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THE SMOKE AND EMISSIONS MODEL INTERCOMPARISION PROJECT

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1. INTRODUCTION

Fire emissions and smoke impacts from wildland fires are a growing concern due to increasing fire season severity, the public's dwindling tolerance of smoke, more rigorous air quality regulation, and fire's role in climate change issues. While numerous smoke and emissions models are available to address these issues, a lack of quantitative information on the limitations of smoke and emissions models impedes the use of these tools in real-world applications. To date, no rigorous quantitative assessment has been performed on these models, and decision makers and regulators have received little or no guidance on the strengths, limitations, and uncertainties of these models in real-world situations (Joint Fire Science Program 2007). Both the Joint Fire Science Program (JFSP) and the interagency Office of the Federal Coordinator (OFCM) Joint Action Group (JAG) for the Wildland Fire Weather Needs Assessment agree that a significant need exists to define the current state of the science and the limitations of fire emissions and smoke models, and to compile more comprehensive observational data to further model development and validation (Office of the Federal Coordinator for Meteorological Services and Supporting Research 2007).

Model intercomparisons are a useful way to determine the strengths and limitations of a model, to discover why different models produce different output in response to the same input, and to identify aspects of the simulations in which "consensus" in model predictions or common problematic features exist. Highly successful intercomparison projects for global circulation models, including the Atmospheric Model Intercomparison Project (AMIP) (Gates et al. 1992, 1999) and its successor, the Coupled Model Intercomparison Project (CMIP) (Meehl et al. 2007), have established a precedent for other successful intercomparison projects for land-surface models (Henderson-Sellers et al. 1993), paleoclimate models (Joussaume et al. 1999), and global tracer transport models (Gurney et al. 2002). These model intercomparison projects establish standard test cases for all models to run, and enable scientists to submit results from their models for these cases. Models are then tested against each other and against observational data using a standardized set of model performance and evaluation metrics.

To address the current limitations in fire impacts modeling and fill the needs outlined by the JFSP and the OFCM JAG, the Smoke and Emissions Intercomparison Project (SEMIP) is being developed by the U.S. Forest Service (USFS). SEMIP is an ongoing community effort to evaluate and intercompare the growing number of fire smoke and emission models that have been developed in the fire sciences community. SEMIP will be based on principles developed by previous successful model intercomparison projects, and will provide a valuable model evaluation and intercomparison framework for the fire impact modeling community.

The first phase of SEMIP has two major objectives: (1) create an ongoing, open access intercomparison project run by a governing board of scientists and users, and (2) complete the first round of evaluations under SEMIP and create user guidance tailored to specific model applications.

This paper describes SEMIP methodology and the initial test cases, a new prototype of the SEMIP Viewer user interface, and some preliminary results from the first phase of the project.

2. SEMIP DESIGN

2.1 Design Goals and Approach

SEMIP will provide a flexible and enduring framework for evaluating and intercomparing present and future fire impact models. The specific design goals of SEMIP include

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- creating an open standard for comparing smoke and emissions models against each other and against real-world observations for use now and into the future;
- performing rigorous evaluations of selected publically available models through a sequence of standard case studies identified by the open standard; and
- translating results into user-accessible guidance as to which models perform best under which circumstances.

SEMIP standards and protocols are being developed in association with the larger scientific and fire management communities through the creation of a Scientific Advisory Board and Governing Board. The protocols will specify open criteria for data set inclusion, test-case scenarios and observational data sets, evaluation metrics, and analysis procedures. The SEMIP standards and protocols will be presented to the Scientific Advisory Board, and then to the wider fire science research community for comment and feedback. The finalized protocol will subsequently be submitted to the JFSP for approval. This process will ensure that SEMIP will be an open standard for the evaluation of fire emissions and smoke transport models that meets the needs of model users at all levels within the fire sciences community.

Though SEMIP is similar in many ways to other model intercomparison projects like AMIP and CMIP, SEMIP is unique in that it will facilitate model evaluations and intercomparisons of individual model sub-processes, as well as different combinations of sub-process model pathways. Modeling emissions and transport of smoke from fires involves the sequential linking of numerous sub-process modeling steps, including fuel loading, fuel consumption, smoke emissions, plume rise, and transport and diffusion. Within each sub-process, several models have been developed, each with unique formulations, assumptions, strengths, weaknesses, and uncertainties. Furthermore, different combinations of sub-model choices can yield different results at the various downstream modeling steps. All combinations of models and pathways must be considered by SEMIP.

