Final Report to the Joint Fire Science Program
Project #08-1-6-10

Phase 1 of the Smoke and Emissions Model Intercomparison Project (SEMIP): Creation of SEMIP and Evaluation of Current Models

SEMIP Smoke and Emissions Model Intercomparison Project

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Abstract

Managers, regulators, and others often need information on the emissions from wildland fire and their expected smoke impacts. In order to create this information, combinations of models are utilized. The modeling steps follow a logical progression from fire activity through to emissions and dispersion. In general, several models and/or datasets are available for each modeling step, resulting in a large number of combinations that can be created to produce fire emissions or smoke impacts. Researchers, managers, and policy makers need information on how different model choices affect the resulting output, and guidance on what choices to make in selecting the models that best represent their management requirements. Baseline comparisons are needed between available models that highlight how they intercompare and, where possible, how their results compare with observations. As new models and methods are developed, standard protocols and comparison metrics are necessary to allow for these new systems to be understood in light of previous models and methods.

The Smoke and Emissions Model Intercomparison Project (SEMIP) was designed to facilitate such comparisons. This project was designed to be the first step in a broader effort, and hence was titled Phase 1 of SEMIP. In Phase 1, SEMIP:

- Examined the needs for fire emissions and smoke impact modeling;
- Determined what data were available to help evaluate such models;
- Identified a number of test cases that can serve as baseline comparisons between existing models and standard comparisons for new models;
- Created a data warehouse and data sharing structure to help facilitate future comparisons; and
- Performed a number of intercomparison analyses to examine existing models.

SEMIP so far has resulted in:

- Multiple peer reviewed journal articles and other documents;
- Over 20 presentations;
- Discussions with the EPA, JFSP, USFS F&AM, DOI, NWCG, and others on how to improve fire emissions calculations;
- New fire emissions analysis tools;
- Presentations and discussions with the JFSP on how to gather field observations useful to this type of analyses; and
- Discussions with the JFSP on data sharing and archiving.

SEMIP has also been acknowledged in recent RFAs from both the JFSP and NASA.

1. Background and Purpose

The scientific community has created many datasets and models that can be used to estimate fire emissions and downwind smoke pollutant concentrations from wild and prescribed fires. To estimate emission and/or smoke impacts, several of these models and datasets must be linked into a chain, consisting of fire location information, available fuel loading, fraction of fuel consumed, consumption rate over time, emission factors, plume height, and dispersion/plume chemistry. Land managers, air quality managers, regulators, and practitioners rely upon these estimates to make decisions about planned burning, air quality forecasting, and regulation. These decisions are critical to wildland management and the protection of public health. Managers, researchers, and others requiring fire emissions and smoke impact information need information on how models inter-compare and perform against observations. Which steps in the modeling chain are the most critical to obtaining realistic values? How does choosing one model versus another affect the results? Where do the biggest scientific weaknesses and greatest uncertainties lie?

The Smoke and Emissions Model Intercomparison Project (SEMIP) was designed to provide an expandable and open framework for organizing and addressing these critical issues in fire emissions and smoke impact modeling. The SEMIP structure includes:

1) Definition of a sequence of *model steps* necessary to estimate emissions and downwind concentrations;
2) Definition of *model output levels* in between model steps where different model pathway results can be directly compared;
3) Creation of *test cases* that are designed to evaluate one or more models by comparing model output to other model output and/or to observed data; and
4) Development of infrastructure for supporting model and data intercomparison, including a *data warehouse* and *metadata catalog*.

The development of this structure provides many benefits:

- Systematic intercomparisons between models and between model chains can be performed;
- Systematic comparisons between models and observations can be performed;
- Areas most critically in need of research can be identified;
- Areas of greatest uncertainty can be identified;
- New models and datasets can be tested against existing models and established benchmarks for specific test cases;
- New test cases can be added as evaluation data become available or key needs are identified; and
- Researchers can contribute their own models, datasets, and test cases.

In addition to laying out the structure needed to organize future research, as part of this project, labeled as Phase 1 of SEMIP, numerous analyses were identified and performed, spanning six model output levels across nine test cases. Key findings are detailed in this document, but additional information can be found in a detailed Technical Report (Larkin et al., 2012).

2. Study Description and Location

Modeling fire emissions and smoke impacts follows a logical progression of questions:

- Where were the fires and how big were they?
- What fuels were available to burn?
- How much fuel was consumed?
- When and how was it consumed?
- What emissions were produced?
- How high up into the atmosphere did the smoke go?
- Where did the smoke get transported?
- How was the smoke altered during transport?

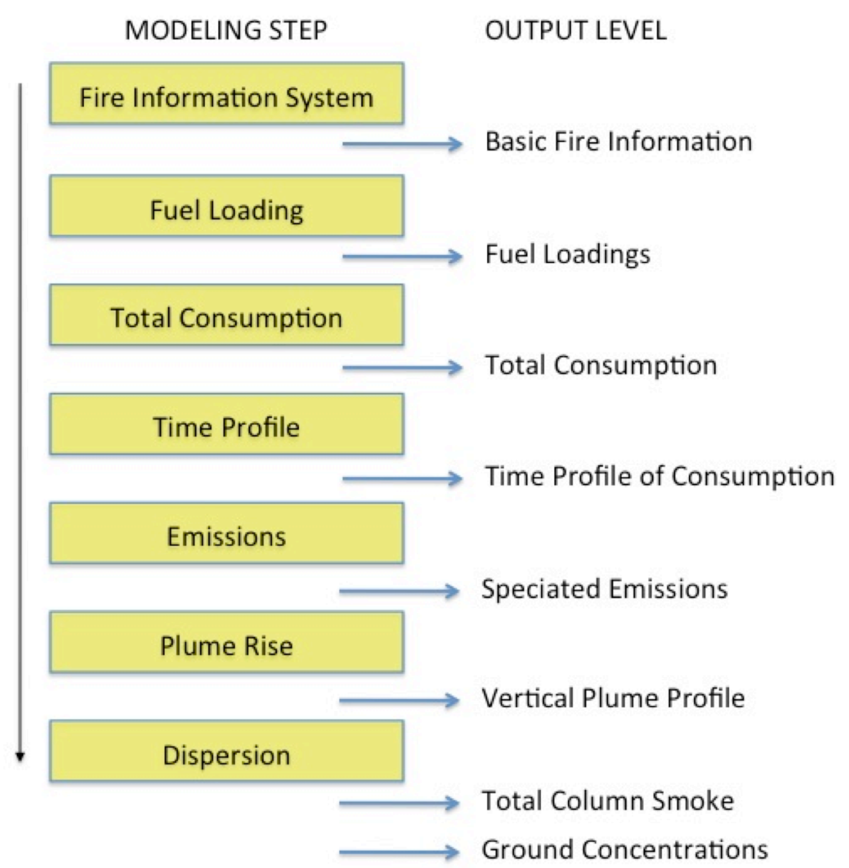


Figure 1. Modeling chain including modeling steps and output levels identified and examined by SEMIP. See Section 3.1 for more details. Note that the TIME PROFILE modeling step can also be placed after EMISSIONS, in which case the output level becomes the Time Profile of Emissions. Plume chemistry was not treated by SEMIP:Phase 1.

These questions form a sequence of *modeling steps* (Figure 1) from Fire Information to Fuels, Total Consumption, Time Profile of Consumption, Emissions, Plume Rise, and Dispersion. Fire emissions modeling stops after Emissions, while surface ($PM_{2.5}$) concentration modeling stops after Dispersion. The Time Profile of Consumption step is only needed if time-resolved emissions are required.[1]

Each modeling step results in an *output level* (Figure 1) where output from the models can be evaluated. SEMIP specifies a set of output levels, output variables, and statistical analyses at each output level (see Larkin et al., 2012 Appendix D for details).

SEMIP has identified a number of *test cases* (Figure 2) to create a focus for analyses and enable a standard set of metrics in order to create a baseline for evaluation of models both now and into the future. Test cases were selected to represent real-world applications of the various models and modelling chains tested within SEMIP. In aggregate, these test cases ideally cover the majority of real-world use cases. In practice, the test cases are necessarily more limited, largely due to restrictions of data availability. The identified test cases are a cross between available data and the need to represent the widest possible array of usage needs. As the science and usage needs evolve, or as additional data become available, additional test cases will be necessary to fully represent the needs of the scientific and management communities. The current test cases can only provide an initial, imperfect attempt to capture as much of the needed initial analyses as possible.

The test cases used in SEMIP:Phase 1 (Figure 2) were:

1. **Fires Everywhere:** for examining fuels, consumption, and emissions throughout CONUS;
2. **2008 National Emissions Inventory:** for examining the fuels, consumption, and emissions as they create a multi-use emissions inventory (test case currently limited to large fires);
3. **2007/2008 California Wildfires:** for examining emissions and smoke in a large regional fire setting;
4. **2007 Bugaboo Complex:** for examining emissions and smoke in a large wildfire complex in the southeast that has deep organic consumption;
5. **2006 Tripod Complex:** for examining emissions and smoke in a large wildfire complex in the west;

[1] Depending on the models used, the time profile step can occur simultaneously with computing total consumption, after computing total consumption, or simultaneously with computing total emissions. We make the distinction between Total Consumption and Time Profile of Consumption modeling steps because there are different observations and analyses that can be applied to the total amount of fuel consumed and to the time resolved rate of consumption.

6. **Northwest Prescribed Burning:** for examining emissions and smoke in a large regional prescribed burn setting in the west; [deprecated for Phase 1]
7. **Southeast Prescribed Burning:** for examining emissions and smoke in a large regional prescribed burn setting in the southeast; [deprecated for Phase 1]
8. **2009 Naches Prescribed Burn:** for examining emissions and smoke from a single prescribed fire; and
9. **Multi-year Plume Case:** for examining plume rise as seen by satellites across multiple years.

