P5.13

MODELING POST-FRONTAL COMBUSTION IN THE *FARSITE* FIRE AREA SIMULATOR

Mark A. Finney *, Robert C. Seli, and Patricia L. Andrews
USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana

1. INTRODUCTION

Modeling capabilities of the *FARSITE* fire area simulator have been expanded to include post-frontal combustion and smoke production. *FARSITE* previously simulated only fire growth, with fire behavior calculations applicable only to the edge of a fire (Finney 1998). *FARSITE* can now simulate the burnout of duff and woody fuels behind the flaming front. A time dependent combustion history for both flaming and smoldering burning allows the smoke and heat production to be displayed for all or part of the fire simulation area. *FARSITE* accounts for both temporal and spatial variation in conditions. *FARSITE* software and information can be found at www.fire.org.

Post-frontal combustion is defined as fire activity occurring after the passage of the advancing edge of the fire. Post-frontal combustion is essential to the production of smoke and to understanding patterns of heat-evolution from large fires that are believed critical to lofting of the smoke and interactions with the atmosphere (Rothermel 1991, 1994, Linn and Harlow 1998). *FARSITE* does not include modeling of smoke dispersion, but the output from *FARSITE* could be used for such a model.

2. MODELING

The Burnup model (Albini and Reinhardt 1995, Albini et al. 1995) simulates the combustion history of a fuel complex composed of duff and woody fuels. The fuel complex is described as horizontal loading (kg m^{-2}) of any number of woody fuel classes and their individual physical characteristics including density (kg m^{-3}), heat content (kJ kg^{-1}), and size class. The model requires an input of the initial fire conditions that ignite the elements of the fuel complex, namely fire intensity (kW m^{-2}) and the residence time (sec) of the ignition pulse. The environmental conditions are also required, including wind speed and the moisture contents of the woody fuels and duff. The Burnup model then simulates the burning of the fuel elements over time, but explicitly excludes effects of wind on burning rate of the woody fuels or duff. Time steps are typically 5-30 seconds, short enough to capture the burning time of the finer fuel elements. The outputs from Burnup are intensity (kW/m^2) and fuel weight loss at each time step. These apply to a unit-area of the specified fuel complex.

The Burnup model was modified to distinguish flaming from smoldering combustion. This distinction permitted emissions factors to be applied separately to each fraction of the fuel weight lost. Flaming was distinguished from smoldering using an intensity threshold (17 kW m^{-2}) for each size class of fuel particle in the fuel complex at each time step. Below this threshold, smoldering combustion was assumed. The threshold was the average of 15 intensities measured at visually estimated end points of flaming combustion on slash fires (data provided by R.D. Ottmar, PNW Research Station). The observation range of about 5-40 kW m^{-2} probably reflects the vagueness of a criterion for cessation of flaming in field fuel beds and the spatial variation in fire activity across the burning area. The fire intensity at those end points was then obtained from the sample emissions data on those fires that permitted an intensity to be calculated from the CO and CO_2 outputs. Duff combustion was assumed to occur by smoldering only. Thus, the weight loss and intensity occurring at every time step was divided into smoldering and flaming fractions. These can be graphed over time to show the decline in flaming combustion and increasing smoldering fraction.

The use of the Burnup model in computing emissions of large fires was dependent on modifications to the *FARSITE* simulation model that preserved the spatial histories of fire progress. *FARSITE* was modified to allow the storage of spatial data on past fire progress. The data structures, called "rings", essentially contain two consecutive fire perimeters that are each composed of vertex pairs. Each vertex pair represents the trajectory of a single vertex over a single time step (its position at the start end of the time step). The ring structure contained the vertices, the starting and ending times of each perimeter, and descriptions of the fire behavior and fuel types at each vertex. Thus, during a simulation, each ring could be retrieved at an arbitrary time step to make calculations for the area bounded by the two fire perimeters. The storage of each ring is complicated by the fact that the number of vertices in the ring changes over time. As the fire gets bigger, vertices are inserted along the longest segments. Also, vertices may be clipped out along concave portions of the perimeter or when a fire merges with other fires. The order of the vertices also changes depending on many vector operations performed within *FARSITE*. All of these complexities required corrections to preserve the geometry of each ring, the trajectories of its vertices, and the area burned.

* *Corresponding author address*: Mark A. Finney, Fire Sciences Laboratory, P.O. Box 8089, Missoula, MT 59807; e-mail: mfinney@fs.fed.us

3. DATA AND COMPUTING REQUIREMENTS

Use of the post-frontal combustion modeling capabilities of *FARSITE* require input data in addition to the needs for simulating fire growth. Ideally in addition to the fuel model parameters, duff loading and large woody fuel (3"+) GIS grid themes would be used to feed the model. But landscape-wide constants can be used if the user is willing to ignore the variability of duff and large woody fuels.

