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COUPLED WEATHER AND WILDFIRE BEHAVIOR MODELING AT LOS ALAMOS: AN OVERVIEW

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1. INTRODUCTION

Over the past two years, researchers at Los Alamos National Laboratory (LANL) have been engaged in coupled weather/wildfire modeling as part of a broader initiative to predict the unfolding of crisis events. Wildfire prediction was chosen for the following reasons: 1) few physics-based wildfire prediction models presently exist; 2) LANL has expertise in the fields required to develop such a capability; and 3) the development of this predictive capability would be enhanced by LANL's strength in high performance computing. Wildfire behavior models have historically been used to predict fire spread and heat release for a prescribed set of fuel, slope, and wind conditions (Andrews 1986). In the vicinity of a fire, however, atmospheric conditions are constantly changing due to non-local weather influences and the intense heat of the fire itself. This non-linear process underscores the need for physics-based models that treat the atmosphere-fire feedback. Actual wildfire prediction with full-physics models is both time-critical and computationally demanding, since it must include regional- to local-scale weather forecasting together with the capability to accurately simulate both intense gradients across a fireline, and atmosphere/fire/fuel interactions. Los Alamos has recently (January 1997) acquired a number of SGI/Cray Origin 2000 machines, each presently having 32 to 64 processors. These high performance computing systems are part of the Department of Energy's Accelerated Strategic Computing Initiative (ASCI). While offering impressive performance now, upgrades to the system promise to deliver over 1 Teraflop (10^{12} floating point operations per second) at peak performance before the turn of the century. This parallel ASCI machine is key to our initial wildfire prediction effort, since it enables detailed testing, validation, and prediction phases of the project at full-scale. This will accelerate the development of research models to better understand coupled weather/wildfire behavior. We are currently in the process of optimizing our codes to maximize their performance on this parallel architecture.

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2. THE MODELING SYSTEM

A diagram of the LANL wildfire modeling framework is shown in Fig. 1. Within the main flow of the diagram are three components, the Regional Atmospheric Modeling System (RAMS), the model for HIgh resolution and strong GRADient applications (HIGRAD), and FIRETEC, a physics-based fire behavior model. RAMS is a widely-used, comprehensive atmospheric modeling system based upon fundamental conservation relationships. A general description of RAMS can be found in Pielke et al. (1992) and may other publications. The HIGRAD model is described in more detail in Reisner et al. (1998) (this volume) and references included therein. The FIRETEC code is a recent LANL development and is described in Linn (1997) and Linn and Harlow (1998) (this volume). The three primary model components are enveloped by a dashed-line indicating that they are presently targeted at high performance computing (HPC) architectures. Also included in the model flow is the US Forest Service's BEHAVE system, which has been coupled to HIGRAD and lies outside the HPC environment, due to the low computational requirements of the BEHAVE system. This HIGRAD/BEHAVE coupling shows a pathway for how this wildfire prediction system might be implemented for operations where the emphasis must be on computational speed as opposed to detailed physics.

At the end of the flow diagram lies the end-user product. This presently includes scientific visualization images for understanding detailed physical processes within the simulation, but could also include pre-defined products such as predicted hourly fire perimeters that might be useful to a fire manager. To the right of each model component are dashed arrows indicating the primary data sets necessary for each code. These are discussed in the following section.

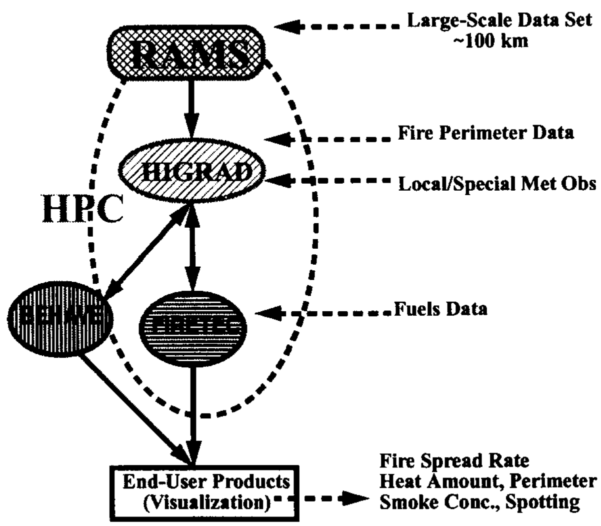

Figure 1. Schematic of the wildfire prediction project modeling components and data needs.