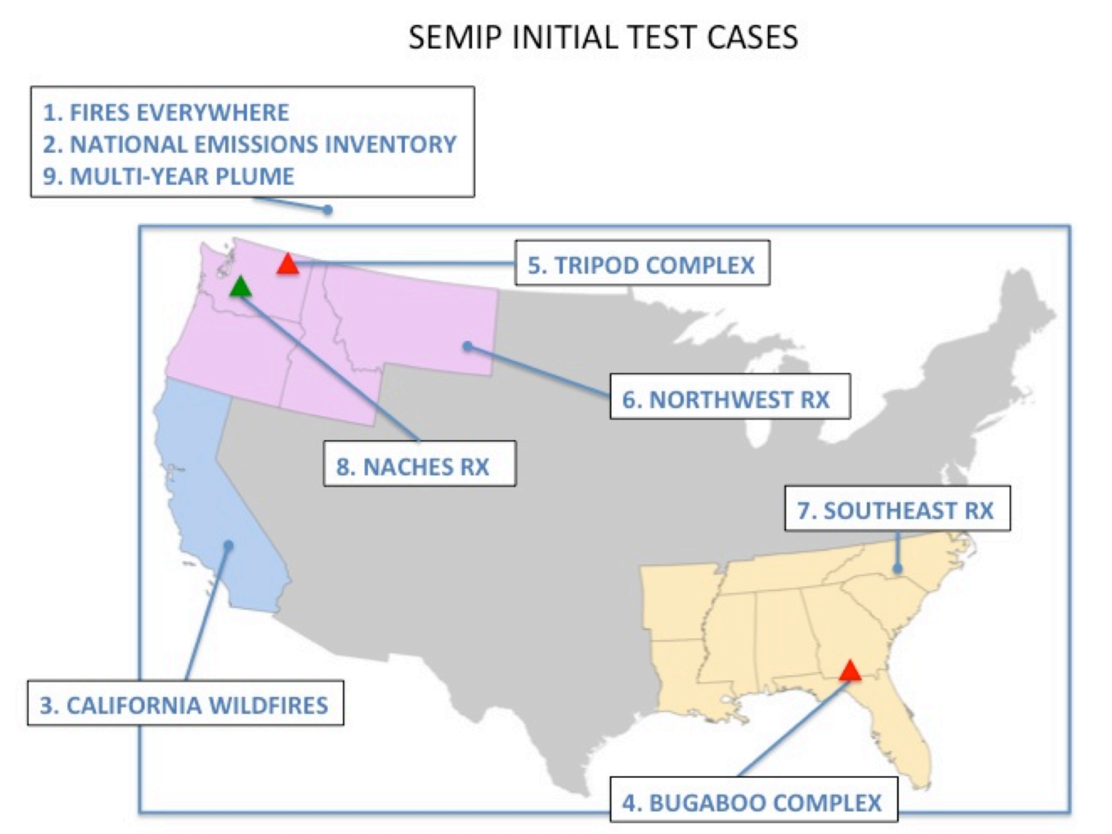


Figure 2. Map showing the locations of the SEMIP test cases. Locations of individual fires (Tripod Complex, Bugaboo Complex, and Naches Prescribed Fire) are shown with triangles. The area of interest is shaded for the regional cases (California Wildfires, Northwest Prescribed Fires, Southeast Prescribed Fires). As discussed in the text, the test cases cannot fully represent the usage needs for fire emissions and smoke impact modeling; additional test cases will be needed as data become available.

For each test case a number of potential analyses were identified, and a subset of the most urgent analyses were performed as part of SEMIP:Phase 1 (Figure 3).

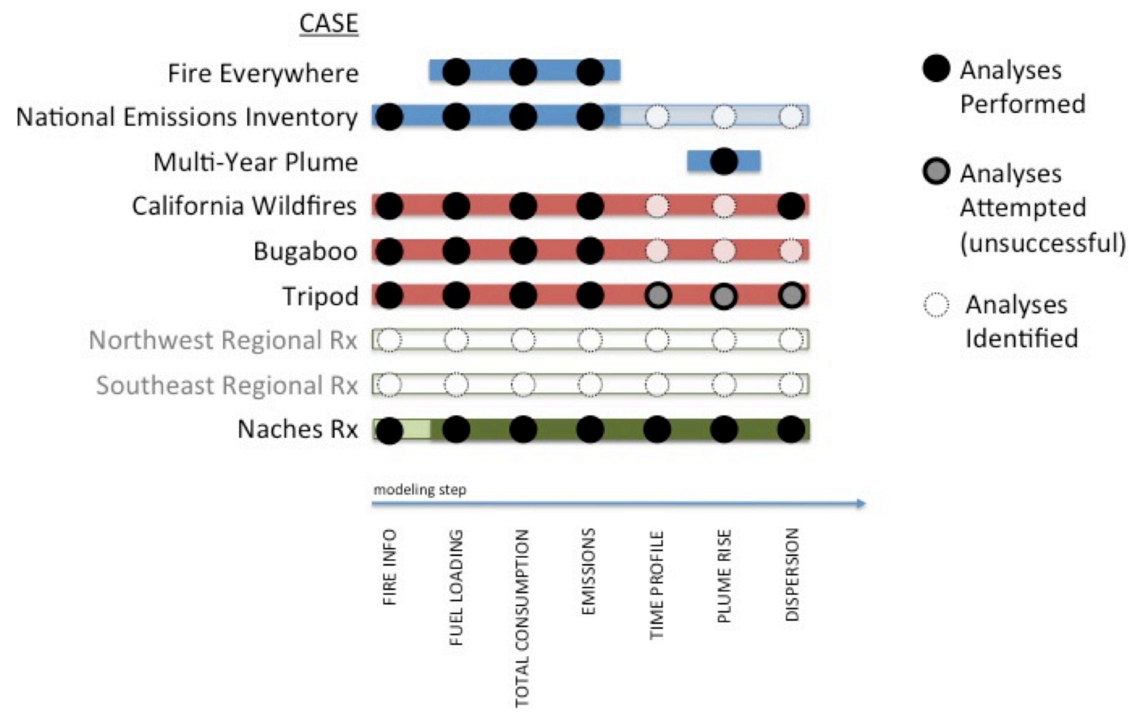


Figure 3. Analyses identified, performed, and attempted by modeling step and test case. Where analyses related to a modeling step were completed, black circles are shown. Unsuccessful analyses are shown with a grey circle. Where potential analyses were identified but not performed as part of SEMIP:Phase 1, a dashed grey line and grey circle are shown. Solid-color bars for a test case indicate the original intention of the test case; lighter-colored bars show how test cases were extended into additional modeling steps.

3. Key findings

SEMIP covered a wide swath of activities, models, datasets, and analyses. As such, the results of SEMIP are broad. Highlights of key findings are listed here, but the interested party is advised to also see the SEMIP General Technical Report (Larkin et al., 2012) for a more detailed discussion of these issues.

3.1 Key Overall SEMIP Findings:

There is a community need to share and maintain data. While a large amount of data has been collected across the area of interest studied in SEMIP, access to observational data and model code has been problematic. Data access issues are now being directly addressed by the JFSP; however, questions still remain as to whether the preferred archives (e.g., the USFS Data Archive) are capable of housing the ancillary (not directly observed) data required to maintain a functioning test case. Of particular concern is meteorological model output data sets (e.g., from the National Weather Service) which can range in size from tens of Gigabytes to Terabytes and are required to enable smoke modeling.

There is a community need for test cases. While there is are many scattered data sets available, making a worthwhile focus (test case) for extended study requires a density of data that is difficult to find in order to allow for many different comparisons and analyses. In particular, addressing questions with regard to smoke modeling requires data from all parts of the fire modeling chain – fire behavior, fuels, consumption, emissions, plume structures, meteorology, and smoke impacts. Perhaps in part due to recommendations arising out of SEMIP, the JFSP has embarked on a large scale observational campaign (RXCADRE). Such campaigns have the potential to provide new and useful test cases for a wide range of modeling.

The largest sensitivities / uncertainties vary by how the modeling will be used. An important finding of SEMIP is that the form of the output required of fire emissions and smoke modeling largely controls where the largest uncertainties in the model chain occur. First, are only fire emissions needed or is smoke modeling also needed? Second, how *aggregated* or *spatially and temporally resolved* is the needed output? To illustrate this difference in key uncertainties depending on usage, we examined two cases involving the computation of:

1. Total annual national fire emissions; and
2. Smoke concentrations from a single fire.

Overall sensitivity for total fire emissions is dominated by (in descending order):

a. Fuels information (overall fuel loadings and fuel loadings in specific important types, such as canopy fuels and deep organic fuels);
b. Fire information (overall total area burned and area burned by type of fire);
c. Consumption model assumptions (for canopy fuels, deep organic consumption);
d. Emission factors for major non-CO_2 smoke components (e.g., $PM_{2.5}$).

A caveat to total fire emissions sensitivity results is that there is little information on emission factors for species emitted in lower quantities (e.g., volatile organic compounds [VOCs], black carbon).

For smoke concentrations from a single fire, overall sensitivity as found here is dominated by (in descending order):

a. Time profile (the timing of consumption throughout the day and its relation to meteorological conditions);
b. Plume rise (the number of assumed plume heat cores); and
c. Uncertainties in fire emissions (see above).

Not studied by SEMIP at this point, but known to effect smoke concentrations, are the uncertainties of in-plume chemical processes, transition of these processes with plume age, and the difference between clean-air smoke plume chemistry verses urban-air smoke plume chemistry. Sensitivity studies that include plume chemistry should be included in future work.

3.2 Key Findings by Modeling Step:

Fire Information

Errors within the Fire Information step have a critical impact on emissions and smoke modeling; many issues still exist in obtaining fire information, especially temporally and spatially resolved information needed for smoke modeling.

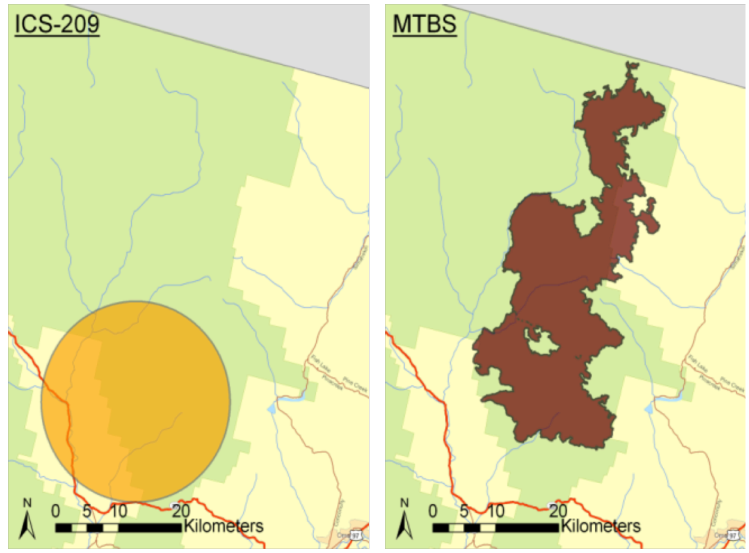
There is no comprehensive national fire information dataset for smoke modeling applications. Fire information is available from a large number of sources, but no comprehensive database exists. Ground based fire information datasets generally have limitations on the types, regions, and/or land ownership of the fires they contain. Satellites have comprehensive geographic coverage but cannot detect fires through clouds and smaller and understory burns are problematic. Additionally, for smoke modeling applications, daily and/or hourly growth information is required and even retrospective analyses, such as the MTBS dataset, do not provide this temporal detail.

