Development of Modeling Tools For Predicting Smoke Dispersion From Low Intensity Fires

Warren E. Heilman[1], Sharon Zhong[2], Joseph J. Charney[1], John Hom[3], Kenneth Clark[4], Gil Bohrer[5], Nicholas Skowronski[4], Xindi Bian[1], Michael T. Kiefer[2], and Ryan Shadbolt[2]

[1]USDA Forest Service, East Lansing, MI; [2]Michigan State University, East Lansing, MI; [3]USDA Forest Service, Newtown Square, PA; [4]USDA Forest Service, Silas Little Experimental Forest, NJ; [5]Ohio State University, Columbus, OH

Abstract

Prescribed burning can be a viable tool for managing forest ecosystems. However, smoke from prescribed fires, which often occur in the wildland-urban interface (WUI), can linger in an area for relatively long periods of time and have an adverse effect on human health. Smoke from low-intensity prescribed fires can also reduce visibility over roads and highways in the vicinity of these fires, producing hazardous conditions for transportation. Improved tools that quantitatively predict the potential impacts of smoke are necessary in order to maximize the benefits of prescribed fires and balance the conflicting needs of ecological fire use and effective smoke management.

This three-year (2009-2012) study, funded by the Joint Fire Science Program and the National Fire Plan, is focused on the evaluation and potential adaptation of three state-of-the-art fine-scale atmospheric dispersion modeling systems for predicting short-range, near-source smoke transport and diffusion from low intensity fires within and above forest vegetation layers. These modeling systems include the Weather Research and Forecasting (WRF) – FLEXPART system, the Regional Atmospheric Modeling System (RAMS) – Forest Large Eddy Simulation (RAFLES) system, and the Atmosphere to Computational Fluid Dynamics (A2C) system. Smoke concentration, meteorological, and fuel measurements via surface and tower-based instrumentation within and in the vicinity of prescribed burn units in the New Jersey Pine Barrens will be used to validate the modeling systems. Through this study, we seek to (1) improve our understanding of the effects of different forest canopies on particulate matter and water vapor transport and diffusion within and above those canopies, (2) examine how those effects could be included in operational smoke prediction systems, (3) determine the uncertainties and limitations of current models in predicting smoke dispersion from low intensity fires, and (4) develop new observational data sets for effective validation of smoke dispersion models.

Project Goal and Hypotheses

Study Goal

Adapt three existing numerical models for predicting short-range smoke transport and diffusion from low intensity fires and evaluate their performance using observational data from prescribed burn experiments.