3. MODEL INITIALIZATION DATA SOURCES

One of the many challenges encountered in this project to date has been locating data sources with sufficient resolution to adequately describe the state of the atmosphere, fuel, and fire at the start of the simulation. This aspect of the work has also led to collaborative research efforts with other organizations. In the following section we provide a description of some existing data sources and ongoing efforts to develop new data sets for LANL's wildfire behavior models.

3.1 Large-Scale Data

Initial data for a RAMS weather forecast can be ingested from various gridded weather data analyses, such as the MAPS analysis used for the South Canyon simulation (next section). These gridded data sets are generated by interpolation methods from actual weather balloon soundings and other observations. For RAMS, a capability has also been developed to assimilate data from the National Center for Environmental Prediction's (NCEP) Regional Spectral Model. For the purpose of initializing past case studies, we have recently acquired a 6-year archive of NCEP's reanalysis data of the Global Spectral Model (2.5^0 horizontal resolution).

3.2 Local Weather/Special Observations

Local weather data near the fire and fire perimeter data are needed to augment the large-scale data analyses for model initialization. These data are often non-existent until the fire reaches a certain size that warrants intensive monitoring and suppression activity, which can be hours after a coupled weather/fire behavior prediction would have started. Nevertheless, these data are always useful for assessing the wildfire behavior forecast or for reinitializing a simulation that is not generating the observed fire behavior. Airborne infrared sensors are extremely useful for local fire observations and can offer faster response times. Infrared imagery can be used to delineate a fire perimeter for model initialization as well as provide ongoing information on fire spread rate, heat intensity, and perimeter for model validation. In a collaboration with the US Forest Service's Riverside Fire Laboratory the AIRDAS four-channel infrared scanner was flown for a prescribed burn (described in section 5) to get relevant fire parameters for model testing. We hope to fly this instrument on additional prescribed burns and actual wildfire events and further examine its potential for model initialization and validation.

3.3 Fuels Characterization Data

Radiance information from NASA's Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS) are being used to develop new data sets of vegetation type, canopy water content, and other relevant parameters at 20 meter resolution (Roberts et al. 1997). We are presently working with researchers at the University of California at Santa Barbara and with the County of Los Angeles Fire Department to use this information for the Santa Monica Mountain region of Los Angeles County to improve the spatially-explicit representation of fuel for fire modeling. This region is especially fire-prone during Santa Ana wind conditions and was the site of the Calabasas fire, which has been simulated by the HIGRAD/BEHAVE coupled fire behavior model (Reisner et al. 1998). Adding other data layers to this spatial fuels data for total available fuel biomass, live/dead fuel moisture ratios, and vertical structure of the fuel canopy should greatly improve the accuracy of fire spread predictions.

4. MODELING SYSTEM APPLICATION - WEATHER FORECASTING

In this section we describe the weather simulation with RAMS that was performed for the tragic South Canyon fire near Glenwood Springs, Colorado on July 6, 1994, that claimed the lives of 14 firefighters. The fire behavior portion of this simulation is described in Reisner et al. (1998) (this volume). From the atmospheric scientists' perspective, the South Canyon case is of particular interest because of the diverse scales of motion that influenced the fire behavior. These scales range from flow through the steep and narrow canyon where the fire blow-up occurred (100s of meters), up to the scale of the western U.S. (1000 km) where a strong upper-level disturbance was located that moved through Colorado over the course of the day.