Assignment of management purpose or fire type is critical for regulatory air quality modeling and, therefore, smoke emissions modeling. Wildfires, prescribed burning, and agricultural burning are considered separate emission source types in the national and state emissions inventories. The emissions breakdown between source types is used to evaluate control measures and expected results from application of these controls. Direct information about fire type is lacking, and fire type must therefore be inferred. This also affects how various pieces of the modeling chain function – in particular assumptions about canopy consumption and other factors in modern consumption models are tied to knowing whether the fire is a wildfire or prescribed fire.

Significantly more information is available for wildfires than for prescribed burns. There are fewer wildfires and the management structures surrounding wildfires are more uniform and integrated making wildfires easier to track and record. Additionally, many national efforts (such as MTBS) focus on larger fires, which are predominantly wildfires. Because of fire differences around the country, this focus results in a regional bias in the collected information. Satellites, in their differential ability to detect larger fires more readily, also exhibit discrepancies. Smaller fires are known to go undetected due to timing of ignition, obstruction of view due to clouds, and fire intensities lower than detection thresholds.

Even for large fires, discrepancies exist among the fire information datasets. For the Tripod Fire Test Case (Figure 4), the MODIS burn area product did not detect any area burned, instead it classified the fire as a snow field. The MODIS active fire burn detect product produced a larger area compared to the MTBS product and the NIFC information sources. While MTBS and NIFC were accurate for this case, they are not universally available. For example, the MTBS products do not exist for most fires < 1000 acres in the west and < 500 acres in the east.

Fire Reporting System	Area Burned Hectares (US Acres)
ICS-209	70,895 (175,184)
MTBS	71,307 (176,203)
NIFC	70,837 (175,042)
MODIS Burn-Detect	99,045 (244,745)
MODIS Burned Area	N/A



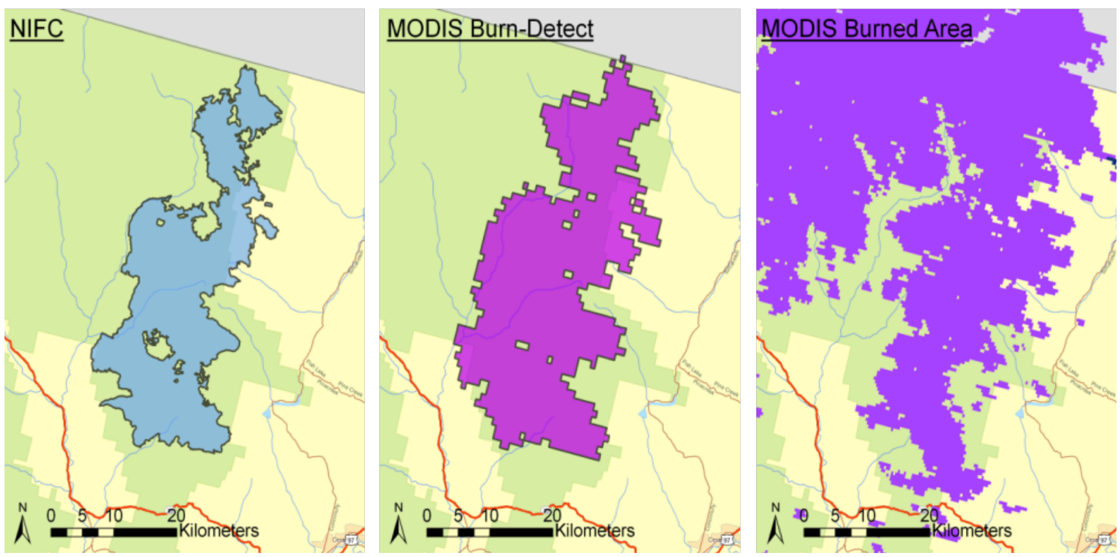


Figure 4. Tripod fire size and perimeter for each of the five fire reporting systems compared in the Tripod Fire Test Case, as presented by Drury et al. (2012). The MODIS Burned Area product assumed the fire was a snowfield and therefore did not produce a fire size.

Pile burning fire activity information is scarce. Pile burning is used across the country and while there are methods available for estimating emissions from piles (e.g., the Consume pile burn calculator), these methods are not used in current daily smoke predictions or emissions inventory modeling. This is primarily due to the lack of available data needed as input to produce emission estimates. Information on piles (existence, quantity, size, and composition) is scarce. Satellite-based instruments can sometimes detect large piles or groups of piles, but the probability of detection is presently unknown and the quantification of size is very difficult.

Fuels

Fuel loading maps show significant differences, which result in large differences in emissions and smoke concentration modeling.

Errors within the fuel loading maps propagate to fire emissions and surface smoke concentration predictions. Results from the Tripod Fire Complex and National Emissions Inventory test cases provide examples of this error propagation. For Tripod, fuel loadings varied by a factor of 4 between the highest fuel loading estimates and the lowest fuel loading estimates. Using these maximum and minimum fuel loadings, fuel consumption varied by a factor of 4.5 and $PM_{2.5}$ emissions varied by a factor of 6. For the National Emissions Inventory test case, the factor of 2 fuel loading difference found between two modern fuel loading maps propagated to the consumption and emissions estimates.

All fuel loading maps showed an overall low bias in limited comparisons against observations. Six different fuel loading maps were examined against plot data, and all were biased low for woody fuel loadings. This bias was true for even the modern maps such as the LANDFIRE 30-m fuel loading map and the FCCS-LANDFIRE crosswalk 30-m fuel loading map. For the Tripod and the National Emissions Inventory Test Cases, the FCCS-LANDFIRE map showed considerably more fuels, and therefore more consumption and emissions, than the LANDFIRE map. This low bias was also found by Urbanski et al. (2012) when comparing LANDFIRE and FCCS-LANDFIRE against Fuels Inventory Analysis plots in the northern Rocky Mountains.

Many of the fuel loading maps do not have fuels critical to smoke modeling. Fire behavior fuel models (Anderson 1982; Scott and Burgan, 2005) and fire danger rating fuel models (Burgan et al., 1997) were built to model expected fire behavior or estimate the potential for a fire to ignite and were not intended for fire emissions and smoke modeling applications. Critical fuel components that are missing include duff, shrub, and canopy and large downed-and-dead fuel loadings. For example, duff and large downed-and-dead woody fuels are often the greatest contributor to smoldering emissions (i.e., CO and $PM_{2.5}$ emissions).

Each of the modern fuel loading maps quantifies total fuel loading differently and recognizes different fuel strata types. Total fuel loadings, and fuel loadings by fuel strata, differed significantly among the modern fuel loading maps compared. An example from the Bugaboo test case is shown in Figure 5. Differences in quantification methods make comparisons difficult and affect the performance of downstream models. Examples of these differences include:

- FCCS-based fuel maps provide detailed accountings of potential fuel loadings for canopy, snags, stumps and shrubs fuels. The LANDFIRE-based maps do not directly provide fuel loadings for canopy, snags, or stumps. Canopy fuel loadings can be calculated using LANDFIRE map products, but the intent of the canopy fuel products was to estimate fire behavior not to estimate smoke emissions.
- The LANDFIRE-FLM data sets have low estimates of shrub biomass.
- FCCS-based maps proportion woody fuels into rotten and sound wood categories, while the LANDFIRE-FLMs combine rotten and sound woody fuels into one category, woody fuels.

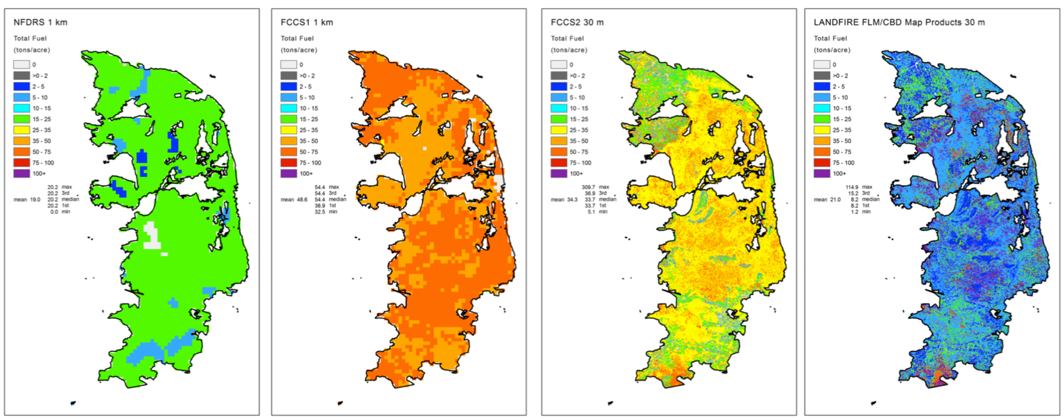


Figure 5. Mapped total fuel loadings for the Bugaboo fire from different sources. From left to right shown are: the NFDRS 1-km map; the original FCCS 1-km map; the FCCS-LANDFIRE 30-m map (labeled FCCS2 for short); and the LANDFIRE FLM/CBD 30-m map. The color scale is held constant between the maps and shown in tons/acre.

National, annual totals of fire emissions are critically dependent on the fuel map used, even for modern fuel maps. Examination of the 2008 large fires showed that national, annual aggregate total emissions were most heavily influenced by the choice of fuel map, and that large differences occurred at this scale between the LANDFIRE 30-m map and the FCCS-LANDFIRE 30 m map, the two most recent national scale fuel maps available.

Local information may be key in improving fuel maps. For the Tripod test case, a locally developed fuel loading map, created based on knowledge of vegetation types, stand history, and management activities, depicted fuel loadings closer to the observed values than all other fuel loading maps. This analysis points to the ability of local information to overcome difficulties that national products have in assigning realistic fuel loadings across the landscape.

Consumption

Consumption models are generally more similar in overall consumption estimates than fuel loading maps; the largest differences occur in the allocation of consumption between flaming and smoldering and in the consumption of certain fuel strata (i.e., canopy, shrubs, herbaceous, and duff).

Consumption models allocate consumption between flaming and smoldering differently and this difference affects emissions calculations. For example, Consume 4.0 proportions fuel consumption phase statically by vegetation type while FOFEM 5.7 dynamically assigns fuel consumed into the flaming or smoldering combustion phases based on fire intensity. For species that are emitted differentially by combustion phase, such as $PM_{2.5}$, this allocation difference affects the total modeled emissions.

