FIRE-WEATHER AND AIR-QUALITY RESEARCH AND PRODUCT DEVELOPMENT IN THE EASTERN AREA MODELING CONSORTIUM

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I. Introduction

The Eastern Area Modeling Consortium (EAMC), established by the U.S. National Fire Plan (NFP) in 2001, is a multi-agency coalition of researchers, fire managers, air-quality managers, and natural resource managers at the Federal, State, and local levels whose mission is to conduct fire-fuel-atmosphere interaction research and develop new predictive tools for fire and air-quality management in the north central and northeastern U.S. The EAMC is one of five regional Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS) (http://www.fs.fed.us/fcamms) established in the U.S. The research and product development program within the EAMC addresses a wide variety of fire-atmosphere interaction processes that span a multitude of spatial and temporal scales. At the core of this program is a fire-weather and air-quality modeling component that is providing the foundation for the development of new predictive fire-weather indices for fire management. This paper provides an overview and synthesis of the five key research and product development programs underway in the EAMC.

II. EAMC Research and Product Development

a. Smoke and Air Quality

In the area of smoke and air quality, the EAMC is collaborating with the Northwest Regional Modeling Consortium in Seattle, WA to implement the BlueSky smoke trajectory and concentration prediction system (Ferguson et al. 2001) for predicting smoke trajectories and concentrations from prescribed and wildland fires in the north central and northeastern U.S. BlueSky is a framework of models, including emissions, trajectory, and dispersion models, that can provide real-time predictions of the cumulative smoke impacts from prescribed and wildland fires. Through partnerships with fire and air-quality managers at the Federal and State levels in these regions, the EAMC is able to provide, on request, 24-48 hour predictions of smoke concentrations and trajectories from prescribed and wildland fires via the BlueSky prediction system. Prediction results are available on a daily basis via the EAMC web site (http://www.ncrs.fs.fed.us/eamc). Figure 1 shows an example output map generated by the BlueSky prediction system following the input of fuel loading and prescribed fire location data from numerous locations in the north central and northeastern U.S. Beyond the practical applications of the BlueSky prediction system for aiding fire management, the EAMC is using the results of the daily BlueSky simulations to investigate the atmospheric dynamics of smoke transport over the north central and northeastern U.S.





Figure 1. Example BlueSky prediction of surface $PM_{2.5}$ concentrations (µg m⁻³) resulting from specified prescribed fires (initiated at 0500 EST) at various locations in the north central and northeastern U.S. valid at 2200 EST on 18 March 2005. Arrows indicate near-surface wind speeds and directions.

In addition to using BlueSky for examining smoke transport from fires in the north central and northeastern U.S., the EAMC in collaboration with the University of Houston is developing a more comprehensive airquality prediction system based on EPA's Community Multiscale Air Quality (CMAQ) modeling system and the Sparse Matrix Operator Kernel Emissions (SMOKE) system coupled with BlueSky to study the impact of episodic fire emissions on regional air quality (In et al. This effort has included a comparison of 2005). simulated concentrations of carbon monoxide (CO), nitrogen oxide (NO), and primary particulate matter (PM) species with and without fire emissions and an examination of the effects of these species on secondary species through photochemical processes. Results to

date suggest the importance of including the emissions of highly reactive volatile organic compounds (HRVOCs) in assessments of fire effects on secondary chemical species.

b. Fire-Weather

The current EAMC research and product development program in the area of fire-weather includes seven different studies (collaborators in parentheses):

- Assessment of fire-weather dynamics over the New Jersey Pine Barrens to improve fire danger rating systems (USDA Forest Service Northeastern Research Station)
- Case studies of previous fire weather events to improve our understanding of the atmospheric boundary layer and mesoscale dynamics of fire-weather evolution
- Objective identification of atmospheric mesoscale boundaries in the planetary boundary layer and their impact on fire-weather in the northeastern U.S. (State University of New York Albany)
- Haines Index relationships with atmospheric synoptic scale circulations (University of Wisconsin)
- Theoretical development of new fire-weather indices
- The use of atmospheric turbulent-kinetic-energy as a fire-weather index
- The development of a prototype atmospheric mesoscale ensemble prediction system for fire-weather applications (Weather Ventures, Ltd.)