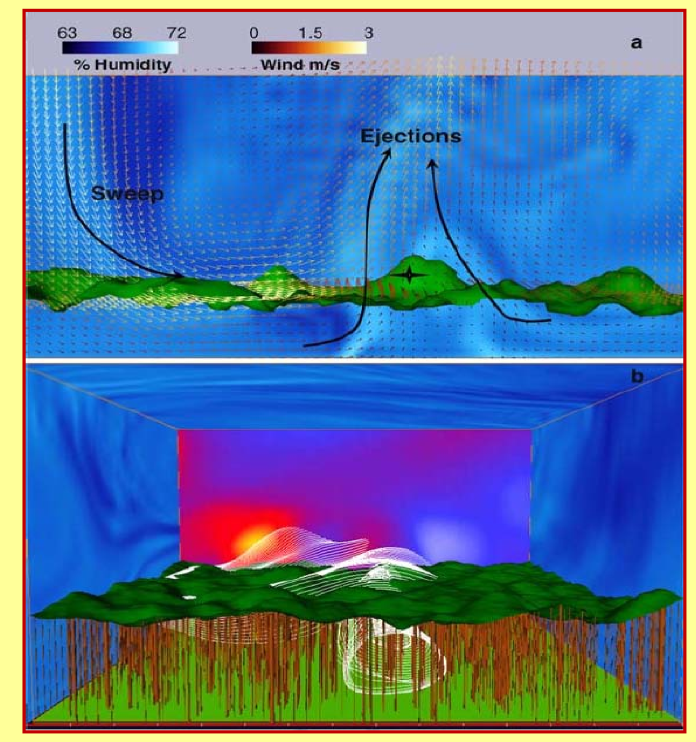
Study Hypotheses

- **Land-surface characteristics, such as terrain and forest vegetation, and near-surface atmospheric processes induced by variations in terrain and vegetation can have significant impacts on smoke transport and diffusion from low-intensity fires.**
- **Improved understanding of these impacts will lead to better predictions of smoke transport and dispersion over areas of complex terrain and forest vegetation.**

Model Adaptation and Evaluation

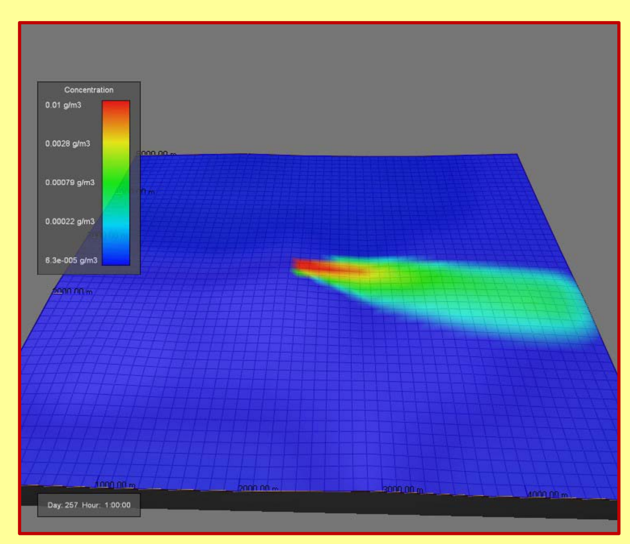
RAFLES

The RAMS-based Forest Large Eddy Simulation (RAFLES) model, which has been used to simulate biological dispersal in forest canopies (Bohrer 2007), will be adapted to simulate smoke dispersion from prescribed/wildland fires and the effects of canopy structure on the dispersion.



Example RAFLES simulations of circulations (ejection-sweep dynamics) and humidity within and above a forest vegetation layer. Green surface in figures represents the canopy top; tree stems are represented by brown; temperature on the back "wall".