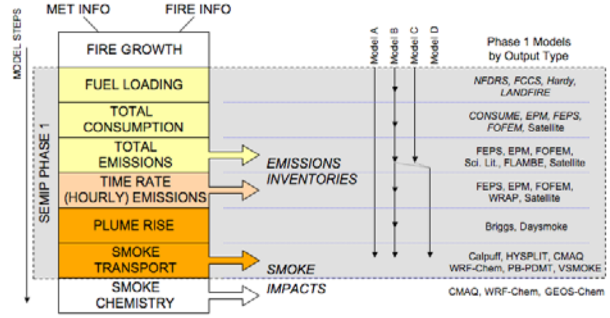

Fig. 1. Modeling steps in calculating smoke impacts from fire. The area covered by SEMIP Phase 1 is shown in grey. Specific models to be included in Phase 1 are listed by output type on the far right.

2.2 Models

SEMIP will facilitate the evaluation and intercomparison of the following smoke modeling sub-processes: fuel loading, consumption, emissions, time rate of change, plume rise, and transport. Individual models that will be included in Phase 1 of SEMIP are shown in **Figure 1**.

Given the number of models involved in the fire smoke and emissions modeling chain, the cross-comparison and evaluation of these models is an ambitious undertaking. The linkage and execution of all possible sub-models and modeling pathways is only possible because of the modularity and extensibility of the BlueSky smoke modeling framework (Larkin et al. 2009). The BlueSky Framework provides a unified platform with the process-level flexibility required to facilitate the model simulations to be performed under SEMIP. The BlueSky Framework allows the various sub-models in the smoke modeling chain to be easily interchanged, and allows for examination of model outputs at the process level. Many of the sub-models to be considered in SEMIP are already built into the BlueSky Framework, while others will be added as the project progresses.

2.3 Test Cases

Test cases are the specific fire events, episodes and seasonal summaries that will be modeled in SEMIP. Each test case consists of a set of fires, an analysis procedure, and observational data sets that will be used to drive the models and evaluate their results. The SEMIP test cases are designed to test the models under a variety of fire types, fuels, geographic regions, and meteorological conditions at a variety of temporal scales as shown in **Figure 2**. The initial SEMIP test cases include

1. the annual national wildfire smoke emission inventory for 2008 for the contiguous United States;
2. a “fires everywhere” sensitivity case;
3. large regional wildfire complexes under varied meteorological conditions in California (southern California fires of 2007, and northern California wildfires of 2008);
4. a large single wildfire complex in the southeastern U.S. (2008 Bugaboo fire);
5. a large single wildfire complex in Washington State (2006 Tripod fire);
6. an understory prescribed burn in the southeastern United States;
7. regional prescribed burns during spring 2008 in the Pacific Northwest; and
8. the Naches prescribed burn in Washington State during spring 2008.

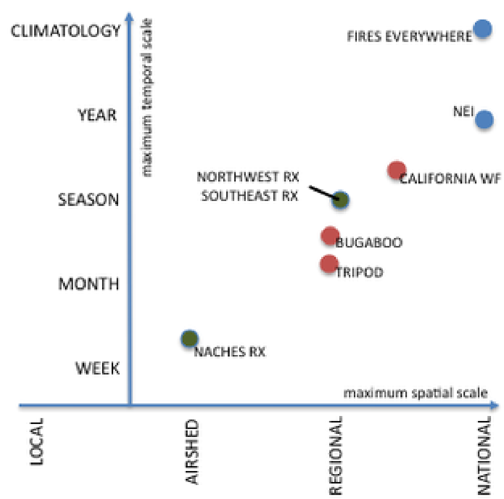

Fig. 2. Maximum spatial and temporal scale encompassed by the initial SEMIP test cases.

Additional test cases can be added to SEMIP as new input and observational data become available. The test case suite will be evaluated periodically under guidance from the JFSP Board.

2.4 Model Analysis and Evaluation

SEMIP establishes a framework of model analysis and evaluation at each step (or output level) in the smoke and emissions modeling chain. The analysis goal at each step is to quantify the model-to-model variations and the model-to-observation differences at that output level to provide scientific and user guidance for the various models at each output level, and to best describe the variability as it relates to the downstream modeling steps. Separate analysis protocols are developed for each output level, because each output level has a unique set of variables, evaluation issues, and observational data constraints that must be considered.

A variety of statistics, performance metrics, and graphical plots will be produced by SEMIP to facilitate model intercomparison and evaluation. Statistical software such as “R” (Venables, et al. 2009) will be used to calculate statistics and generate graphics for SEMIP. R is a free and open source software environment for statistical computing and graphics. Its usage in SEMIP maintains the open source and open access commitment to SEMIP users and stakeholders, and eliminates the need to develop custom software for standard graphical and statistical tasks that can be readily performed with R.