Providing the foundation for many of the above studies is EAMC's atmospheric mesoscale modeling program utilizing the Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model Version 5 (MM5). The EAMC is using the MM5 to generate twice-daily (0Z and 12Z initialization times) 48-hour simulations of weather and fire-weather over a 36 km, a 12 km, two 4 km, and one 1 km grid spacing Figure 2 shows the location and domains. configuration of the nested grid domains. As a service to many Federal, State, and private fire and land management organizations across the north central and northeastern U.S., the EAMC daily fire-weather predictions have been made available to the public via the EAMC web site (http://www.ncrs.fs.fed.us/eamc). The availability of the daily EAMC fire-weather predictions to the fire and land management communities is a critical component of the EAMC research and product development program in that feedback from the user community regarding the

effectiveness of the predictions is helping to guide the fire-weather research directions of the EAMC.



Figure 2. The 36 km (black), the 12 km (white), the two 4 km (yellow), and the 1 km (pink) grid spacing domains used in the EAMC MM5 fire-weather simulations.

Using the MM5 modeling system running in realtime mode, EAMC scientists have developed and continue to test numerous fire-weather indices, including indices based on the parcel exchange potential energy (Potter 2002), surface turbulent kinetic energy (Heilman et al. 2003), descent mixed layer wind speeds and vapor pressure deficits, the ventilation index, the Haines Index (HI), surface potential temperature gradients, mixed-layer depth gradients, and hourly changes in mixed layer depths. Figure 3 shows example maps of two of these indices (hourly changes in mixed-layer depth and surface turbulent-kineticenergy valid at 18Z on 21 March 2005 over the western Great Lakes region). On this particular date, predicted HI values in southern Minnesota, northeastern Iowa, and portions of east-central Wisconsin were high (HI = 5), while the temporal variability in the mixed layer depth and the surface turbulent-kinetic-energy were also relatively high in parts of these states. EAMC scientists are examining the effectiveness of these indices, both individually and collectively, in signaling the potential for dangerous fire behavior due to atmospheric effects. The new fire-weather indices under development in the EAMC also are made available to EAMC collaborators, including fireweather meteorologists in the U.S. Interagency Eastern Area Coordination Center (EACC) and to fire managers in the north central and northeastern U.S., on a daily basis so that they can provide valuable feedback on the effectiveness of the indices as potential operational fireweather predictors.



tke output valid at 1800UTC on MAR 21, 2005



Figure 3. MM5 predictions of (a) hourly changes in mixed-layer depth (m hr⁻¹) and (b) turbulent-kineticenergy (m² s⁻²) at 10 m above the surface valid at 18Z on 21 March 2005 over the EAMC's 4 km grid-spacing domain covering the western Great Lakes region.

c. Small-Scale Fire-Fuel-Atmosphere Interactions

In addition to the atmospheric mesoscale studies focused on fire-weather, the EAMC also is advancing our understanding of the fundamental fire-fuelatmosphere interactions that occur during prescribed and wildland fires. It is this improved understanding that provides the foundation for the development of new and improved operational fire behavior prediction systems for fire managers. The EAMC is currently conducting and supporting the following fire-fuelatmosphere interaction studies (collaborators in parentheses):

• Fuel-atmosphere interactions and fire-danger modeling in the New Jersey Pine Barrens (USDA Forest Service – Northeastern Research Station)

