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COUPLED ATMOSPHERE-FIRE BEHAVIOR MODEL SENSITIVITY TO SPATIAL FUELS CHARACTERIZATION

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1. INTRODUCTION

Recent improvements in the spatial characterization of fuels from remote sensing over localized regions offers the prospect for improving the accuracy of fire behavior models in simulating real wildfire events. This is especially true in the emerging era of coupled weather-fire models, which are run at very high spatial resolution and need to represent the fuel as accurately as possible.

In the present study, we use various spatial fuels data within a coupled atmosphere-wildfire model to compare the simulated fire behavior for a small portion of the16,000 acre Calabasas fire that occurred on 21-22 October 1996 in the Santa Monica Mountains of Los Angeles County (Bamattre et al., 1997). The fire simulation investigates an intense fire that occurred in an isolated canyon around noon on 22 October. Although the Calabasas incident was a typical Santa Ana wind driven conflagration that burned from Highway 101 southwestward to the Pacific Ocean on 21 October, the offshore winds relented overnight, allowing residual fire lines to be affected by the normal onshore sea breeze during the morning of 22 October. The study area, Corral Canyon (Fig.1), is a north-south oriented 4-km long watershed running between the crest of the Santa Monica Mountains (~700 m above ground level) and the Pacific. At the bottom of the canyon is a narrow riparian zone resistant to burning. The steep slopes of the canyon were densely covered in typical coastal chaparral vegetation, with sagebrush/buckwheat dominant on the south-facing slopes and ceanothus on the north-facing slopes, interspersed with stands of chamise.

The fire burned near the bottom of the canyon during the late morning of 22 October, driven by weak sea breezes. Just after noon, a fire blow-up occurred on the steep slopes of the Malibu Bowl, halfway up the canyon. Several firefighters, protecting a community at the top of the Bowl, were overtaken by flame lengths in excess of 100 feet during the fire blow-up, and one firefighter was severely burned. In collaboration with the Los Angeles County Fire Department, Los Alamos scientists simulated the Corral Canyon fire with the HIGRAD/BEHAVE model (Reisner et al., 1998), assuming a uniform distribution of Anderson fuel model type 4 (chaparral). More detailed spatial fuels distributions have since been processed for this region (Roberts et al., 1998). In this study, we revisit the Corral Canyon fire and use these more detailed spatial fuels data to try and understand how much of a difference can more accurate and highly resolved fuels information make in the simulated fire behavior? We also seek to understand the conditions under which the steepness of

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QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 1. Topographic representation of the Corral Canyon fire region. Study area is enclosed by the small box.

topography may overwhelm any detailed specification of fuels.

To examine these questions, we use the HIGRAD/FIRETEC modeling system, described below. This coupled atmosphere-fire modeling system can simulate changes in wildfire behavior due to specification of varying fuel load, fuel moisture, and fuel bed depth and configuration at very high horizontal (10-m) and vertical (5-m) resolutions.

2. FUELS DATA

Three sources and distributions of fuel are considered in the study. The data include 1) uniform Anderson fuel class 4 for chaparral - as would be inferred from 1 km by 1 km resolution AVHRR data. Using vegetation cover maps derived from AVHRR data combined with numerous ground samples, Burgan et al. (1998) developed a national-scale fuels data base and fire potential rating system. 2) a raster-based fuels map at 20-m resolution

(a) (b)