The Coarse Woody theme uses integer values as an index to reference a Coarse Woody Profile text file, which contains the data for the post-frontal combustion model.

A 'Coarse Woody Profile' file contains specific fuel profile data for each index value in the 'Coarse Woody' grid theme. Each index value contains the depth of the fuel bed and one or more fuel classes determined by the user. Following are the data elements required for each size class:

- *Size Class* - The representative size of the class based on surface to volume ratio (in or cm). (e.g., for the 3" to 6" size class the representative size is 4.75)
- *Loading* - Fuel loading of the fuel class (tons/ac or kilograms/ha)
- *Heat Content* - Heat content of the fuel class (BTU/lb or joules/kilogram)
- *Density* – Whether fuel in a given fuel class is sound or rotten is defined by the density of the fuel (lb/ft^3 or kg/m^3). Typical values are 32 lb/ft^3 for sound fuel and 19 lb/ft^3 for rotten.
- *Moisture* – Initial moisture content of the size class (percent). A model is used to calculate the fuel moisture content used for post–frontal calculations.

FARSITE contains several tools to help in creating the Coarse Woody Profile text file. A custom editor is available where the user can create and edit the Coarse Woody Profile text file. The New CWD Profile dialog box (figure 1) will distribute a total woody fuel loading into size classes based on a distribution pattern selected by the user.

The Duff Loading grid theme is attributed directly with the duff loadings (tons/ac and metric tones/ha).

Modeling post-frontal combustion is very computer and data intensive, thus requiring very long simulation run times. A short duration simulation should be attempted first.

4. POST-FRONTAL COMBUSTION RESULTS

The simulated fire display is changed to show fire activity behind the flaming front (figure 2). The combustion zone is color coded to show energy release, ranging from yellow (greatest) through orange, red, maroon, and black (least). When combustion is complete, the simulation area is displayed as a darker shade of the visible theme color.

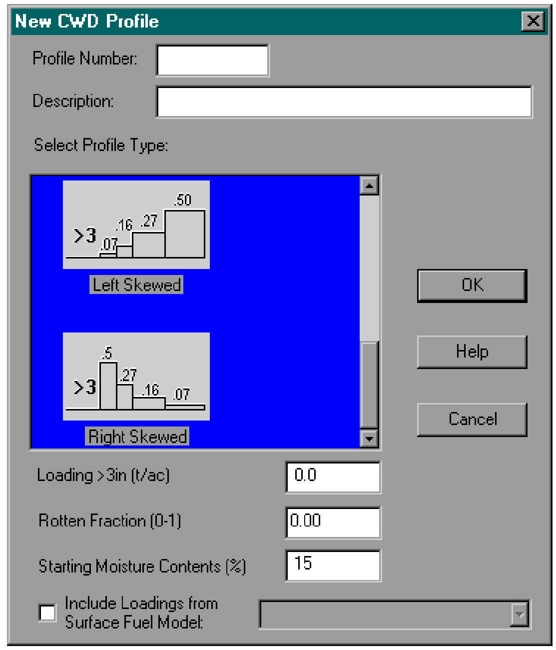

Figure 1. *FARSITE* tool to assist developing a Course Woody Profile.

Raster maps of heat and emission production can be produced while the simulation is suspended (figure 3).

Instantaneous fire activity can be recorded and viewed for all areas within the fire area. The combustion maps show in raster format the rates of heat release, fuel consumption, and smoke production spatially at that time in the simulation. A series of these maps would show the pattern of changing fire activity across the landscape.

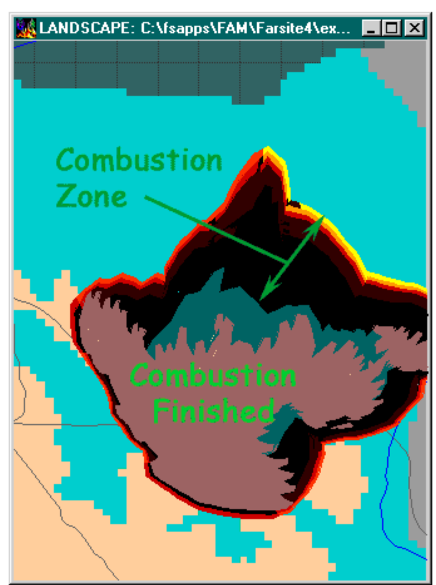

Figure 2. Map display of post-frontal combustion.