- Development of a resolved forest canopy submodel within a large-eddy simulation model to investigate fire-atmosphere interactions (NOAA Air Resources Laboratory)
- Development of a predictive atmospheric firespread index for operational models (North Carolina State University)
- Physically-based wildland fire modeling and its integration into large-eddy atmospheric models (University of Utah, National Institute of Standards and Technology)
- Fuel-moisture impacts on fire-atmosphere interactions
- Fuels and fire behavior in the U.S. Central Hardwoods region (USDA Forest Service – Northeastern Research Station)
- Coupling of the FARSITE fire behavior prediction system with MM5 (USDA Forest Service Rocky Mountain Research Station)

These studies incorporate high resolution atmospheric mesoscale and boundary-layer modeling, large-eddy-simulation modeling, coupled meteorological - fire-behavior modeling, and/or atmospheric boundary-layer monitoring in forested For example, the fuel-atmosphere environments. interaction and fire-danger modeling study in the New Jersey Pine Barrens (Hom et al. 2005) is integrating observational data from a comprehensive atmospheric monitoring network established in the Pine Barrens with high resolution mesoscale model simulations of atmospheric processes important for fire danger and fuel moisture to (1) improve our understanding of why the Pine Barrens are a unique environment for fire occurrence and behavior and (2) improve fire danger predictions there. Current analyses of observational data and model output include an examination of the temporal variations in observed near-surface temperatures, latent heat fluxes, and sensible heat fluxes at instrumented tower sites in the Pine Barrens and how they compare with atmospheric model (MM5) predictions made by the EAMC (Charney et al. 2005). The near-surface observational data available in the Pine Barrens is providing a unique opportunity for assessing model errors and biases in the predictions of atmospheric conditions important for fuel-atmosphere interactions within the Pine Barrens region.

d. Hazardous Fuels

The NFP recognizes the importance of new research to identify the spatial and temporal variability of hazardous fuels in the U.S. and to develop new tools to aid fuels management. The EAMC is contributing to this research effort via a study that is examining the feasibility of integrating high resolution atmospheric mesoscale model predictions of near-surface atmospheric conditions with fuel inventories in order to predict fine woody fuel moisture conditions (Woodall et al. 2005).



Figure 4. Example map of fine woody (1-hour and 10-hour) fuel moisture appropriate for 4 September 2004 based on FIA fuel loading data and EAMC fuel moisture predictions. (From Woodall et al. 2005)

Fine woody fuel (1-hour and 10-hour fuels) loading maps based on data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program have been combined with fuel moisture predictions based on the Fine Fuel Moisture Code (FFMC) in the Canadian Fire Weather Index (CFWI) System to develop an experimental predictive index (Burnable Fuel Index) for characterizing when and where fuel moisture conditions pose a potential hazard. Figure 4 shows an example map of fine fuel moisture generated from EAMC's MM5 simulations over a 4 km grid spacing domain covering the western Great Lakes region.

e. Fire and Climate Change

In support of the U.S. Joint Fire Sciences Program (JFSP), which includes a program component focused on characterizing future fire regimes under a changed climate, the EAMC is collaborating with scientists at Michigan State University to examine the implications of climate change for the HI. The HI is commonly used by fire-weather forecasters and fire managers to characterize the atmospheric potential for large, plume-dominated fires. Using a suite of general circulation models (GCMs), the collaborative study is examining how the atmospheric component of fire risk in the U.S. might change under a perturbed climate, the spatial patterns of those changes, and the uncertainty associated with the projections due to different GCM and downscaling methodology choices.

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IV. Author Biography

Dr. Warren E. Heilman is a Project Leader and Research Meteorologist with the USDA Forest Service-North Central Research Station in East Lansing, MI. Dr. Heilman is the team leader for the Eastern Area Modeling Consortium established under the National Fire Plan. He has a B.S. degree in physics from South Dakota State University, and M.S. and Ph.D. degrees in meteorology from Iowa State University. His graduate studies focused on atmospheric boundary-layer dynamics in complex terrain. His current research portfolio includes studies of small-scale fire-fuelatmosphere interactions, landscape-change impacts on regional air quality, and climate variability impacts on forest health.