The regional- to local-scale weather prediction was performed with a multiply-nested RAMS simulation. The simulation was initialized at 1200 UTC July 6 approximately 10 hours before the fire blow-up (which occurred at 16:00 local daylight time or 2200 UTC) from the 60 km resolution Mesoscale Atmospheric Prediction System (MAPS) analysis data set, provided by NOAA's Forecast Systems Laboratory. In addition, the MAPS analysis at 0000 UTC 7 July 1994 was used to nudge the RAMS lateral boundary conditions toward the observed large scale state through the course of the simulation. The MAPS data was interpolated to the outer RAMS grid which has 46 km grid resolution. Figure 2 shows the RAMS outer grid forecast upper-level winds at 2200 UTC at the time of the fire blow-up. The strong upper level trough (Fig. 2a), very unusual for early summer, induced strong surface low pressure in the lee of the Colorado Rocky Mountains (Fig. 2b). The surface pressure gradient across Colorado, shown in Fig. 2b, produced west-northwest flow up to 10 m/s in the region near Glenwood Springs at this time.

Through five successive nested grids within the RAMS model, each containing a new depiction of topography at the increased resolution of that grid, we are able to focus the regional weather from 46 km down to 70 m horizontal resolution over the local area where the fire occurred (Fig. 3). Obtaining a wind forecast at this resolution is critical for this case, since the total distance across the canyon from ridgeline to ridgeline is only 600 m and optimally 10 grid cells are needed to fully resolve winds across this steep topographic feature. The wind field on this finest mesh shows strong west-southwest flow up to 15 m/s over the local topography near the time of the fire blow-up. These results are in reasonable accord with first-hand accounts from fire personnel and from a local weather station located near Rifle, CO, 30 km to the west (Rosenkrance 1994). Forecast results from this finest grid mesh of RAMS will serve as boundary conditions for a microscale weather prediction with the HIGRAD model that is initialized at the time of the fire blow-up. The numerical formulation of HIGRAD makes it a better choice than RAMS to accurately resolve terrain, wind, and fire interactions. Further details on the HIGRAD/BEHAVE simulation are presented in Reisner et al. (1998) (this volume).