*The canopy, shrub, and duff fuel strata consumption are all treated relatively simplistically, and therefore have high uncertainty, within all consumption model*s. No algorithms exist to estimate canopy consumption; all models use a percentage of canopy consumption defined by the user and given as input. Shrub consumption is characterized through different methods, with some models using an estimate of area blackened and others using vegetation type, season of burning, or both. The duff consumption algorithms in FOFEM 5.7 and Consume 4.0 compute duff consumption differently. The Consume algorithms estimate duff consumption as forest floor reduction in inches. The FOFEM algorithms compute duff consumption as a percent. The largest differences in consumption results between Consume and FOFEM are in the duff and shrub layers (see Figure 6). As total emissions are dependent on these strata, particularly duff consumption, these differences result in substantial differences in total fire emissions.

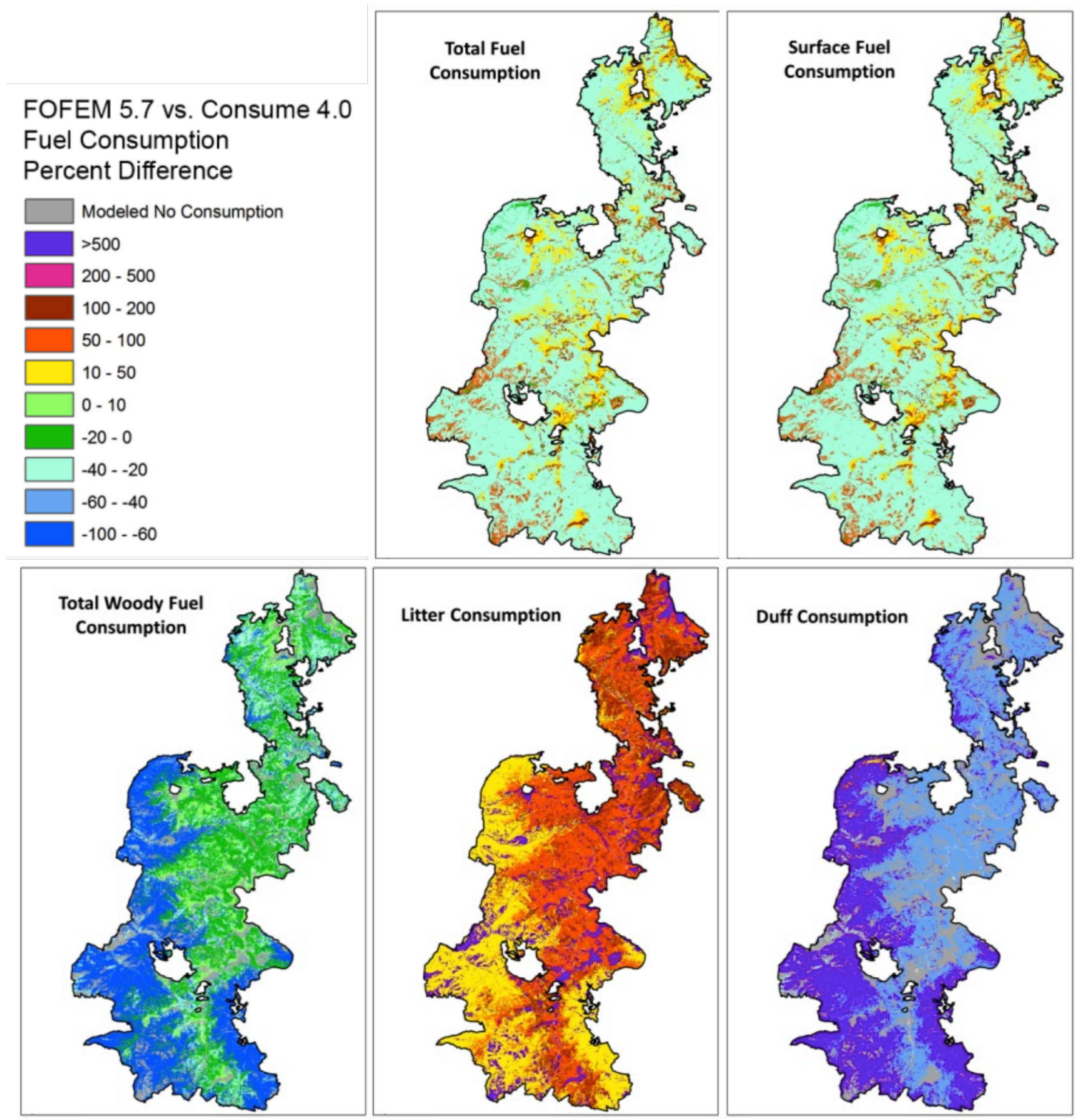


Figure 6. The percent difference in fuel consumption between estimates from FOFEM v5.7 and Consume v4.0 as presented by Drury et al., 2012. The FCCS2 30-m map was used for fuel loading information.

Canopy, shrub, and duff consumption results cannot be comprehensively evaluated due to lack of observation data. Comprehensive observation datasets of these layers and when and how they are consumed is necessary to improve fuel maps and ultimately fire emissions calculations. Recent work by the JFSP can provide valuable insight into how to develop a test case in for this modeling step. Test cases where significant consumption of canopy, shrub, and/or duff are observed and data are available should be a priority for SEMIP.

Modeled fuel consumption, where compared to field observations, performed reasonably well. For example, for the Tripod Test Case, despite the large uncertainty associated with the shrub and canopy layers, the modeled fuel consumption showed good agreement with fuel consumption observations.

Emissions

For major emitted species, emissions estimates vary primarily based on differences in earlier modeling steps; however, emissions factors need to be updated in most models, and significant uncertainties exist for species emitted in lower concentrations (e.g., black carbon, VOCs).

Emission models differ in how they compute emissions, resulting in different totals and ratios of emitted species. Some emission calculators rely upon static emission factors (mass emitted per mass consumed) and others use empirical algorithms based on combustion efficiency or combustion phase. These empirical algorithms provide a means for changing the emission factors based on fire intensity and fuel type. The various methods used to compute emission factors result in different emissions estimates (significantly in some cases) across all gases and particulate species.

Emission factors used within commonly used models should be updated with more recent observations. Emission factors and/or emission factor algorithms used within Consume, FEPS, EPM, and FOFEM models were derived primarily from 1989 to 1998 (Ward et al., 1989; Ward et al., 1993, and Hardy et al., 1998). Recent technological improvements have allowed for more extensive observations and recently reported emission factors (i.e., Burling et al. 2010; Chen et al., 2010; McKeening et al., 2009; and Yokelson et al., 1999) more completely describe the emissions process but these have not yet been incorporated into most emissions models.

Updating the emission factors and their empirical relationships will likely highlight uncertainties in other modeling steps. Updated emission factors will better describe the emission process relative to the flaming and smoldering combustion phase; however, the effect of an update on the emission results is not quantifiable at this time. Uncertainties in fuel maps and consumption models that determine vegetation type, consumption efficiency, and other factors that affect how the emissions factors get used may still result in large emissions differences. These differences may remain even when the same base emissions factors (and/or algorithms) are used in the emissions modeling step.

Emission factor differences for major emitted species are less than the overall differences observed in fire information systems and fuel maps. Comparisons between different systems show that eliminating errors and uncertainties in fire information (particularly fire size and fire type) and fuels are the most critical components for reducing overall fire emissions uncertainties.

Time Profile

Time profiles that specify how emissions are distributed throughout the day are an extremely large uncertainty in smoke concentration forecasts; time profiles affect not only surface concentrations (particularly through interactions with the boundary layer height) but also the area of impact (smoke plume footprint).

Time profiles are highly uncertain. Time profiles are used in smoke modeling to distribute emissions to specific hours throughout the day. For prescribed burns, some information on time profiles may be available based on planned ignition sequences or observed fire behavior. In general, time profiles for wildfires are unknown and often the Western Regional Air Partnership Fire Effects Joint Forum profile is assumed. However, it is widely recognized that a single time profile does not represent actual time profiles, which vary with different atmospheric and surface conditions.

Modeled smoke impacts are critically dependent on the assumed time profile. Small changes to the time profile—such as shifting emissions a few hours in either direction, or concentrating the emissions more narrowly during the day—were found to have large effects on smoke surface $PM_{2.5}$ concentration metrics, including maximum concentration, average concentration, and area of impact. The sensitivities to, and uncertainties in, time profiles combine to make time profiles one of the critical areas needed for future observation campaigns, scientific evaluation, and model development.

Interactions with the boundary layer make smoke impacts sensitive to small shifts in the timing of a fire. In sensitivity analyses, shifts in the time profile of a fire caused greater emissions during periods of low boundary layer heights, changes in atmospheric stability, and/or changes in wind shear. The combined differences led to large changes in smoke impact patterns. These changes are difficult to understand without detailed analysis of the atmospheric conditions. Simple rules of thumb that describe the impact that inaccuracies in the time profile have on model results cannot be created until further analyses are accomplished.

Observations of time rates of growth of fires throughout the day are needed. Many sources (such as the ICS-209 wildfire reports) record daily growth patterns of fires. Few observations of hourly growth patterns of fires throughout the day are currently available, although geostationary satellite platforms like GOES can provide information for some fires. Targeting observations on time profiles of wildfire growth and/or finding ways to get current observations documented and available would significantly help in the creation of new time profile models.

Plume Rise

Modeled smoke impacts depend heavily on plume rise estimates but current plume rise models are unable to accurately predict the complexities of fire plumes; observation campaigns that characterize smoke plume heat cores and their rise-height at a scale important for smoke emissions modeling are needed to advance plume modeling.

Errors in computing plume rise translate into incorrect modeled surface smoke concentrations both near and far from the fire source. If the dispersion model receives plume rise heights that are too high, the model will predict excessive dilution, long-range transport away from the fire, or trapping of the smoke aloft. Conversely, plume rise heights that are too low result in smoke surface concentrations that are too high or too close to the fire. Misrepresentation of plume rise height can also affect predictions for long-range continental and trans-continental transport. Correctly representing plume rise heights that go above the atmospheric boundary layer is important because smoke injected above the atmospheric boundary layer can transport long distances.

Plume rise models vary considerably in complexity, assumptions, and applicability for wildland fires. There are several plume rise methods currently employed in smoke and emissions modeling. These methods include lookup tables developed from expert judgment, adaptations of empirical models designed for smokestacks, empirical approaches that rely on remotely-sensed fire radiative power, and energy balance models. Most of the models and/or plume rise algorithms require inputs that are not known for most fires for either daily prediction or historical case study applications, such as the distribution of heat within the fire over time and space.

The ability to model multiple convective cores is needed to represent the behavior of wildland fire. Wildland fires often exhibit multiple burning fronts, and multiple convective columns even within a contiguous burning area. The multiple heat cores found within most wildland fires (and even the smallest of fires) have their heat distributed among more than one plume core, resulting in several plume rise heights for a single fire. Representing this behavior is critical to modeling plume rise, as assumptions on the number of convective cores can dominate the estimated plume rise calculation.