A2C

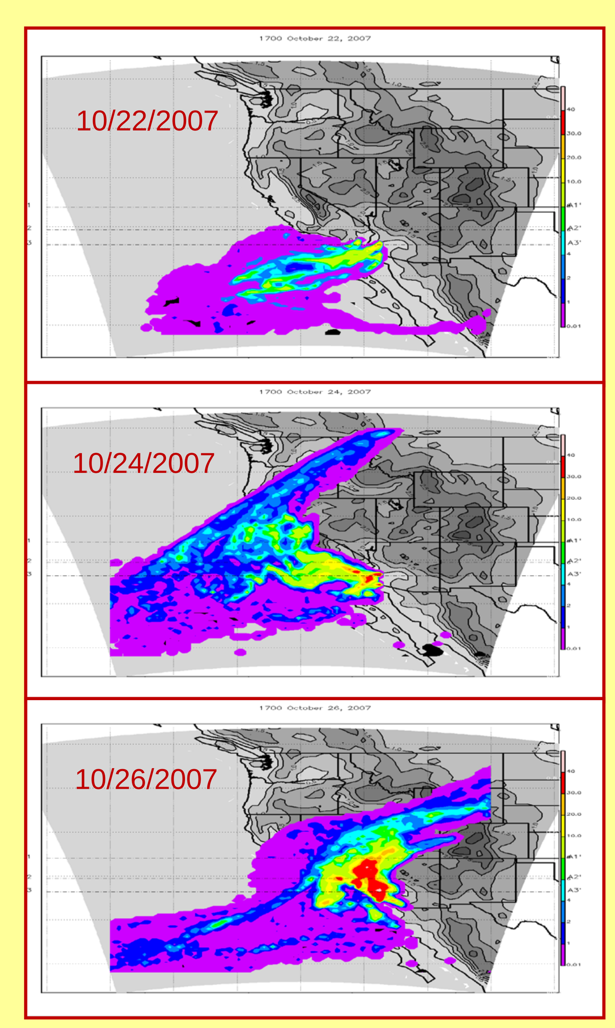


Example A2C simulation result showing downwind particle concentrations at the surface resulting from a surface fire located in the center of the model domain.

A2C is an atmospheric boundary-layer modeling system for air flow and dispersion of pollutants (Yamada 2004). It can simulate turbulent circulations and dispersion over areas of complex terrain and in the vicinity of forest vegetation. The modeling system will be adapted to simulate smoke dispersion from fires within forest stands.

WRF-FLEXPART

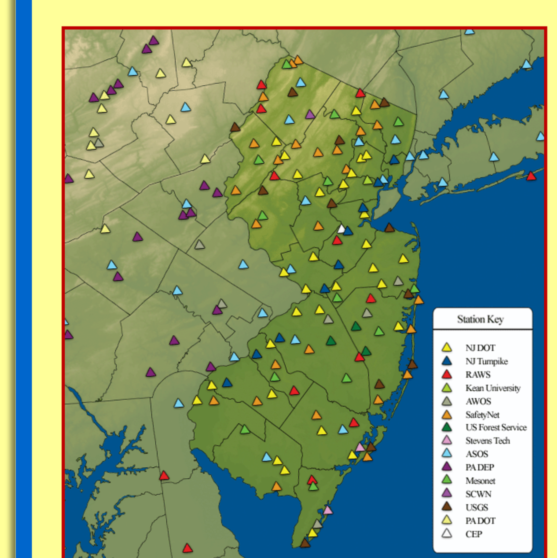
The coupled WRF-FLEXPART modeling system (Fast and Easter 2006) has been successfully employed to simulate atmospheric dispersion from local to regional scales, including the dispersion of smoke from wildfires (see figures to the right from Lu et al. 2009). WRF-FLEXPART is being adapted to simulate the local and regional transport of particulate emissions from fires within forested environments.



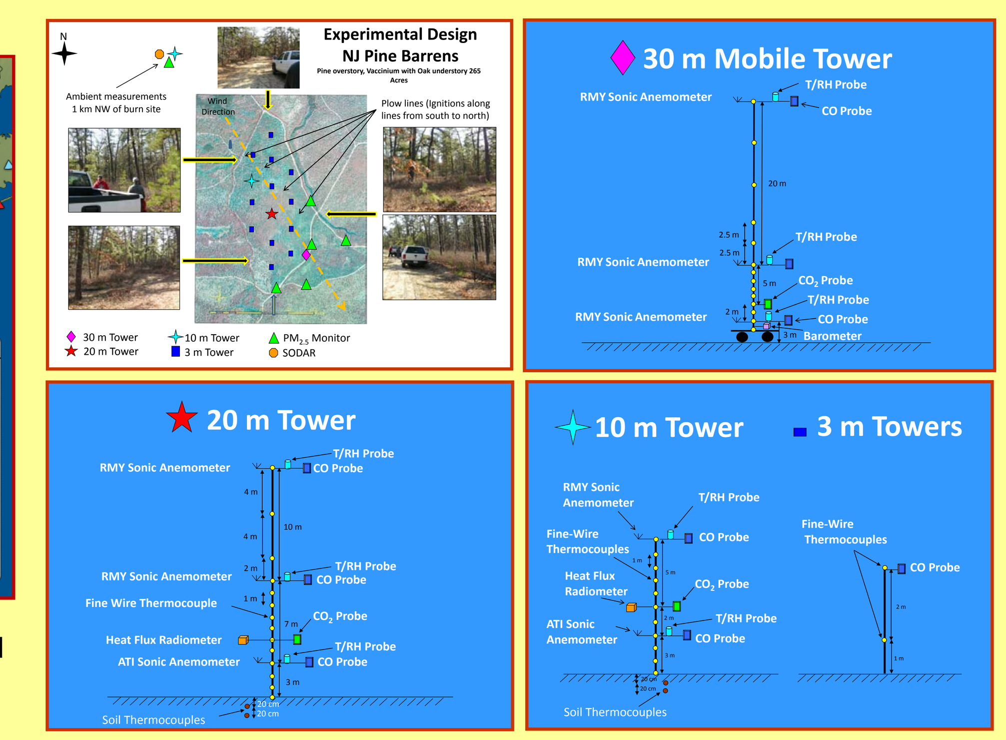
Example WRF-FLEXPART simulated surface CO concentrations during the October 2007 southern California wildfires.

