?

- A changing climate appears to be altering the fire ecology of forests and grasslands through out the US. Climate and ecosystem simulation models used by the United Nations Intergovernmental Panel on Climate Change (IPCC) suggest that changes in future climate may drive significant alterations of forests, shrub and grasslands and their associated fire regimes. Forest managers will be challenged by this uncertain future.
- Among the challenges faced by both forest and air quality managers are increased amounts of smoke deteriorating air quality and visibility.
- This paper reviews the current state of knowledge in the chain of simulation modeling being used to project these changes. This chain includes regional climate models, ecosystem dynamics models, fuels models, fire models and air quality models. Each component model in the chain has different accuracies and uncertainties that are affected by linkages between different modeling approaches.
- The JFSP Smoke Science Plan will provide estimates of changes in smoke over the 21st century. This paper will provide background to help managers evaluate and properly use these estimates.

What did we learn?

Key Findings

- The paper identifies 4 alternate pathways through the chain of models required to simulate smoke in a climate-changed future. These alternative pathways are chosen to: (1) minimize cumulative errors, uncertainties and biases; (2) be computationally feasible; (3) yield transparent results, and; (4) be robust toward future projections. Each of the pathways has advantages and disadvantages that are discussed in depth.
- The paper offers a few concepts to consider when selecting alternative modeling approaches. They are: (1) dynamic and coupled models are better than static and linked models; (2) projecting distributions is better than projecting points; (3) scales must match up; (4) keep it as simple as possible; (5) limit use of adjustments, and; (6) consider which uncertainties are acceptable and which are unacceptable.

Management Implications

- If the climate is changing, models are the only way to estimate of future impacts of smoke.
- This paper provides background on how to interpret and potentially utilize model results from JFSP projects that will be projecting climate-changed future forests, fire regimes and resulting smoke and air quality impacts.

Publications

Keane, Robert E., Uma Shankar, E. Natasha Stavros, Warren E. Heilman, Allen C. Riebau, Douglas G. Fox, and Don McKenzie. 2014. "Smoke Consequences of New Wildfire Regimes Driven by Climate Change." Earth's Future 2 (2): 35–59.

JFSP 13-1-01-4: Estimating the effects of changing climate on fires and consequences for US air quality using a set of global and regional climate models.
Preliminary findings as of March 2017.
PI – Jeffrey Pierce

Why is this work important?

The extent and intensity of wildfires has been increasing and that trend is predicted to increase in future years. It is important to understand the consequences of future fire activity on air quality over the United States so that air quality and fire managers can prepare to protect human health. This project focused on two major air pollutants, fine particulate ($PM_{2.5}$) and ozone. The global Community Earth System Model (CESM) was employed for this project and used the IPCC Representative Concentration Pathway (RCP) climate, emissions and land use and the Shared Socioeconomic Pathway (SSP) population projections. Within CESM, a complex-based fire parameterization [Li et al., 2012] was used to project future climate-driven and human-caused fire emissions.

What did we learn?

<u>Key Preliminary Findings</u>

- After 2050, fire emissions may be the dominant source of summertime $PM_{2.5}$ in many regions across the US, and offset the benefits of reducing anthropogenic emissions.
- An unexpected result was that after 2050, fire emissions may be the dominant source of summertime PM_{25} over the eastern U.S., and many states in this region may not attain the EPA National Ambient Air Quality Standard of 12 ug/m^3. The eastern US region is not traditionally considered under high fire risk, but it is located downwind from Canada and Alaska and increased emissions from fires over the boreal forests are projected to have a significant impact on future air quality over the eastern US.
- Demographic changes may be a key factor controlling future fire emissions. Area burned is very sensitive to population density, and future population growth may reinforce or counteract the impact of fire activity due to climate on a regional scale.
- Simulations showed that future changes in area burned over North America will be more noticeable after 2080 and this led to expanding the scope of the project to the end of the century.
- In the future, agricultural fires will account for about 5-10% of the total area burned across the US.

<u>Management Implications</u>

- Controlling anthropogenic emissions may not be enough to attain future air quality targets. (Air Regulators)

- In future studies that project fire activity, researchers need to take into account both climate and demographic changes. (Researchers)
- Agricultural fires need to be considered in future air quality studies. (Researchers)
- Better agricultural practices will need to be developed and new fire suppression strategies established to minimize fire pollution impacts. (Smoke managers)

Publications

Val Martin, Maria, Jeffrey Pierce, and Collett Heald. 2015. "Studying the Effects of Changing Climate on Wildfires and Impacts to the Unites States Air Quality." Fire Management Today 74 (3): 28–30.