Models or rules of thumb are needed to predict the number of convective cores that should be used to model a fire. Observational data on the number of convective cores exhibited by a fire is not available to smoke modelers. When heat is not distributed among more than one plume core, the resulting modeled plume rise is unrealistically high. Therefore it is necessary to correctly estimate the various fire heat cores on a scale relevant for smoke emissions and surface concentration modeling. Procedures for estimating the number convective columns are an area of needed research.

There are very few sources of on-the-ground plume rise observations for use in model evaluation analyses. New data sets are starting to emerge and this is a promising area of further research. Ground based LIDAR, such as the ceilometer employed by Liu et al (2012) in JFSP 08-1-6-06, can provide detailed plume height information for research burns. In addition, Natural Resources Canada has recently experimented with outfitting fire spotters with inclinometers to record plume heights (Anderson, 2012). Further development of ground-based plume rise field campaigns will add to these data sets and provide the means for further model analyses.

Despite recent advancements in on-the-ground measurements, remote sensing offers the most comprehensive data sets. NASA's Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observation (CALIPSO) and Multi-angle Imaging Spectroradiometer (MISR) instruments both record plume height information for a large number of fire source plumes. In particular, thousands of plumes have already been analyzed by the MISR team and are available for additional analysis and model evaluation. Satellite based measurements have their own limitations and uncertainties. For example, the MISR data are limited to a late morning snapshot, before most wildfire smoke plumes have fully developed, and perhaps not representative of short-lived prescribed burn plumes.

Analyses of plume rise data with satellite information found model results vary regionally and by fire size. Satellite observed plume heights were found to be lowest in the Southeast and modeled plume rise was similar; however, plume rise modeling throughout the West did not match observations, which showed greater variability and higher plume heights overall (Raffuse et al., 2012). Plume rise model results by fire size showed an underestimation of plume height for small fires and an overestimation of plume height for large fires (Figure 7).

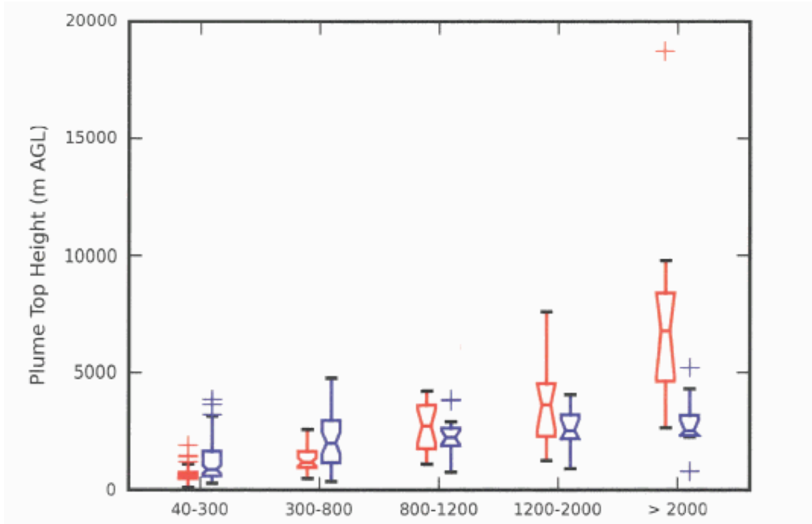


Figure 7. Box and whisker plots of modeled (red) and satellite observed (blue) plume heights as a function of modeled area burned (shown in ha). Modeled plume rise is from the BlueSky Gateway real-time prediction system. Overall modeled plume heights were found to be too low for smaller size fires and too high for larger size fires (from Raffuse et al., 2012).

Dispersion

Dispersion modeling uncertainties and errors do not appear to dominate the smoke modeling chain, although terrain resolution can be critical in some areas (e.g., narrow valleys); sensitivity tests show that improvements to time profile, plume rise, and fire emissions are most critical for modeling ground smoke concentrations.

Dispersion modeling errors are hard to evaluate given the uncertainties in the previous modeling steps. The differences between dispersion model outputs appear to be less critical than characterizing the source location (fire information), source emissions (fuels-consumption-emissions), source diurnal timing (time-rate), and source height of emission (plume rise).

Comparison of model surface smoke concentrations to observations found that results were dependent upon the synoptic meteorology. Steep concentration gradients develop during synoptic patterns that produce striated or low mixing conditions (i.e., inversion). The concentration gradients are difficult to model during these synoptic patterns without reducing the model's horizontal (or, in some cases vertical) resolution.

Modeled surface smoke concentrations are sensitive to domain grid resolution especially in areas with terrain-induced weather effects. Specifically, grid resolution was critical for smoke surface predictions during periods of high winds that funneled the smoke down narrow canyons and at locations influenced by terrain-induced weather changes (i.e., valley-slope flows) (Strand et al., 2012). During well-mixed boundary layer conditions, coarser grids (36 km) sufficed for producing predictions near the observation values.

Smoke concentration values are sensitive to the parameterizations utilized; however, these sensitivities appear lower than sensitivities to time profile, plume rise, and fire emissions changes. Comparison of various options within the HYSPLIT dispersion model found some sensitivity to options such as the treatment of the horizontal and vertical particle representation (particle, puff, etc.), but overall smoke impact sensitivities were dominated by other modeling steps.

Observational campaigns are needed to narrow the range of results found at each modeling step and in the concluding dispersion step. These campaigns should directly address the lack of data for plume rise and (diurnal) time profiles - this requires some "coupling" between smoke and fire behavior. It is important to understand fire behavior as it relates to smoke production at the scale at which current and future smoke emissions and concentration operational models will function.

4. Management Implications

The management implications of SEMIP are widespread, as the analyses and results found by SEMIP can help inform all management applications where fire emissions and/or smoke impact modeling is required. These applications include:

- Smoke impact predictions done during a fire in support of air quality decisions and notifications, including fire fighter safety, public health, and transportation concerns;
- Smoke impact predictions done as 'what if' scenarios to determine best time (hour, season, etc.) for prescribed burns;
- Emissions reporting, including national emissions inventories and carbon accounting reporting;
- Smoke modeling done in retrospect as part of exceptional event reporting; and
- Smoke modeling done for other regulatory and policy purposes.

Specifically, management implications of SEMIP include:

- ***The choice of models is critical***
  Model-to-model variations are significant at nearly every level of the modeling chain; therefore the choice of models used can have a significant impact on the results produced. These uncertainties need to be considered when utilizing model output in decision support. Comparisons between models or modeling chains can vary in magnitude and sign across the country.

- ***Fuels are the most uncertain part of emissions calculations***
  The choice of fuel loading map can greatly affect emissions calculations, in general more so than the choice of consumption models. The choice of fuel loading maps is important at all fire-scales – from individual fire emissions to national annual total emissions.

- ***Consumption models treat fuel input information differently***
  Consumption models use the given fuel information in different manners, depending on their algorithms. In some cases, fuel layers are ignored (i.e., deep organic, shrubs) or treated through different consumption phases or treatment (i.e., fully consumed, % not consumed).

- ***Local data are key to having the best numbers***
  Many uncertainties in the fire emissions and smoke impact modeling chain are due to lack of direct observations. The use of direct observations within the

modeling chain can significantly reduce uncertainty. For example, the use of local fire information (e.g., prescribed burn plans) reduces the uncertainty in overall fire emissions inventories. The use of fuels information, fuel moisture observations, and/or observations of duff/deep organic consumption will also reduce the uncertainty in overall emissions. The use of observed plume rise heights and/or the timing of the fire throughout the day, even if it is based on what happened the preceding day, can reduce the uncertainty in overall smoke impacts.

- ***Sensitivity to time rate of consumption, plume rise, and/or emissions depends on the planetary boundary layer***
  Modeled surface concentration results are sensitive to the time rate of consumption and plume rise as the emissions correspond to different aspects of the diurnal changes in the height of the planetary boundary layer. It is important to model both the timing of emissions and the boundary layer height (meteorological models) as accurately as possible. Conversely, local knowledge of boundary layer behavior is especially useful for assessing smoke predictions by the model in the three to four hours surrounding the morning boundary layer rise and evening boundary layer lowering.

- ***Threshold impacts (such as National Ambient Air Quality Standard exceedances) can be very sensitive to uncertainties***
  Many management applications require knowing whether smoke impacts will exceed one of the National Ambient Air Quality Standards (NAAQS) or the visibility reduction standards. Model exceedances are highly sensitive to model uncertainties. That is, relatively small changes in the model output may result in a "hit" or a "miss" in predicting an exceedance. When using models to examine where exceedances will occur, uncertainties need to be accounted for to ensure that the model results are fully understood.

5. Relationship to Recent Findings and Ongoing Work

The process of SEMIP and the preliminary results are related to numerous ongoing efforts. We attempt to cover the breadth of these interconnections here, citing the most relevant examples.

Methodological discussions were held with organizations interested in SEMIP's process and findings. These include the JFSP Board, National Wildfire Coordination Group's Smoke Committee, the EPA, the National Weather Service, Environment Canada, National Center for Atmospheric Research (NCAR), and numerous other researchers and groups. Specific presentations/discussions that can be related to outcomes include:

- Specific presentations and discussions with the JFSP Board on how to enable data warehouses and data sharing;
- Specific presentations and discussions with the EPA, USFS, and DOI on how to improve the U.S. National Emissions Inventory for wildland fire.

In each case, later decisions taken by these groups (in the JFSP's case to require projects to submit data management plans for review and project collected data into a data repository; and in the EPA's case to change the methodology used in the NEI) have been in line with the results and recommendations stemming from SEMIP. These decisions were not the result of SEMIP; however, in each case SEMIP's findings were potentially useful in the decision-making process. Additionally, SEMIP was directly mentioned as a resource in recent JFSP and NASA RFAs on wildland fire.

SEMIP has received data from other JFSP projects funded in from the 2009 RFA for submission to the SEMIP warehouse. The data from these projects may become good SEMIP test cases, should SEMIP continue (i.e., projects #09-1-04-1 and #09-1-04-2 both collected comprehensive suites of data at each modeling step described in SEMIP). Additionally, SEMIP has been in discussion with the JFSP regarding what to do with these data, data collected for SEMIP, and other datasets received; these discussions are ongoing.

