4M.4 THE MESOSCALE ANALYSIS AND PREDICTION OF FIRE WEATHER

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1. INTRODUCTION

Recent advances in the theoretical understanding of fire-atmosphere interactions and fire weather prediction have opened up broad new areas of active research into the mesoscale processes involved with fire events (Heilman et al, 2003). By employing established mesoscale models and mesoscale analysis techniques, the atmospheric structures that can promote or inhibit extreme fire behavior are being explored in greater detail. This paper will describe the new fire weather prediction tools, techniques, and theoretical developments produced by recent mesoscale research efforts, and how these tools are being employed to improve fire weather analysis and prediction.

2. MESOSCALE MODELS

Mesoscale models have played a key role in the recent development of mesoscale fire weather predictions. By analyzing daily, real-time mesoscale atmospheric simulations and building upon atmospheric parameters developed to address severe weather, such as convective available potential energy (CAPE), certain types of erratic and extreme fire behavior have been associated with atmospheric stability and moisture characteristics (Potter, 2002). Additionally, the planetary boundary layer (PBL) processes routinely predicted by mesoscale models are intrinsic to fire plume behavior, smoke dispersion, and fire-atmosphere feedback processes that can have a profound impact on fire behavior (Charney and Keyser, 2004). By developing modified CAPE calculations and exploring the development of PBL structures that can lead to the sudden appearance of dry, windy conditions at the ground, mesoscale-model-derived products contribute to firefighting activities and potentially enhance firefighter safety. Two examples of these mesoscale model fire weather products are shown in Figs. 1 and 2. Fig. 1 represents the theoretical change in CAPE above a fire that is supplying heat and moisture to surface parcels. Fig. 2 indicates the rate at which the PBL is mixing dry air down to the ground during the growth of the daytime PBL. Both of these diagnostics can be associated with an increased potential for extreme or erratic fire behavior.

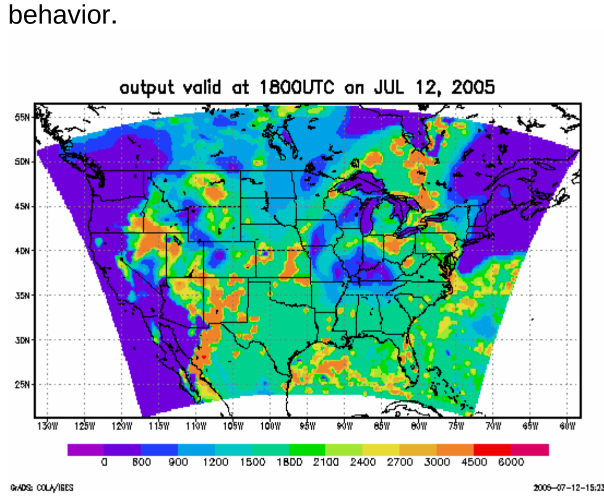

Figure 1: Simulated difference in CAPE when the surface parcel is assumed to be modified by a fire such that its temperature and moisture are increased.

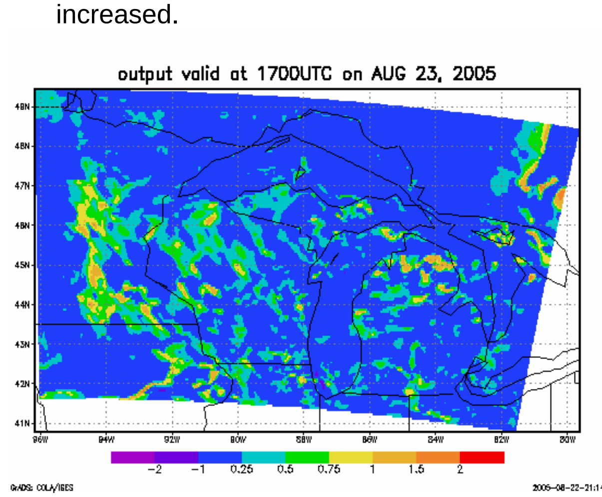

Figure 2: Simulated rate at which dry (low RH) air is being advected downward into the PBL in units of $10^{-2} ms^{-1}$.