2.5 SEMIP User Interface and Data Warehouse

Results from SEMIP will be accessible to the fire sciences community through the SEMIP Viewer (**Figure 3**). This web interface will allow users to interactively browse SEMIP analysis results by test case, by modeling sub-process, or by region. The user can search for data sets and analyses by location and date range. The SEMIP Viewer enables the user to see the big picture through maps and other large-scale analysis outputs, and then focus the analysis on a regional or sub-regional level by clicking on a location of interest (see **Figure 4**).

Fig. 3. The SEMIP Viewer home page.

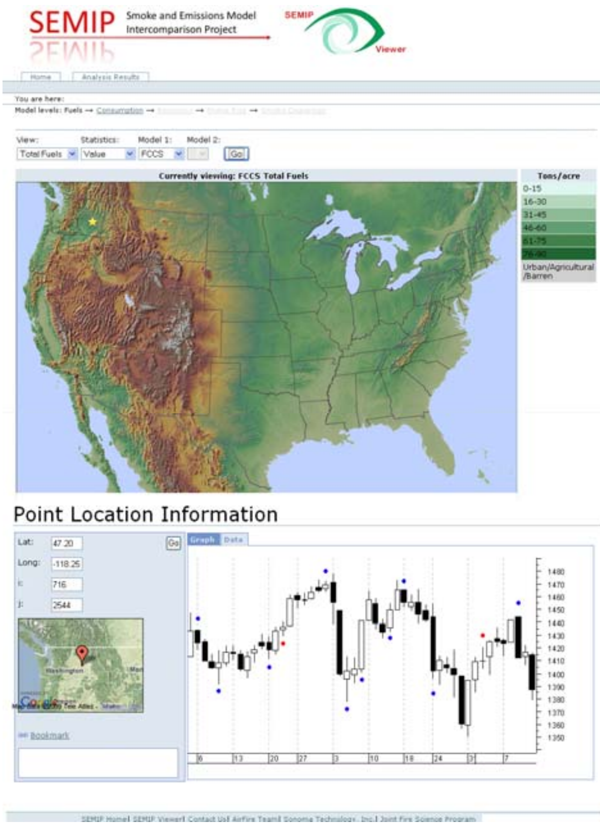

Fig 4. An example of a SEMIP Viewer analysis page.

The SEMIP Viewer will also act as the interface to the SEMIP data warehouse. Initial model runs will be carried out internally by the USFS AirFire Team, but community participation will be important for the overall success of SEMIP. The SEMIP Viewer will provide a centralized portal to the data warehouse for users to access the necessary data to initialize and drive test case simulations, and upload model output data that conform to SEMIP formatting standards. The SEMIP viewer will also accept observational data sets that can be used for SEMIP evaluations. Users who receive data from or submit data to the SEMIP data warehouse are asked to agree to the SEMIP fair use data policy, and users would have the option to restrict access to data submitted to the SEMIP data warehouse.

3. SEMIP PROTOTYPE AND PRELIMINARY RESULTS

At the completion of development, SEMIP will facilitate model-to-model and model-to-observation comparisons of the entire smoke emissions and modeling chain, and all its sub-processes for all the initial test cases. In the meantime, a prototype has been developed to demonstrate the capabilities of SEMIP and the SEMIP Viewer. The SEMIP Viewer prototype consists of a user interface to facilitate a limited model-to-model intercomparison of fire science models from the first two output levels of the smoke and emissions modeling chain—fuel loading and consumption. The fuel loading models considered in the SEMIP prototype phase are based on 1-km resolution fuel loading maps from on the Fire Characteristic Classification (FCCS) (McKenzie et al. 2007), the National Fire Danger Rating System (NFDRS) (Burgan et al. 1998), and HARDY (Hardy et al. 1998). Consumption models considered include CONSUME (Ottmar et al. 2006), the Fire Emissions Production Simulator (FEPS) (Anderson et al. 2004), the Emissions Production Model (EPM) (Sandberg et al. 1984),, and the BURNUP consumption sub-model (Albini and Reinhardt 1997) of the Fire Order Fire Effects Model FOFEM (Reinhardt 2003). This subset of sub-models allows for 12 unique modeling pathways that can be examined.

Preliminary model simulations have been completed for these two output levels by the USFS AirFire Team, and preliminary results have been made available through the SEMIP Viewer prototype.

When SEMIP is fully implemented, a wide array of model performance and intercomparison metrics will be available through the SEMIP Viewer. In the prototype phase, simple metrics, such as differences and ratios between modeled data values, will be available for analysis.