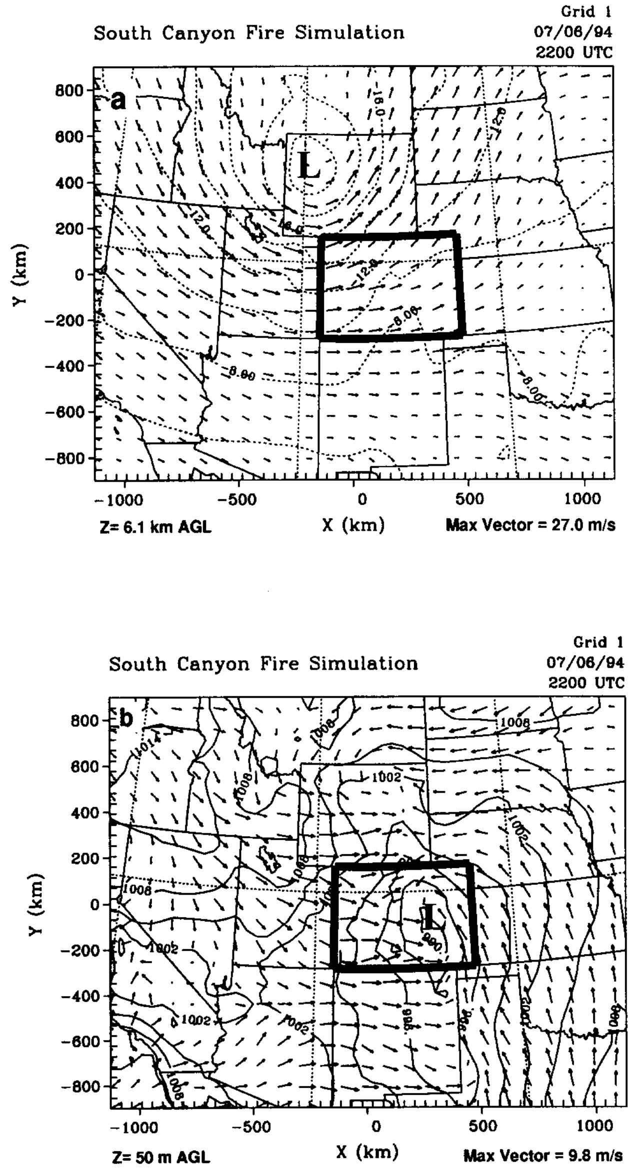

Figure 2. South Canyon fire simulation with RAMS, showing Grid 1 (a) wind vectors and temperatures (contour interval 2.0^0 C) at 6.1 km AGL, and (b) wind vectors and mean sea level pressures (contour interval 3.0 hPa) at 0.05 km AGL at 2200 UTC 6 July 1994.

5. MODEL VALIDATION

In addition to data sets for model initialization data on fire spread rate, heat output, and overall perimeter shape and area must be obtained to validate a simulation. Due to the lack of comprehensive historical data bases on these parameters, fully instrumented prescribed burns appear to be the best method to develop these data bases. To date, we have participated in two prescribed burns in very different fuels types and atmospheric conditions. The first of these was conducted on April 11, 1997 at the Kennedy Space Center, where several hundred acres of flat Florida scrub intermixed with marsh areas and small forest stands was burned. Both live and dead fuel samples were collected just before the fire. A 200 m tower with 7 levels of meteorological data was located less than 1 km to the south of the initial fireline. Overflights with the AIRDAS four-channel scanning infrared sensor aboard a NASA-Ames Lear jet provided information on fire spread rate and intensity during the burn. The fire burned vigorously after ignition, but died prematurely, perhaps due to the fire propagating into areas of vegetation with much higher live fuel moisture. Analysis and modeling of this case is still in progress.

In collaboration with the Los Angeles County Fire Department, two smaller controlled burns (5 acres) were conducted on June 17, 1997 in steep hilly terrain near Newhall, CA. The burn area was in fairly continuous chaparral, with moderate fuel loads. Portable weather stations and pilot balloons were used to record the meteorological conditions. The fire behavior was continuously recorded from a videocamera aboard a helicopter. Two different slope faces were burned, one facing against the prevailing wind and one facing into the wind. The heading fire burned very rapidly, as expected. The fire in the lee of the hill and against the wind required extensive ignition and heat production to develop, then burned intensely in only limited areas. These data sets should provide the complex real world fire behavior from which to thoroughly test the models in localized settings.

6. SUMMARY AND FUTURE RESEARCH

This paper has described an ongoing project in wildfire prediction at Los Alamos National Laboratory. The overall objective is to develop a fully coupled weather and wildfire behavior prediction system. The system will have the capability to provide forecasts of fire behavior for wildfire incidents and to fulfill scientific research objectives of investigating fire behavior and its sensitivity to external parameters. The project has been in an active development phase for two years, during which the basic modeling framework has been developed. Test simulations have produced good results, and support the concept of using full-physics models for wildfire prediction.

Near-term research goals are to continue development of the physics-based FIRETEC code, including radiation and spotting parameterizations. The FIRETEC equations are also being incorporated into HIGRAD to develop a fully integrated wildfire prediction model. This integrated system will then undergo extensive sensitivity testing and validation efforts, including comparisons with both prescribed burn data sets and the HIGRAD/BEHAVE coupled model. Other research topics that will be addressed within the longer-term goals of the project include the development of a smoke model from the gaseous and particulate effluents from the fire. These constituents of the fire can be modeled via tracer transport equations. At issue is an understanding of the radiative properties of the smoke plume. Additional effort will examine methods to transport these concentration fields upscale across the localized boundary of the wildfire simulation model to the RAMS grid to determine regional smoke effects. We will also be investigating methods of assimilating local and remotely-sensed data into the wildfire prediction codes and developing and an uncertainly analysis via ensemble forecasting to aid in determining levels of confidence in the wildfire predictions.

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REFERENCES

Andrews, P.L., 1986: BEHAVE: Fire behavior prediction and fuel modeling subsystem. USDA Forest Service Report INT-194, Intermountain Research Station, Ogden, UT 84401, 130 pp.