JFSP 13-1-01-16: Assessing the impacts on smoke, fire and air quality due to changes in climate, fuel loads, and wildfire activity over the Southeastern U.S.
Progress and Methodology as of March 2017.
PI – Uma Shankar

Why is this work important?
The extent and intensity of wildfire has been increasing steadily in recent years and that trend is expected to increase given the projected changes in climate. Emissions from larger and more intense fires impact a greater portion of the pubic. It is important to understand the potential impacts on air quality so that information can be factored into public health and air quality regulation planning.

Progress and Methodology

- Completed selection of high and low fire years from two representative decades, current (2000 - 2005) and future (2040-2050), using two general circulation model (GCM) results. Future years were simulated with two different Representative Concentration Pathways (RCP 4.5 and RCP 8.5) for greenhouse gas forcing by the end of the century.
- Completed regional climate modeling for the Southeastern U.S. for the 12-member ensemble of cases developed above.
- Developed a methodology for fuel load projections using the GCMs' Dynamic Global Vegetation Model outputs in three carbon compartments: leaf, litter and coarse woody debris, relative to the FCCS fuel loads representing the historical period (2005).
- Completed the baseline (no fuel load change) estimation of daily wildfire emissions to create wildfire emission inventories for the 12 cases, and merged these with anthropogenic emissions for the air quality modeling.
- Work continues on estimating the sensitivity of wildfire emissions to fuel load changes. Inputs to the BlueSky/CONSUME fire emissions model are being modified to capture changes in the spatial variability of the fuel loads in the Southeast by mid-century relative to the baseline spatial distribution in 2005. Currently testing these modifications for sensitivity to fuel loads with a short-term study (3 months) comparing the baseline impacts on wildfire emissions to the impacts in the 2016 wildfire season in the Southeast. The combination of unusually large amounts of fuel and drought conditions led to catastrophic wildfires late in 2016 that offer good data for evaluating the fuel load projection methodology developed by this project.
- Work continues on modeling the future decade (2040-2050) air quality for the RCP4.5 and RCP8.5 scenarios.
- A background methodology paper was published on projecting annual area burned into future years. This provided the basis for the daily "area burned" estimates for the fire inventories.

Publications

Prestemon, Jeffrey P., Uma Shankar, Aijun Xiu, K. Talgo, D. Yang, Ernest Dixon, Donald McKenzie, and Karen L. Abt. 2016. "Projecting Wildfire Area Burned in the South-Eastern United States, 2011–60." International Journal of Wildland Fire 25 (7): 715–29. doi:10.1071/WF15124.

JFSP 16-S-01-2: Potential Climate Feedbacks of Changing Fire Regimes in the US: A Review
PI – Richard Birdsey

Why is this work important.
Wildland fire is a disturbance that can profoundly impact the environment and human health and welfare. While climate is generally a critical driving factor shaping the occurrence and impacts of fire, fire can also play a role in shaping climate. With an increasing trend in wildland fire occurrence and extent, it is important to understand how this change might influence climate.

What did we learn?
<u>Key Findings</u>

- Both the effects of wildland fire emissions on atmospheric radiative forcing and fire-induced landscape modifications that change earth's surface influence climate.
- Biomass burning is considered one of the major sources of organic carbon (OC) emissions. OC is likely to cause strong warming effects, not only from its black carbon component but also from other carbon aerosols whose radiative climate impacts are less well quantified in most climate models.
- Aerosol and related VOC emissions vary considerably across vegetation and fuel types, vegetative state, and species composition and with regard to fire intensity. This makes quantification of emissions, and subsequent warming and cooling effects on climate, difficult.
- Poor characterization of ozone production from fire plumes largely impedes assessment of the impacts of wildfires on air quality. One example is that oxygenated volatile organic compounds (OVOCs) may account for 60-70% of VOC mass emitted from wildfire plumes, but OVOCs are not well characterized in emissions inventories. Characterization of OVOCs and their evolution in fire plumes is essential to assess the impact of fire emissions on regional and global air quality and climate.

<u>Management Implications</u>

- The biggest challenge in quantifying the impacts of wildland fire on climate is the lack of high-quality and extensive data streams for fire occurrences and emissions. Fire data on fuel characteristics, burn severity, burn area, fuel consumption and the fire weather, all at appropriate spatial scales, is especially important.
- Current estimates show that carbon emissions from all fires in the US are comparable to the net uptake of carbon from the atmosphere by forests in the US; meaning that US forests may not be a net carbon sink when fires are taken into account.
- Three key issues for future mechanistic studies of fire feedback to climate are: the composition and dynamics of fire-emitted aerosols and their functional mechanisms in radiation budget and cloud formation, clarification

of the role of secondary products from fire emissions in radiative budgets and atmospheric boundary processes, and the use of a coupled modeling approach with ground and satellite derived data to investigate the mechanisms and contribution of fire-induced vegetation dynamics, land use and land cover changes to climate.

Publications *(None reported as of March 2017)*