4. SUMMARY AND CONCLUSIONS

SEMIP will provide ongoing unified benchmarks for emissions, smoke, and component model evaluations. SEMIP results will assist fire managers, air quality forecasters, emission inventory creators, and others who rely on smoke and emissions models by providing guidance on the strengths and weaknesses of the various smoke and emissions models and their component pathways in comparison to other options. SEMIP will enable decision makers to assess whether a modeling system performs with sufficient reliability to justify its use in analysis and planning activities. Continued model evaluation and intercomparison activities through SEMIP will define areas of future research, including observational campaigns and model improvements. SEMIP will also improve the scientific knowledge base of the various models used in the fire sciences community, and provide a standard for evaluation of new models or model improvements.

Because SEMIP uses many generic intercomparison methods, there is a potential to extend these methods to the broader environmental modeling community. For example, the SEMIP intercomparison framework could be used to compare and evaluate a variety of meteorological and air quality models.

4.1 Future Plans

In the coming year (2010), SEMIP development will continue. Observational data sets for all the test cases will be obtained, formatted, and made available to SEMIP users. Features of the SEMIP Viewer will be expanded to facilitate the analysis and display of data from the full smoke and emissions modeling chain. SEMIP test cases, standards, and protocols will undergo a round of revisions based on community feedback.

4.2 Documentation

Extensive documentation on SEMIP, including its goals, design features, test cases, and standards and protocols, are available at http://semip.org.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Albini, F.A. and Reinhardt, E.D. (1997) Improved calibration of a large fuel burnout model. *Int. J. Wildland Fire*, **7**, 21-28.

Anderson, G.K.; Sandberg, D.V; Norheim, R.A. (2004) Fire Emission Production Simulator (FEPS) User's Guide. Available at http://www.fs.fed.us/pnw/fera/feps/FEPS_users_guide.pdf

Burgan, R.E.; Klaver, R.W.; Klaver, J.M., 1998. Fuel models and fire potential from satellite and surface observations. *Int. J. Wildland Fire*, **8**, 159-170.

Gurney, K. R., et al. (2002) Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models. *Nature*, **415**, 626-630.

Henderson-Sellers A. Yang L, and Dickinson R.E. (1993) The project for intercomparison of land-surface parameterization schemes. *Bull. Amer. Meteor. Soc*., **74** (7), 1335-1349.

Joint Fire Science Program (2007) Smoke and air quality roundtables, research needs and assessment. Joint Fire Science Program. 16pp. Available at http://www.firescience.gov.

Joussaume, S., et al. (1999) Monsoon changes for 6000 years ago: Results of 18 simulations from the paleoclimate modeling intercomparison project (PMIP). *Geophys. Res. Lett.*, **26**, 859-862.

Larkin N.K., O'Neill S.M., Solomon R., Raffuse S., Strand T.M., Sullivan D.C., Krull C., Rorig M., Peterson J., and Ferguson S.A. (2009) The BlueSky smoke modeling framework. *Int. J. Wildland Fire* (accepted).

McKenzie, D.; Raymond, C.L.; Kellogg, L.-K.B.; Norheim, R.A; Andreu, A.G.; Bayard, A.C.; Kopper, K.E.; Elman. E. (2007) Mapping fuels at multiple scales: landscape application of the Fuel Characteristic Classification System. *Canadian Journal of Forest Research*. **37**, 2421-2437.

Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R. J. Stouffer, and K. E. Taylor (2007) The WCRP CMIP3 multi-model dataset: A new era in climate change research. *Bull. Amer. Meteor. Soc*., **88**, 1383-1394.

Office of the Federal Coordinator for Meteorological Services and Supporting Research (2007) National wildland fire weather: a summary of user needs and issues. Joint Action Group, Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCMSSR), 63pp. Available at http://www.firescience.gov.

Ottmar, R.D.; Prichard, S.J.; Vihnanek, R.E.; Sandberg, D.V. (2006) Modification and validation of fuel consumption models for shrub and forested lands in the Southwest, Pacific Northwest, Rockes, Midwest, Southeast, and Alaska. Final report, JFSP Project 98-1-9-06.

Reinhardt, E. (2003) Using FOFEM 5.0 to estimate tree mortality, fuel consumption, smoke production and soil heating from wildland fire. Presentation at the *2nd International Wildland Fire Ecology and Fire Management Congress, 16-20 November 2003, Orlando, FL*.

Sandberg, D.V.; J. Peterson (1984) A source strength model for prescribed fires in coniferous logging slash. Annual Meeting, Air Pollution Control Association, Pacific Northwest Section, Reprint #84.20, 2-14 November, Portland, OR.

Venables W.N., Smith D.M. and the R Development Core Team (2009) An Introduction to R - Notes on R: A Programming Environment for Data Analysis and Graphics Version 2.9.2, ISBN 3-900051-12-7, August.