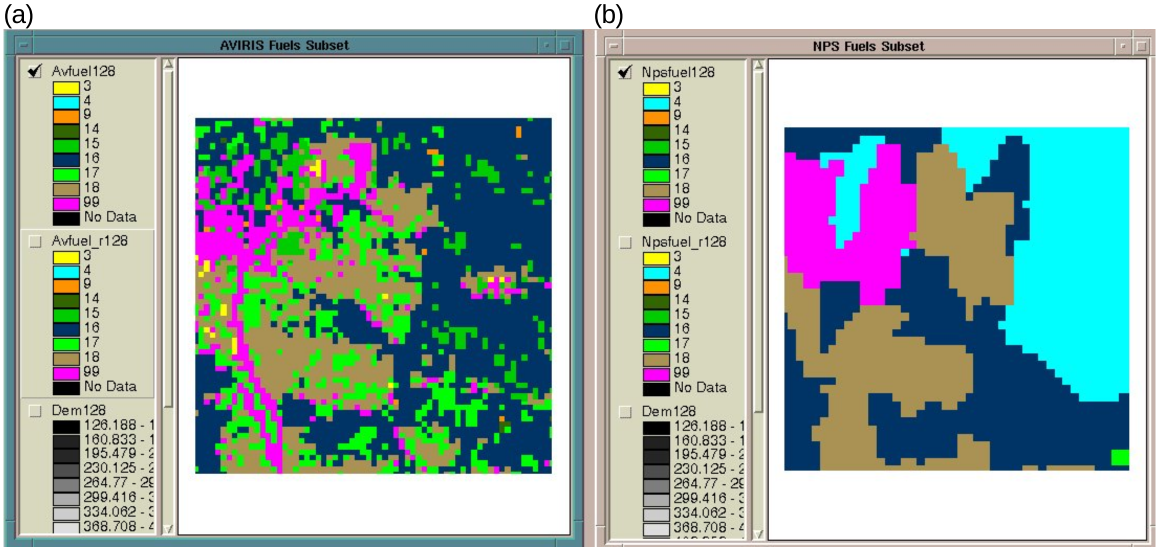

Figure 2. (a) airborne AVIRIS and (b) National Park Service derived fuels map for the Corral Canyon area indicated by the box in Fig. 1.

derived from the AVIRIS hyperspectral infrared sensor (Roberts et al. (1998), shown in Fig. 2a. 3) a data set derived for the Santa Monica Mountains by the National Park Service, with representation of spatial fuel patterns by dominant species (Fig. 2b). Incorporated into these spatial fuels data are several custom fuel models for dominant chaparral species (manzanita, chamise, ceanothus, and sagebrush/buckwheat) derived from extensive field samples by Forest Service personnel.

The fuel model data consists of various parameters designed to be used with the Rothermel (1972) fire behavior model. The FIRETEC model used in this study requires that these parameters for fuel load and distribution be adapted for the transport equation representation within this explicit fire behavior model. These modifications are described in the following section.

3. MODELING SYSTEM

The HIGRAD/FIRETEC coupled atmosphere-fire modeling system is used to test the sensitivity of fire behavior to these different fuel representations. HIGRAD is an advanced atmospheric dynamics model that is ideal for representing the sharp temperature and flow gradients encountered in the vicinity of a wildfire. The model is fully second-order in time and space, includes monotonicity constraints to handle the over- and under-shoots associated with numerically representing strong gradients, and minimizes numerical diffusion that tends to diminish steep gradients with time. The model is explained in more detail in Reisner et al. (1998), Reisner et al. (1999), and Reisner et al. (2000; this volume). The FIRETEC code (Linn, 1997) is a transport-based wildfire behavior model that has been fully-coupled to the HIGRAD atmospheric model. FIRETEC includes a representation of fuel pyrolysis, turbulent transport of combustion products, and radiative preheating of fuel due to the approaching flame front. The model allows a full three-dimensional characterization of fuel. For the present study, the dependent fuel parameters include the fuel load expressed in kg/m^3, fuel moisture expressed as a ratio to the dry wood mass weight, and a length scale dependent upon the size of the fuel.

To convert the Rothermel model fuel types into values for the FIRETEC model initially requires conversion from fuel load in tons/acre to fuel load in kg/m^3 . This includes consideration of the height of the fuel, which in the case of chaparral is always between 1 and 2 meters. Since a large fraction of the total biomass is consumed in chaparral fires, both dead and live fuels were included in the fuel load. The total load was

Total load (kg/m^3) = total 1-hr dead
+ (0.5) total 10-hr dead
+ total live herbaceous.