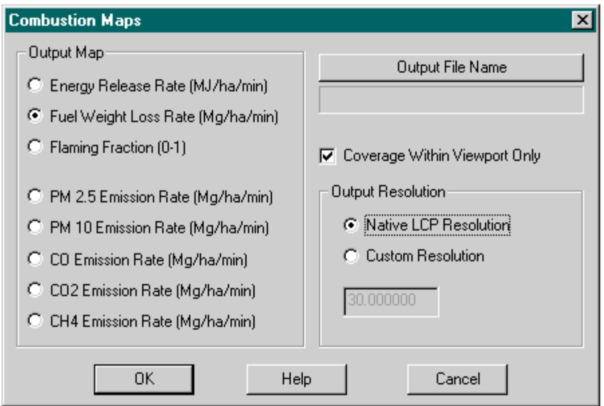

Figure 3. Combustion map options.

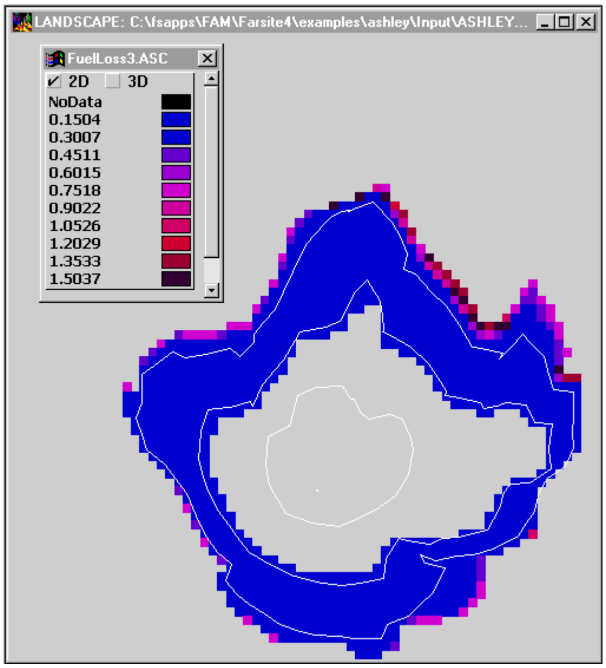

Figure 4. Fuel Weight Loss Rate map.

Figure 4 shows a raster map of the default Fuel Weight Loss Rate map. Note that this is a map of rate; the units are tons/ac/min. The center, where combustion is complete, does not have values.

Non-spatial post-frontal combustion results can be displayed by graphs and data tables (figures 5 and 6).

Right-clicking the graph or table shows a shortcut menu with a variety of display options. Different emission rates, data export, totals for selected time periods, as well as 1st and 2nd derivatives can all be selected from the shortcut menus.

5. APPLICATION AND LIMITATIONS

During the Powell Wildland Fire Use in Grand Canyon National Park in 2003, *FARSITE* was used to

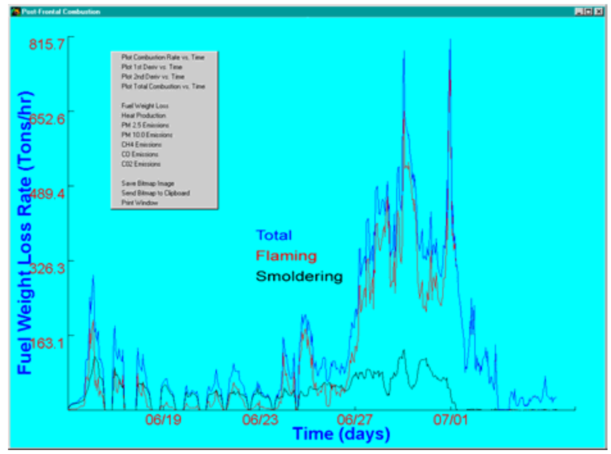

Figure 5. Graph results showing fuel weight loss rate for flaming, smoldering, and total combustion.

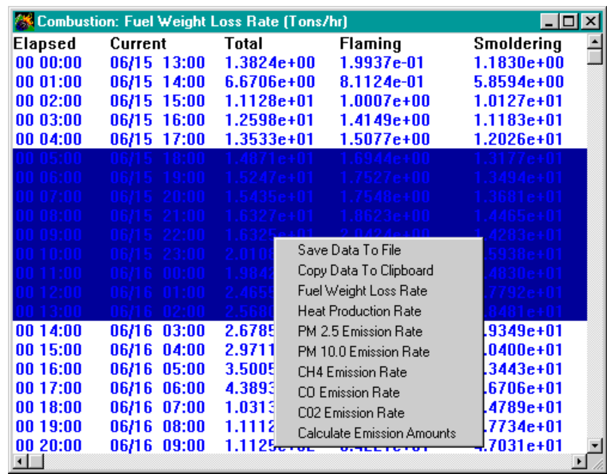

Figure 6. Table results for the data shown in figure 6.

predict impacts to visibility from smoke. Visibility was measured by the In-Canyon transmissionometer. The results are shown in figure 7.