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3. THEORETICAL DEVELOPMENTS

Several important theoretical developments have accompanied the modeling efforts described above. First, the impact of the water vapor released by the combustion process on the ensuing plume growth and the magnitude atmospheric feedback on the fire have been addressed. Atmospheric observations recently collected above a fire during a prescribed burn indicate the extent to which a fire can modify the atmospheric moisture and temperature characteristics on scales of 100s to 1000s of meters (Fig. 3). These observations have been used to calibrate theoretical predictions of mixing rates above a fire to establish that the water vapor released by combustion can substantially augment the environmental moisture, leading to different plume rise, condensation, and instability mechanisms above a fire than would be expected from the environment alone.

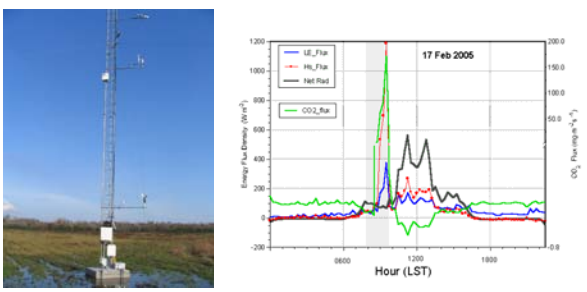


Figure 3: A meteorological tower and the energy flux measurements collected from the tower during a prescribed burn.

Additional studies have investigated the unbalanced circulations associated with jet streak dynamics and interactions, and the influence of mesoscale atmospheric boundaries such as fronts and sea breezes on observed fire behavior. Fig. 4 shows a simulation of vertical coupling that between a lower tropospheric pool of dry air and the surface during the Double Trouble State Park Wildfire (Charney et al, 2003). This simulation establishes that the formation of the mid-tropospheric dry air and the coupling of that dry air with the surface resulted from mesoscale circulations associated with jet streak interactions with PBL circulations. The arrival of dry air at the ground coincided with observations of extreme fire behavior by firefighters during the fire (NJFFS, 2003).

Fig. 5 shows a mesoscale simulation of a sea breeze front in southern New Jersey that compares well clear-air radar reflectivities from that time. Detailed predictions of the timing and strength of a sea breeze front passing over a wildfire can provide firefighters with valuable advanced warning of impending changes in fire behavior.

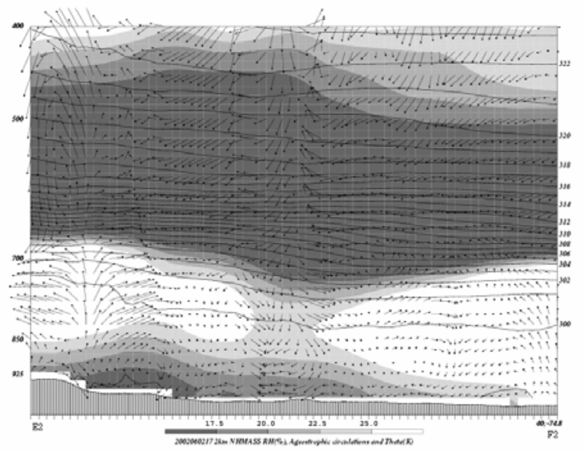
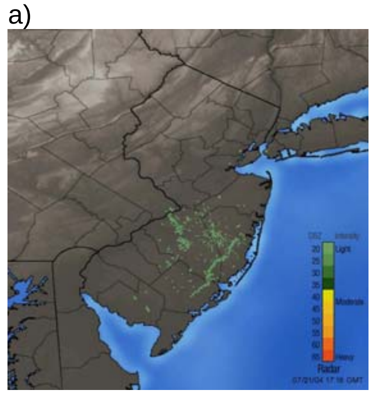