Meteorological and Smoke Monitoring

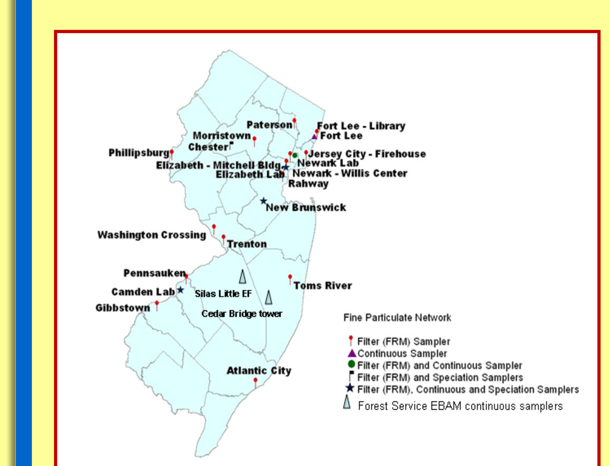
The experimental site for the monitoring component of this study is located in the New Jersey Pine Barrens Administrative Area and National Reserve. The Pine Barrens have some of the most volatile fire cycle vegetation in the East (Pitch Pine, scrub oaks and shrubs). Smoke emissions and air quality are major concerns here.



Network of surface and tower based meteorological monitoring sites in New Jersey that will provide initial conditions and validation data for the meteorological components of the models examined in this study.



Experimental design and meteorological tower configurations that will be used to monitor atmospheric and air quality conditions within and in the vicinity of prescribed burn units in the New Jersey Pine Barrens.



Network of surface $PM_{2.5}$ monitoring sites in New Jersey that will provide validation data for the air-quality components of the models examined in this study.

The existing network of meteorological stations in NJ and the additional on-site meteorological and air-quality instrumentation that will be set up within forested prescribed burn units in the Pine Barrens will provide the data necessary for examining local smoke dispersion and validating the RAFLES, A2C, and WRF-FLEXPART modeling systems.

References

Bohrer, G. 2007. Large eddy simulations of forest canopies for determination of biological dispersal by wind. Ph.D. Dissertation, Department of Civil and Environmental Engineering, Duke University.

Fast, J. D., and R. C. Easter. 2006. A Lagrangian particle dispersion model compatible with WRF. 7th Annual WRF User's Workshop, 19-22 June 2006, Boulder, CO.

Lu, W., S. Zhong, X. Bian, J. J. Charney, and W. E. Heilman. 2009. A numerical study of smoke transport and dispersion associated with the October 2007 southern California wildfires. 8th Symposium on Fire and Forest Meteorology, 13-15 October 2009, Kalispell, MT.

Yamada, T. 2004. Merging CFD and atmospheric modeling capabilities to simulate airflows and dispersion in urban areas. Computational Fluid Dynamics Journal 13(2),47:323-335.