The fuel load values ranged from 0.1 to 0.3 kg/m^3 after accounting for equal distribution of the mass vertically through the lowest 5-m grid cell. FIRETEC can be used to consider multi-story fuel canopies involving ground and crown fuels (Linn et al., 2000; this volume), but in the present case, the fuel distribution is vertically thin, and as such, multiple vertical fuel layers were not considered.

The next conversion involved the fuel moisture and consideration of the relative proportions of the fuel that are live or dead. The fuel moisture in FIRETEC is expressed as the ratio of water mass to dry wood mass. This quantity was obtained from the fuel model data by assuming a moderate amount of fuel moisture for each chaparral species, with values of 10% for dead fuel and 120% for live fuel. The ratio of total dead to total live fuel, a parameter found in the Rothermel fuel models, was then used to obtain the total fuel moisture

Total moisture (fraction) =
total dead ratio*(0.1)
+ total live ratio*(1.2)/total ratio.

The fuel moisture values used in the simulations varied from 0.4 to 0.7. The final parameter to be specified for the FIRETEC model from Rothermel model parameters is the fuel scale, a size scale that characterizes the burning fuel. This quantity is obtained by converting the micro-scale surface area to volume ratios for live and dead fuels (by ratios, as above for fuel moisture), and taking the inverse of this quantity times a proportionality constant (that assumes the fuel to be characterized as small cylinders) to arrive at a mixing length. These lengths are on the order of a millimeter.

This study constitutes one of the first attempts to run the FIRETEC model at both "coarse" resolution and with real terrain. Thus, it has been necessary to carry out sufficient testing of the model in 2-D, before performing full 3-D simulations with spatially varying fuels (shown in Figs. 1 and 2). The preliminary simulations shown here are only 2-D and consider each fuel type separately to initially determine its effect on the fire behavior within the FIRETEC model. The HIGRAD/FIRETEC model was initialized with a constant horizontal westerly wind of 2.0 ms^{-1}, characteristic of a weak sea breeze. The model resolution is 10-m in the horizontal and 5-m in the vertical. The vertical coordinate is stretched over 26 layers following a geometric progression that establishes the model top at 1.3 km. The simulation domain is 1.27 km (128 grid cells) and incorporates a topographic slice through the bottom of Corral Canyon at 10-m resolution for the lower boundary.

4. PRELIMINARY RESULTS

The simulated fire is initialized at grid cells 35-37 (-250 m) at the bottom of the canyon in each of the four runs that are described here. The simulated fire takes several minutes to achieve sufficient temperatures to begin propagating into adjacent cells and up the terrain slope. An example of one of the four simulations is shown in Figure 3 at three separate times for the sagebrush custom fuel model, which is one of the dominant species on the south-facing slopes of the canyon. After 2.5 minutes of simulated time the fire is beginning to accelerate up the slope toward the head of the canyon. Maximum temperatures are still relatively cool at 550 K. The inflow wind (running from left to right in the figure) has begun to accelerate in the vicinity of the fire. This effect can be seen in the heat plume that is rising 200 m up the slope from the maximum temperatures. After 8 minutes of simulated time (Fig. 3b), the fire has burned up to the break in the slope gradient. Hot gases from the fire, which has attained a maximum temperature of 831 K, can be seen rising above the next, steeper portion of the slope. This convective heating of the slope causes the equivalent of a "blow-up" within this simple simulation, as shown in Fig. 3c. Here, after only an additional minute of simulated time we find that the entire steep slope between x=200 m and x=350 m is engulfed in fire, with a large convective plume rising from the fire front. The average spread rate of the fire in this simulation, while variable, is nearly 1.5 ms^{-1}, a relatively fast moving fire.