Results from SEMIP may have also helped spur interest in large observational campaigns that can measure across many model output levels (fire behavior, fuels, consumption, emissions, plume rise, etc...). SEMIP's findings were presented at the 2011 JFSP Models and Measurements Workshop, which resulted in the eventual funding of the RX-CADRE (Project #11-2-1-11) field campaign set to begin in the Fall of 2012 at Eglin Air Force Base in Florida. The measurements taken as part of RX-CADRE may fit as a test case for a future SEMIP or SEMIP-like analyses, at least through the Plume Rise modeling step. Adding a test case with detailed measurements for all modeling steps would be a high priority for future SEMIP or SEMIP-like work.

The results from SEMIP on fire information led directly to the development of a revised SmartFire fire information system (v2, created 2011) that can serve as a platform for associating and reconciling local fire information databases with more national ones. SEMIP showed that fire information databases, including satellite fire detections perform better when coupled together than when used independently. The major hurdle in doing so is the difficulty in associating and reconciling disparate data sources together. SmartFire v2 was built to address this issue and therefore to allow for more data to be more easily used in building fire emissions inventories. SmartFire v2 allows for many potential reconciliation paths; work underway as part of JFSP Project #12-1-7-02 is designed to determine a scientifically defensible reconciliation algorithm. SmartFire v2 served as the core of the revised 2008 wildland fire NEI version 2 effort recently completed and published by the EPA (January 2012). SmartFire v2 is serving as the basis for gathering fire information for the 2011 EPA NEI, and for a USFS/DOI effort to create a 10-year climatology of wildland (including prescribed) fire emissions for the U.S. This work is also related to other JFSP projects including work on black carbon (Project #11-1-5-13).

The SEMIP study on emissions factors and the literature review in this area complements recent emissions factor reviews done on a global scale (i.e., Akagi et al., 2011). This study focuses on emission factors relevant for national-scale and smaller smoke modeling applications. The global-scale emission factor reviews analyze emission factors relative to global vegetation types (i.e., boreal forest, tropical, etc.), while the SEMIP review examines emission factors on the scale used by smoke modeling applications, specific fuel loading vegetation types (i.e., Ponderosa pine, Douglas fir, etc.).

SEMIP's test cases on fire emissions complement global efforts to compare global fire emissions systems conducted as part of the Community Initiative for Emissions Research and Applications (CIERA, http://ciera-air.org). Discussions with some of the CIERA lead investigators have led to the conclusion that SEMIP and CIERA have different scales and aims, but are directly complementary. Methods to leverage work done for SEMIP:Phase 1 for the CIERA project are in active discussion.

The JFSP-funded project led by Liu (#08-1-6-06) evaluated and improved smoke plume rise models. In particular, the project evaluated Daysmoke and an empirical regression model for determining smoke plume height in conditions of prescribed burns in the southeastern United States. Evaluation data were collected from a ceilometer for 20 burns. Several of Liu's key findings are relevant to SEMIP. The observation of large plume height fluctuation over short time scales points to the need to use satellite-based instantaneous measurements of plume heights with caution, particularly for small prescribed fires. Liu's overall findings reinforce the SEMIP finding that plume heights and many plume rise models are controlled in large part by the distribution of heat among one or more plume cores. This distribution is not measured and not known for most fires.

SEMIP's efforts to cross-compare models coincides with efforts, in part spawned from the success of the BlueSky Modeling Framework, to create viable scientific modeling frameworks in various areas. Notable in this regard is the JFSP's Interagency Fuels Treatment Decision Support System. The availability of such frameworks will make SEMIP-style efforts possible in other areas beyond fire emissions and smoke impact modeling.

6. Future Work Needed

In discussing future work and the possible continuation of SEMIP or a SEMIP-like effort, we must distinguish between the larger structure of SEMIP, and the specific work completed as part of JFSP Project 08-1-6-10, which we identify here as SEMIP:Phase 1.

Future work needed can be divided into two distinct parts:

- Work identified by SEMIP:Phase 1 that is needed to advance fire emissions and smoke impact modeling capabilities.
- Work to continue a SEMIP or SEMIP-like project to serve as a test bed and platform for baseline comparison for model advancements.

We treat each of these parts separately below.

6.1 Development Work Needed to Advance Fire Emissions and Smoke Impact Modeling

A number of model development, model evaluation, and field observation needs were identified in SEMIP:Phase 1. Table 1 shows summary recommendations for development needs to advance fire emissions and smoke modeling, shown by modeling step. Each recommendation is discussed further in Section 3: Key Findings. Additional discussion can be found in Section 4 of the SEMIP General Technical Report (Larkin et al., 2012).

Table 1: Recommendations by modeling step (*continued on next page*).

Modeling Step	Recommendations
Fire Information	Community-accepted methods of reconciling fire information datasets to one complete, cohesive whole needed. (Note: this is the focus of current JFSP projects under the latest RFA.)
Fuels	Newest datasets (LANDFIRE-FCCS 30 m/1 km and LANDFIRE 30 m) are not in close agreement. Need significant fuel research-led effort to determine why and how to determine the best dataset for a given area.
Consumption	Models compare reasonably well overall. However, there are significant issues with certain fuel components (e.g., deep organics, shrubs, canopy, etc.)
Time Rate	A large unknown. Intrinsically related to fire behavior and the lack of reliable fire behavior predictions.

Table 1: Recommendations by modeling step (*continued from previous page*).

Modeling Step	Recommendations
Emissions Factors (EFs)	Need to focus research on smoldering vs. flaming EFs; $PM_{2.5}$ and NO_x along with lesser emitted species (VOCs, BC) including toxics; may need vegetation-specific or fuel layer specific emissions factor work.
Plume Rise	A major unknown. Statistical corrections to current models possible using large-scale comparisons like ones done here, but dynamic plume models with realistic plumes awaiting fire behavior modeling advancement.
Dispersion	Dispersion models appear not to be the current weakest link in the smoke impact chain. Results are critically dependent on the plume rise, time rate, and overall emissions calculated, as well as the accuracy and grid scale of the available meteorological models.
Plume Chemistry	Not currently assessed within SEMIP. This would be a logical expansion for SEMIP.
Fire Behavior	Note: many issues above (time rate, plume rise) point to the need to advance fire behavior modeling. These models were not assessed as part of SEMIP. However, our findings point to the need for advances in fire behavior modeling done *specifically for smoke modeling* purposes to predict: fire growth, consumption, and emissions by hour or sub-hour time step including how these emissions are organized into convective “cores” or plumes.

6.2 Continuation of SEMIP or a SEMIP-like Structure

We believe SEMIP, or something like SEMIP, should be continued into the future in order to establish and maintain baseline comparison Test Cases and to ensure that standard comparisons between models and model validations needed by model users are conducted on a regular basis (e.g., as models are updated).

The future of SEMIP, or something like SEMIP, can be divided into three basic paths:

1. No continuation;
2. Paring down work to a relatively small scale effort focused on continuing model testing and providing baseline comparisons as new models or new versions of existing models are developed; and
3. Continuation of a large scale effort similar to SEMIP:Phase 1 that can continue to include significant analyses and further development and expansion of the SEMIP concept.

If SEMIP is to continue (Options 2 or 3 above), we advise that:

- SEMIP be converted from a *project* into a *community effort*. This will be a primary challenge faced in creating any ongoing SEMIP or a SEMIP-like effort. The original SEMIP proposal had identified the need to build a community effort through development of an oversight science board and other infrastructures, but these actions were subsequently placed on hold after discussions with the JFSP in favor of getting useful scientific results and proving the SEMIP concept (J. Cissel, personal communication, 2008). As such, the existing SEMIP project has focused on developing methodologies, protocols, and analyses to create useful results, combined with a significant outreach and communication strategy designed to disseminate SEMIP results to both scientific and non-scientific audiences. However, the actual development and work has been centralized with the project team although with input and consultation from other scientists and managers within the smoke community. Creation of a sustainable SEMIP-like structure will require involvement and input of a broad array of scientists and model developers so that SEMIP-based analyses become commonplace when new model versions are distributed.

A baseline SEMIP-like effort (Option 2 above) would include: (a) data/test case maintenance, (b) continued model comparisons/evaluations, and (c) communicating overall summaries to researchers and managers:

(a) To maintain data and test cases, we suggest an invested structure (e.g., a small scientific oversight board) chartered to be responsive to requests/comments from the larger scientific and management communities. This group would maintain and approve the SEMIP Test Cases to be maintained and advise the JFSP Board on critical needs for model inter-comparisons and evaluations. Data/test case maintenance would include collecting new datasets, ensuring dataset quality and availability, and, if existing archives (e.g., the U.S. Forest Service Data Archive) are not capable of containing all of the needed ancillary data to maintain a test case, maintaining a dataset server. Potential data maintenance costs would depend highly on the ability of existing data archives to absorb these datasets without additional costs, and on any data assurance/data quality requirements imposed on researchers before data can be finalized in the archive.

(b) Continued model comparisons/evaluations would minimally need to be targeted model runs where new versions of models (and/or new models) are run through a series of test cases to establish where they fit into overall model performance. Some targetable funding might be useful to enable the most urgent comparisons, with larger efforts done through the standard JFSP RFA process. Note that the specific researchers receiving this funding might vary, depending on the needed research; priorities could be directed by the oversight board suggested above.

(c) Communicating overall summary findings to scientists and managers. SEMIP:Phase 1 focused on generating analyses to identify and quantify sensitivities, errors, and uncertainties in the modeling chain. While standard analyses were identified and utilized as part of SEMIP:Phase 1, communication was done through meetings, presentations, and journal articles. Less emphasis was placed on developing simple, accessible, and standard forms describing individual models and their performance. Should SEMIP become a routine part of new and revised model evaluations, having a seet of standard summaries of model performance will become increasingly important.

Continuation of SEMIP at a significant level of effort (Option 3 above) would be valuable from a scientific and technology transfer viewpoint. In addition to providing the baseline functions for test case maintenance and comparing new and revised models described in Option 2 above, such an effort would allow significant new analyses to be performed that were not done as part of SEMIP:Phase 1. A continued SEMIP-like project could also:

(d) Perform analyses identified but not performed as part of SEMIP:Phase 1. These would include utilization of data being collected for 2011 for analyses of the Northwest and Southeast Prescribed Fire test cases; expanded sensitivity analyses to examine the connections between Time Profile assumptions and smoke impact modeling; evaluation of additional Plume Rise models against satellite observations; and comparisons of dispersion model settings and their impact on smoke impact modeling.

(e) Expand SEMIP to include fire behavior modeling as part of the fire emissions and smoke impact modeling chain. Many aspects of the fire emissions and smoke impact modeling chain require information from fire behavior models such as hourly fire growth and the organization of heat release into convective plumes. Interconnecting these types of models has rarely been done, but is likely needed in order to advance smoke modeling and our ability to predict smoke impacts. SEMIP could be expanded to develop new test cases and evaluation metrics for this work. At the same time, SEMIP could also be expanded into the critical area of smoke plume and atmospheric chemistry.