FARSITE's post-frontal combustion model roughly predicted peaks in the Grand Canyon haze levels. Several issues limit the application of this type of analysis. First, emission production is not always a good predictor of air quality; dispersion of the production tends to be much more important. Second, haze is a regional issue, not the result of a single fire. When one fire becomes active, others in the area are usually contributing to the haze.

The addition of post-frontal combustion to FARSITE permits for the first time the ability to realistically simulate emissions and energy release from the fire as a whole, not just the flaming front. Although the full utility of this feature is not yet known, smoke production and heat evolution can perhaps be used as input for smoke lofting and dispersion models.

6. REFERENCES

Albini, F.A. and E.D. Reinhardt. 1995. Modeling the ignition and burning rate of large woody natural fuels. Intl. J. Wildl. Fire. 5(2):81-92.

Albini, F.A., J.K. Brown, and R.D. Ottmar. 1995. Calibration of a large fuel burnout model. Intl. J. Wildl. Fire. 5(3):173-192.

Finney, M.A. 1998. *FARSITE*: Fire Area Simulator—model development and evaluation. USDA Forest Service, Res. Pap. RMRS-RP-4. 47 pp.

Linn, R.R. and F. H. Harlow. 1998. FIRETEC: A transport description of wildfire behavior. In Proc. 2nd Symp. on fire and forest meteorology. Am. Met. Soc. pp 14-19.

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the northern Rocky Mountains. USDA For. Serv. Res. Pap. INT-438.

Rothermel, R.C. 1994. Some fire behavior modeling concepts for fire management systems. *in* Proc. 12th conf. Fire and Forest Meteorology, pp164-171.

7. ACKNOWLEDGMENTS

The Joint Fire Science Program funded the addition of post-frontal modeling capabilities to *FARSITE* and the development of related online help and training material.

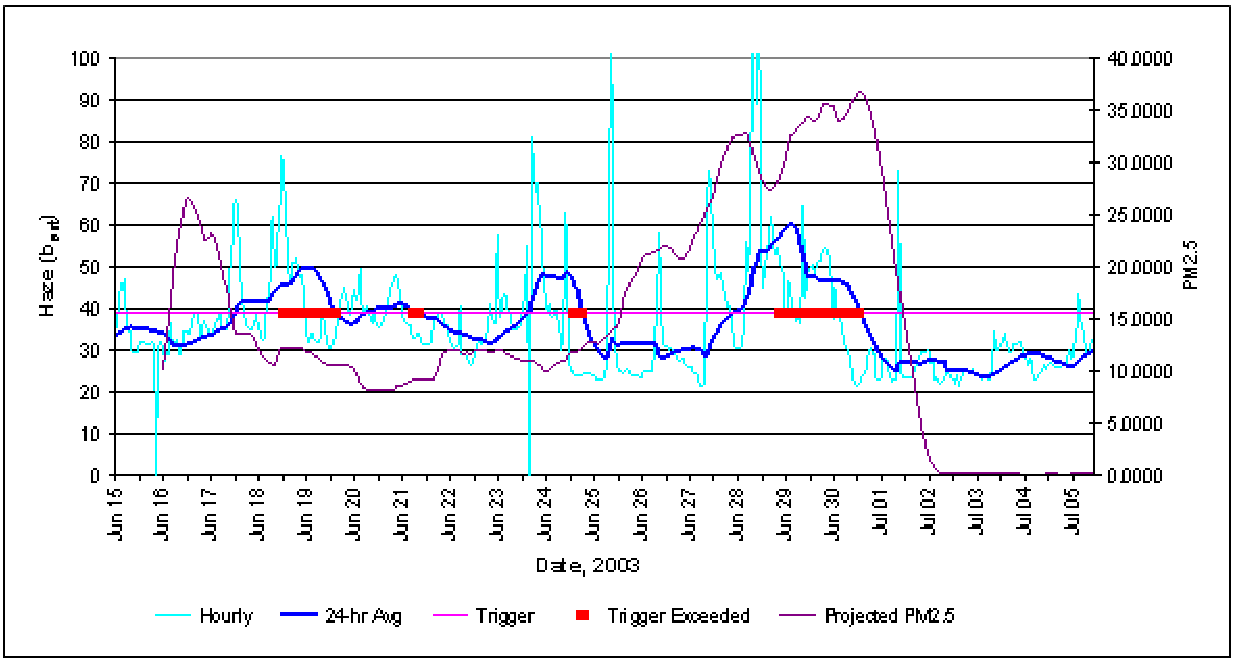

Figure 7. In-Canyon Hourly Visibility (blue) and PM2.5 Projections (red), Powell Fire, Grand Canyon N.P.