The spread distances at discrete time intervals for the four fuel types considered in the simulations are shown in Fig. 4. While the fuel load and moisture parameters were variable among the fuel types, the numerical values were not dramatically different in three of the four cases (sagebrush, ceanothus, and chaparral model 4). Due to only subtle differences, 3 of the 4 fuel models had similar burn characteristics. In contrast, the chamise fuel model had the lightest fuel load and highest moisture content. This led to radically different behavior in that the fire never achieved sufficiently high temperatures to sustain itself up the slope, and essentially died after 8 minutes of simulation. This result shows that the FIRETEC model is sensitive to the specification of fuel load and moisture. More testing is needed to establish the criteria for whether the light fuel load or high moisture content was the dominant factor in the weak fire response. Further tests will focus on incorporating all of the fuel models following the spatial fuel maps shown in Fig. 2, in both 2-D and more realistic 3-D simulations. We also plan to perform identical simulations to those shown here without terrain, to try and separate, albeit in a crude way, the effect that the terrain slope has on establishing the uniformity in rate of burn between most of the fuel models.

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REFERENCES

Bamattre, W., R. Hinz, and P.M. Freeman, 1997: Calabasas incident entrapment analysis. Los Angeles County Fire Department report.

Burgan, R.E., R.W. Klaver and J.M. Klaver, 1998: Fuel model and fire potential from satellite and surface observations. USDA Forest Service Report.

Reisner, J. M, J. Bossert, and J. Winterkamp, 1998: Numerical simulation of two wildfire events using a combined modeling system (HIGRAD/BEHAVE). Preprints of the Second Symposium on Forest and Fire Meteorology. AMS 78th Annual Meeting, Phoenix, AZ, January 11-16, 1998, pp. 6-13.

Reisner, J.M., S. Swynne, L. Margolin, and R. R. Linn, 1999: Coupled atmosphere-fire modeling using the method of averaging. (Submitted to Monthly Weather Review, August, 1999).

Roberts, D.A., M. Gardner, J. Regelbrugge, D. Pedreros, and S. Ustin, 1998: Mapping the distribution of wildfire fuels using AVIRIS in the Santa Monica Mountains. *Remote Sens. Environ.,* v. 65(#3) pp. 267-279 .

Rothermel, R. C., 1972: A mathematical model for predicting fire spread in wildfire fuels. USDA Forest Service Research Paper INT-115, Intermountain Forest and Range Experiment Station, Ogden, UT.

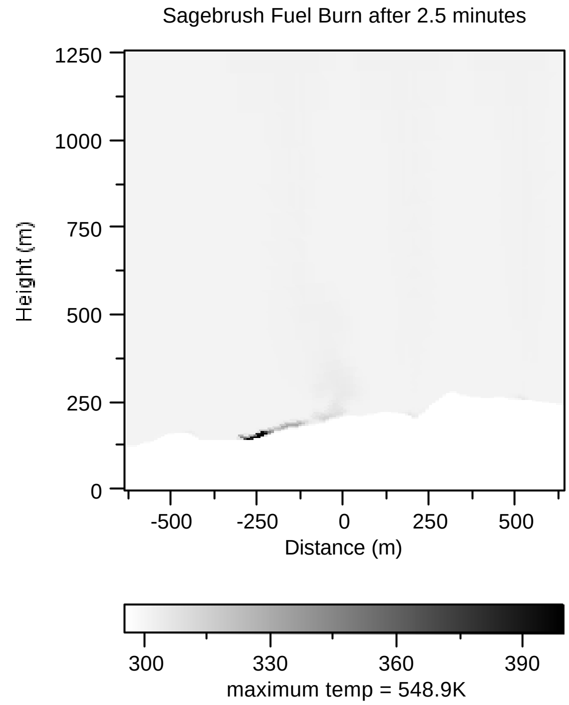

Figure 3. Fire behavior after (a) 2.5, (b) 8, and (c) 9 minutes simulated time.