(f) Create new targeted Test Cases. The analyses done as part of SEMIP:Phase 1 have identified a number of areas for future research that cannot be done with the existing test cases. Fully implementing the two identified, but not used, regional prescribed fire test cases would be useful for evaluating fire emissions and smoke impact modeling used for emissions inventories and assessment of regional health issues. Additional test cases are required to examine deep organic consumption. Rangeland burning is also not currently covered by SEMIP. If expansion into fire behavior was done, the RX-CADRE field experiment may provide a wide range of data useful for evaluating the fire behavior through plume rise components of the modeling chain.

(g) Work with field campaigns to help focus observational efforts and ensure the utility of field campaigns in constraining model uncertainties. Even to evaluate one modeling step, such as plume rise, data are needed across a range of modeling steps in order to constrain the modeling uncertainties and evaluate model performance. Observational data limitations to full model performance evaluations were identified for every modeling step analyzed. New field campaigns are needed to build test cases that range through all fire types (i.e., wildfire, prescribed fire, rangeland, etc.) and fire environments (i.e., complex terrain, non-uniform fuels, etc.).

7. Deliverables

Table 2 shows the deliverables table from the original proposal with completion details for each item. A list of publications and documents stemming from SEMIP, as well as SEMIP-related presentations to scientific and management (user) level audiences, are shown below. In general, SEMIP exceeded the promised deliverables in every quantifiable metric with 3 peer-reviewed publications published and in review as of September 30, 2012, another 3 manuscripts drafted for submission to peer-reviewed journals within the next two months, an additional 5 non-refereed publications produced, as well as over 20 presentations, informational sessions, and trainings given to both scientific and non-scientific audiences.

Table 2. Deliverables Crosswalk
(Items in grey were not completed/replaced with other deliverables;
Items in green were completed in excess of promised deliverables)

Deliverable Type	Description	Completion Notes
Non-Refereed Publication	SEMIP Study Plan and Standards (once approved by JFSP board)	Complete - Published on website; Letter sent to JFSP Board for review after Year 1; now available in SEMIP Technical Document (see publication list below)
Conference Presentation	At National Air Quality Conferences	Complete – March 2010; see presentations list below.
Invited Presentation	At EPA Emissions Inventory Conference	Complete - Results presented at both the 2010 and 2012 EPA EIC; see presentations list below.
Dataset	SEMIP standard case datasets (to allow others to run standard cases)	Complete - Uploaded to SEMIP Data Warehouse.
Dataset	SEMIP collected model output	Complete – Uploaded to SEMIP Data Warehouse
Website	SEMIP website, with standards and ability to submit model results	Complete - Available through links at the project page http://airfire.org/projects/semip
~~Refereed Publication~~	~~SEMIP Announcement Paper (IJWF, BAMS, EOS, etc…)~~	Switched to a presentation at several conferences – see presentation list below; also see publication list below for refereed publications.

Invited Presentation	At National Weather Service Air Quality Workshop	Complete – Work presented to the National Weather Service at the USFS – NWS FCAMMS meeting.
Poster	At major conference (e.g., Fire Ecology or AGU Fall Meeting)	Complete - see presentations list below.
Invited Presentation	At Fire and Forest Meteorology Symposium	Complete - see presentations list below; multiple presentations done at both the 2009 and 2011 FFMs.
Dataset	SEMIP collected observations for standard case evaluations	Complete - uploaded to SEMIP Data Warehouse
Conference Presentation	At major conference (e.g., Fire Behavior and Fuels Management)	Complete – many conference presentations done - see presentations list below.
Non-Refereed Publication	JFSP Annual Progress Report	Complete– submitted to the JFSP each year of the project.
Training Session	At major conference (e.g., Fire Behavior and Fuels Management)	Complete – as part of IAWF Fire Behavior and Fuels Management conference 2010; other trainings also completed.
Dataset and Website	Final Phase 1 Evaluation Results	Done - data available through Warehouse; results available through SEMIP Technical Document
Non-Refereed Publication	User guidance summary	Done - available through multiple recorded presentations and web available slides.
Refereed Publication	GTR of Phase 1 Evaluation	SEMIP Technical Document in community review and to be published in FY13.
Refereed Publication	Journal article of Phase 1 Evaluation	Multiple journal publications done (2 published, 2 in review, 2 in draft as of 9/30/12) – see publication list below.
Non-Refereed Publication	Final Report to JFSP	(This document); submitted to the JFSP for consideration
3 Training Sessions	At 3 user meetings, including National Predictive Services Group	More than 3 user webinars and other informational sessions were held – see presentation list below.

Conference Presentations	Additional round of conference presentations on results	Many conference presentations given on SEMIP and SEMIP results – see presentations list below.

More information and resources are available through links on the project page (http://airfire.org/projects/semip), including:

- Project updates as available;
- Updated additional reports and findings;
- Access to the Data Warehouse and Data Viewer as available;
- An updated list of published papers arising from SEMIP; and
- Links to presentations on SEMIP.

The current list of published papers and documents arising from SEMIP:

Drury S.A., Larkin N.K., Raffuse S.M., Strand T.M., Huang S-M. (2012) Comparing fire size, fuels, consumption, and smoke emissions estimates: A case study using the 2006 Tripod wildfire. *Ecological Modeling* (in review).

Larkin N.K., Raffuse, S.M., Strand, T.M., Huang, S-M. 2012. Comparison of fire emissions inventories. *Forest Ecology and Management* (in prep.)

Larkin N.K., Strand T.M., Solomon R., Raffuse S., Drury S., Sullivan D., Wheeler, N., Chinkin L., 2010. Developing an improved wildland fire emissions inventory. 19th Annual EPA Emissions Inventory Conference, San Antonio, Texas, August 2010. Available at http://www.epa.gov/ttn/chief/conference/ei19/index.html

Larkin N.K., Strand T.M., Drury, S.A., Raffuse, S.M., O'Neill, S.M., Solomon, R.C., Wheeler, N., Huang, SM. 2012. Phase 1 of the Smoke and Emissions Model Intercomparison Project (SEMIP): Test cases, methods, and analysis results. *General Technical* Report, *U.S. Forest Service PNW Research Station, Portland, Oregon,* (in review).

Raffuse, S.M., Larkin, N.K., Lahm P.W., Du, Y. (2012) Development of the 2008 wildland fire national emissions inventory. *20th International Emission Inventory Conference, August 13-16, Tampa, Florida.* Available on the Internet at http://www.epa.gov/ttn/chief/conference/ei20/session2/sraffuse.pdf. 12pp.

Raffuse S., Strenfel S., Ruminski M, Larkin N.K, Hanna, J., McCarthy, M., 2012. Evaluating fire detection success rates of satellite detection methods. (in prep.)

Raffuse S., Larkin, N., Lahm P., Du Y. (2012) Development of the wildland fire portion of the 2008 National Emissions Inventory. (in prep.)

Raffuse S.; Craig K.; Larkin N.; Strand T.; Sullivan D.; Wheeler N.; Solomon R. (2012) An evaluation of modeled plume injection height with satellite-derived observed plume height. *Atmosphere, 3*, 103-123.

Rorig M., Solomon R., Krull C., Peterson J., Rutherford J., and Potter B. (2012) Analysis of Meteorological Conditions for the Yakima Smoke Intrusion Case Study, 28 September 2009. Forest Service Pacific Northwest Research Station Research Paper. In press.

Strand T. M., Larkin N., O'Neill S. M., Peterson J., and Martinez N. (2012) A synthesis and review of wildland fire emission factors for smoke modeling applications in the United States. *J. Geophys Res*., in prep.

Strand T. M., Larkin N., Solomon R., Rorig N., Craig K. J., Raffuse S., Sullivan D., Wheeler N., and Pryden D. (2012) Analyses of BlueSky Gateway PM2.5 predictions during the 2007 southern and 2008 northern California fires. *J. Geophys. Res.,* 117, D17301, doi:10.1029/2012JD017627.

<u>Presentations given to scientific audiences</u>:

Larkin N.K., Solomon R., Strand T., Raffuse S., Craig K. December 2009. Uncertainties in fuel loading and fire consumption calculations and the Smoke and Emissions Model Intercomparison Project. AFE 4th Intl. Fire Ecology & Management Congress, 30 Nov - 4 Dec 2009, Savannah, GA.

Larkin N.K., Strand T., Solomon R., Sullivan D., Raffuse S., Craig K., Pryden D., Wheeler N., Chinkin L. December 2009. BlueSky modeling framework: status, products, and future directions. AFE 4th Intl. Fire Ecology & Management Congress, 30 Nov - 4 Dec 2009, Savannah, GA

Strand T., Larkin N.K., Solomon R., Sullivan D., Raffuse S.M., Pryden D., Craig K., Wheeler N., Chinkin L. December 2009. BlueSky modeling framework: current application, user tools, and future additions. AGU Fall Meeting 14-18 December 2009, San Francisco, CA

Raffuse S.M., Pryden D., Larkin N.K., Strand T., Solomon R., Sullivan D. December 2009. Merging satellite-detected wildfire information with ground reports for improved fire and smoke modeling in emergency response. AGU Fall Meeting 14-18 December 2009, San Francisco, CA.

Larkin N.K., Solomon R., Strand T., Raffuse S., Craig K. December 2009. Uncertainties in fuel loading and fire consumption calculations and the Smoke and Emissions Model Intercomparison Project. AGU Fall Meeting 14-18 December 2009, San Francisco, CA.

Larkin N.K., Raffuse S., Strand T., Pryden D., Solomon R., Wheeler N., Sullivan D., Chinkin L., March 2010. The BlueSky modeling framework: recent developments and tools. National Air Quality Conferences, 15-18 March 2010, Raleigh, NC.

Larkin N.K., Strand T., Solomon R., Drury S., Raffuse S., Wheeler N., Chinkin L., Soja A., June 2010. Uncertainties in wildland fire emissions (and trying to fix them). Air Waste & Management Associate Annual Meeting (ACE-2010), Calgary, Alberta, Canada.

Strand T.M., Larkin N.K, Sullivan D., Craig K., Solomon R., Raffuse S., Pryden D., Wheeler N., October 2010. BlueSky Modeling Framework: status, products, and future developments, IAWF Third Fire Behavior and Fuels Management conference, Spokane Washington.

Larkin N.K., Strand T.M., Martinez N., Rorig M., Krull C., Solomon R., Drury S., Raffuse S., Wheeler N., Craig K., Chinkin L., October 2010. Uncertainties in fuel loading, fire consumption, plume rise, and smoke concentration calculations. IAWF Third Fire Behavior and Fuels Management conference, Spokane Washington.