Figure 4: Vertical cross section of simulated winds and relative humidity showing the coupling between a mid-tropospheric pool of dry air and the mechanism by which that dry air was mixed down to the ground.

a)



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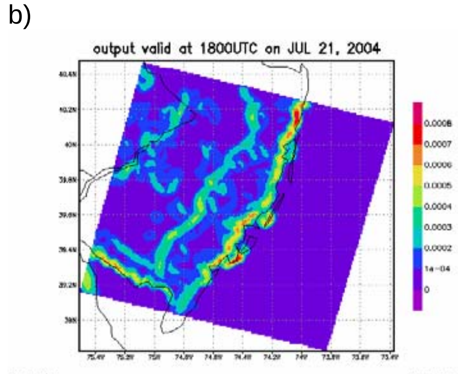

Figure 5: (a) Clear air radar reflectivities and (b) simulated surface potential temperature gradients (in °Ckm^{-1}) (b) showing the location of a sea breeze front in southern New Jersey on 21 July, 2004.

4. COUPLED MODELS

This new emphasis on mesoscale fire weather and predictability has contributed to the development of a new generation of coupled atmosphere-combustion models and the analysis of their results. These models explicitly resolve the combustion process to predict the energy exchanges between the fire and the atmosphere, and allow both systems to dynamically and non-linearly adjust to each other. Understanding the mesoscale processes that contribute to the simulated fire-atmosphere interactions in this new generation of coupled models plays a vital role in the analysis and validation of these tools. Fig. 6 shows output from the National Institute of Standards and Technology (NIST) Wildland Fire Dynamics Simulator (WFDS) model. These coupled models are both resource intensive and still in the early stages of their development. Thus they are only suitable for use in a research environment and not yet ready for operational implementation. Nevertheless, these models have already begun to demonstrate the enormous potential for numerical simulations for studying the physics of fire-atmosphere interactions (Linn et al, 2002; Mell et al, 2005).

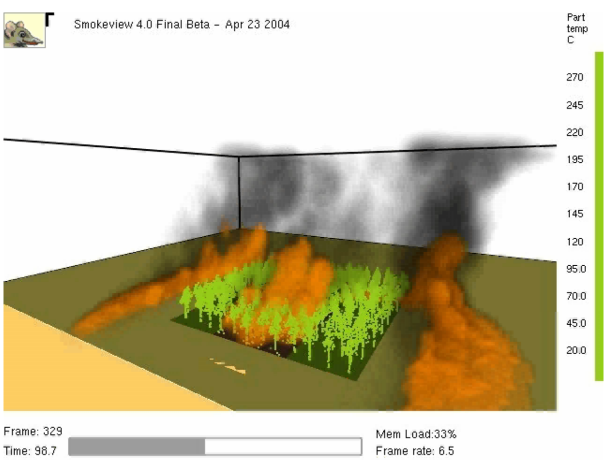

Figure 6: A snapshot of WFDS model output showing fuels (green trees), particle temperatures (orange/fire), and smoke generation (black clouds).

5. DISCUSSION

The tools and concepts outlined in this paper represent a dramatic shift in the way that fire weather research and development are being carried out. Fire weather products currently in use by operational forecasters and firefighters are based almost exclusively on empirical and statistical formulations of atmospheric processes. Historically, there has been little attempt to address the underlying physical mechanisms responsible for the observed atmospheric phenomena and their interaction with the fires. By employing mesoscale models, mesoscale dynamical theory, and new observational datasets, fire weather meteorologists are able to detect and explain aspects of fire weather environments that have never before been studied. This enhanced physical understanding of fire weather processes is already contributing to the development of new indices and diagnostics, analogous to mesoscale severe weather indices (e.g. the Lifted Index, among others), that predict the potential for certain types of fire behavior based on simulations of mesoscale conditions. Additionally, fire weather meteorologists are working to develop fire-atmosphere interaction parameterizations that could lead to improved operational prediction of fire behavior characteristics.

6. REFERENCES

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