Linn, R.R., 1997: A transport model for prediction of wildfire behavior. Ph.D. Dissertation, New Mexico State University; also published as Los Alamos National Laboratory Report LA-13334-T.

Linn, R.R., and F.H. Harlow, 1998: FIRETEC: A transport description of wildfire behavior. *Preprints* of Second Symposium on Forest and Fire Meteorology, AMS 78th Annual Meeting, Phoenix, AZ, January 11-16, 1998.

Pielke, R.A., W.R. Cotton, R.L. Walko, C.J. Tremback, M.E. Nicholls, M.D. Moran, D.A. Wesley, T.J. Lee, and J.H. Copeland, 1992: A comprehensive meteorological modeling system – RAMS. *Meteor. Atmos. Phys.*, 49, 69-91.

Reisner, J., J. Bossert, and J. Winterkamp, 1998: Numerical simulations of two wildfire events using a combined modeling system (HIGRAD/BEHAVE). *Preprints* of Second Symposium on Forest and Fire Meteorology, AMS 78th Annual Meeting, Phoenix, AZ, January 11-16, 1998.

Roberts, D.A., Green, R.O., and Adams, J.B., 1997: Temporal and spatial patterns in vegetation and atmospheric properties from AVIRIS, *Remote Sens. Environ.*, in press.

Rosenkrance et al., 1994: Interagency report on the South Canyon fire-accident investigation team. Bureau of Land Management and USDA Forest Service.

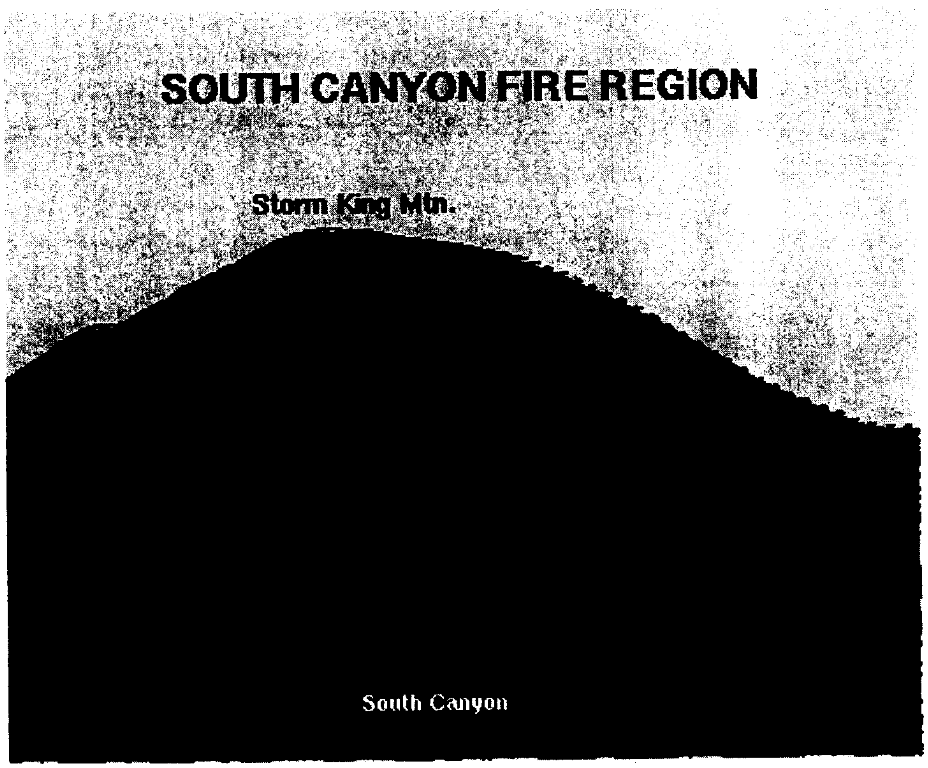

Figure 3. Image of the wind vectors on RAMS Grid 6 over the South Canyon fire region at 11 m AGL for 2200 UTC 6 July 1994.

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