Martinez N., Drury S., Raffuse S., Strand T.M., Solomon R., Larkin N.K., October 2010. Uncertainties in modeling emissions and smoke from wildland fire. . IAWF Third Fire and Fuels conference, Spokane Washington

Larkin N.K., Raffuse S., Strand T.M., Healy A., Pryden D., Wheeler N., October 2010. A community data warehouse for fire and smoke information. IAWF Third Fire and Fuels conference, Spokane Washington

Drury S., Larkin N.K., Huang S-M., Strand T.M., Strenfel S., O'Brien T., Raffuse S.M., October 2010. Fuel loading, fuel consumption, and smoke emissions simulations under wildfire conditions: the 2006 Tripod wildifre case study. IAWF Third Fire and Fuels conference, Spokane Washington

Larkin N.K., Raffuse S., Strand T., Drury S., Solomon R., Wheeler N., December 2010. Developing an improved wildland fire emissions inventory. AGU Fall Meeting, San Francisco, California.

Larkin N.K., May 2011. Some thoughts on smoke. National Cohesive Strategy Science Team Meeting, Webinar.

Larkin N.K., Strand T., Solomon R., Raffuse S., Drury S., Healy A., Wheeler N., October 2011. Lessons from SEMIP. JFSP Models and Measurements Workshop, Boise, Idaho.

Larkin N.K., Strand T., Solomon R., Drury S., Raffuse S., Huang S., Strenfel S., October 2011. Uncertainties in modeling smoke impacts from wildland fire. Ninth Symposium on Fire and Forest Meteorology, Palm Springs, California, 18-20 October 2011

Solomon R., Strand T., Larkin N.K., Raffuse S., Craig K., Sullivan D., Pryden D., Drury S., Stilley J., DeWinter J., Leung F.Y., October 2011. BlueSky smoke

modeling framework development. Ninth Symposium on Fire and Forest Meteorology, Palm Springs, California, 18-20 October 2011

Raffuse, S., Strenfel S., Larkin N.K., October 2011. Understanding how well satellites detect fires. Ninth Symposium on Fire and Forest Meteorology Palm Springs, California, 8-20 October 2011

Strand, T., Drury S., Larkin N.K.,. Raffuse S.M., December 2011. Analysis and cross-comparison of emissions calculations from specific wildland fires. AGU Fall Meeting, San Francisco, California.

Strand, T.M., December 2011. Micrometeorology, turbulence, and plume dynamics. Presentation at the Scion, New Zealand Forest Research Institute All-Staff and Webinar, Rotorua, New Zealand.

Weidinmyer, C., Emmons L.K., Raffuse S.M., Larkin N.K., December 2011. Emissions from open burning: evaluation challenges at different scales. AGU Fall Meeting, San Francisco, California.

Raffuse, S.M., Larkin N.K., Pryden D.A., Dedecko T.M., December 2011. New methods for modeling and monitoring wildfires using multiple data sources: SmartFire v2. AGU Fall Meeting, San Francisco.

Larkin, N.K., Strand T.M., Raffuse S.M., Drury S., December 2011. Quantifying uncertainties in U.S. wildland fire emissions across space and time scales. AGU Fall Meeting, San Francisco.

Presentations given to management / user group audiences:

Larkin N.K., October 27, 2009. Smoke and Emissions Model Intercomparison Project (SEMIP). webinar, host: NWCG Smoke Committee

Larkin N.K., Strand T., Brown T., Raffuse S., Healy A., Pryden D., May 2010. Wildland Fire Decision Support System (WFDSS) - air quality tools update. Webinar, host: WFDSS RD&A and Users Meeting.

Larkin N.K., Brown T., Raffuse S., Strand T., Zimmerman T., Lahm P., May 2010. Wildland fire and air quality: science and tools. U.S. Forest Service National Fuels Meeting, Sacramento, California.

Larkin N.K., Strand T., Solomon R., Raffuse S., Drury S., Wheeler N., August 2010. Smoke and emissions model intercomparison project (SEMIP): infrastructure and suggestions. Webinar, host: Joint Fire Science Program Board Meeting, Fairbanks, Alaska.

Larkin N.K., August 2010. Wildland fire air quality tools. Webinar, host: California Air Resources Planning Alliance (CARPA) Data Committee.

Potter B., Krull C., Larkin N.K., Rorig M., Strand T., Solomon R., September 2010. AirFire research and tools. US Forest Service/NOAA Joint Meeting, Washington, D.C.

Rorig M., Krull C., Larkin N.K., Potter B., Strand T., Solomon R., September 2010. AirFire research and tools. South Korean delegation visit, USFS PWFSL, Seattle, Washington.

Larkin N.K., Strand T., Solomon R., Raffuse S., Drury S., Sullivan D., Wheeler N., Chinkin L., September 2010. Developing an improved wildland fire emissions inventory. 19th Annual EPA Emissions Inventory Conference, San Antonio, Texas.

Larkin N.K., May 2011. SEMIP and the RFA 2011-2 Proposals. JFSP Board Meeting. Webinar.

Larkin N.K., Strand T., Martinez N., Rorig M., Krull C., Potter B., Drury S., Raffuse S., Wheeler N., Craig K., Chinkin L., March 2011. Emissions inventories and smoke: uncertainties and working towards a better EI. NWCG Smoke Committee Meeting, Seattle, Washington.

Larkin N.K., June 2011. The 2008 NEI, BlueSky, SmartFire, WFEIS, FINN, and Flambe. Minnesota Interagency Fuels Working Group. Webinar.

Larkin N.K. July 2011. AirFire science applications: beyond BlueSky. USFS PNW Station Management Team. Webinar.

Larkin N.K., September 2011. Smoke modeling: BlueSky and beyond. USFS Conversations with the Chief series. Webinar.

Strand T.M. and Mickler R., October 2011. Sub-Canopy smoke dispersion: Measurements of fire-behavior, fuels, consumption, emissions, plume rise and dispersion near and in a prescribed fire-source. The Nature Conservancy, North Carolina, Workshop for fire, land, and air quality managers in the south-eastern region, Chapel Hill, North Carolina.

Larkin N.K., Raffuse S., January 2012. Creating wildland fire emissions inventories using SmartFire and BlueSky. LADCO webinar .

Larkin N.K., Raffuse S., March 2012. National Emissions Inventory version 2 fire emissions. EPA OAP webinar.

Larkin N.K., Raffuse S., Rao V., March 2012. Using SmartFire and BlueSky to calculate wildland fire emissions and the NEI v2 effort. NWCG Smoke Committee, webinar.

References

Achtemeier G. L., Goodrick S. A., Liu Y. (2012) Modeling multiple-core updraft plume rise for an aerial ignition prescribed burn by coupling daysmoke with a cellular automata fire model. *Atmosphere,* 3, 352-376.

Akagi S.K., Yokelson R.J., Wiedinmyer C., Alvarado M.J., Reid J.S., Karl T., Crounse J.D., and Wennberg P.O., (2011) Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics*, 11 4030-4072.

Anderson K., Pankratz A. (2012) A plume-rise model for wildland fires. *Canadian Meteorological and Oceanographic Society Congress*, Montreal, Quebec, May 29 – June 1.

Drury S.A. Larkin N.K., Raffuse S.M., Strand T.M., Huang S-M. (2012) Comparing fire size, fuels, consumption, and smoke emissions estimates: A case study using the 2006 Tripod wildfire. *Ecological Modeling* (in review).

Larkin N.K., Raffuse S.M., Strand T.M., Huang, S-M. (2012) Comparison of fire emissions inventories. *Forest Ecology and Management* (in prep.)

Larkin N.K., Strand T.M., Drury, S.A., Raffuse, S.M., O'Neill, S.M., Solomon, R.C., Wheeler, N., Huang, SM. (2012) Phase 1 of the Smoke and Emissions Model Intercomparison Project (SEMIP): Test cases, methods, and analysis results. *General Technical* Report, *U.S. Forest Service PNW Research Station, Portland, Oregon,* (in review).

Larkin N.K, Strand T.M., Drury S.A., Raffuse S.M., Wheeler N. (2012) Final Report to the JFSP for Project #08-1-6-10: Phase 1 of the Smoke and Emissions Model Intercomparison Project. Available at http://firescience.gov.

Liu Y. Achtemeier G., Goodrick S., Jackson B., Qu J. (2012) Final Report of JFSP Project 08-1-6-06: Evaluation and improvement of smoke plume rise models. Available on the internet at http://www.firescience.gov.

Raffuse S., Strenfel S., Ruminski M, Larkin N.K, Hanna, J., McCarthy, M., Evaluating Fire Detection Success Rates of Satellite Detection Methods. (in prep.)

Raffuse S., Larkin N., Lahm P., Du Y. (2012) Development of the wildland fire portion of the 2008 National Emissions Inventory. (in prep.)

Raffuse S.M., Larkin N.K., Lahm P.W., Du Y. (2012) Development of the 2008 wildland fire national emissions inventory. *20th International Emission Inventory Conference*, August 13-16, Tampa, Florida. Available on the Internet at http://www.epa.gov/ttn/chief/conference/ei20/session2/sraffuse.pdf. 12pp.

Raffuse S., Craig K., Larkin N., Strand T., Sullivan D., Wheeler N., Solomon R. (2012) An evaluation of modeled plume injection height with satellite-derived observed plume height. *Atmosphere, 3*, 103-123.

Rorig M., Solomon R., Krull C., Peterson J., Rutherford J., and Potter B. (2012) Analysis of Meteorological Conditions for the Yakima Smoke Intrusion Case Study, 28 September 2009. Forest Service Pacific Northwest Research Station Research Paper. In press.

Solomon R., Raffuse S., Drury S., Sullivan D., Wheeler, N., Chinkin L., 2010. Developing an improved wildland fire emissions inventory. 19th Annual EPA Emissions Inventory Conference, San Antonio, Texas, August 2010. Available at http://www.epa.gov/ttn/chief/conference/ei19/index.html

Strand T. M., Larkin N., O'Neill S. M., Peterson J., and Martinez N. (2012) A synthesis and review of wildland fire emission factors for smoke modeling applications in the United States. *J. Geophys Res*., in prep.

Strand T., Larkin N., Solomon R., Rorig N., Craig K. J., Raffuse S., Sullivan D., Wheeler N., and Pryden D. (2012) Analyses of BlueSky Gateway PM2.5 predictions during the 2007 southern and 2008 northern California fires. *J. Geophys. Res.,* 117, D17301, doi:10.1029/2012JD017627.

More Information

For more information on SEMIP, please see:

a) The SEMIP project website: http://airfire.org/projects/semip
b) The SEMIP Technical Report (Larkin et al. 2012, available through the SEMIP website above)

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