An Overview of FlamMap Fire Modeling Capabilities

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Introduction

Computerized and manual systems for modeling wildland fire behavior have long been available (Rothermel 1983, Andrews 1986). These systems focus on one-dimensional behaviors and assume the fire geometry is a spreading line-fire (in contrast with point or area-source fires). Models included in these systems were developed to calculate fire spread rate (Rothermel 1972, Albini 1976), fire shape (Anderson 1983, Alexander 1985), spot fire distance (Albini 1979, 1983) and crown fire spread rate (Van Wagner 1977, Rothermel 1991). The FlamMap program was developed for extending the utility of these models to a landscape-level where the necessary inputs have been mapped using geographic information systems (GIS). This paper documents the capabilities in FlamMap 3.0 and discusses some of the uses for such capabilities.

Features of FlamMap 3.0

General Features

All fire behavior calculations assume that fuel moisture, wind speed, and wind direction are constant in time. FlamMap is designed, however, to examine spatial variability in fire behavior, so it utilizes the same set of spatial inputs as the *FARSITE* fire simulation system (Finney 1998). The fire behavior calculations are performed independently for each cell on the gridded landscape.

These spatial inputs include eight GIS raster themes that describe fuels and topography (Figure 1) combined into a Landscape (LCP) File. Any raster resolution (the X- and Y-dimensions of the raster cells) can be used, but all layers must be identical in resolution, extent, and co-registered. The user is required to input initial fuel moisture conditions for each surface fuel model and the fuel model parameters for any custom surface fuel models present. There are two options for using fuel moistures in the calculations,

1. Using a fixed set of fuel moistures (by surface fuel model) is the default and allows direct comparison of fire behavior across the landscape because fuel moisture can be set identically for all surface fuel models.
2. Fuel moistures conditioned by a wind and weather stream is used to calculate localized moisture contents of dead surface fuel size-classes (1hr, 10hr) that are influenced by the elevation, slope, aspect, and canopy cover (Nelson 2000).

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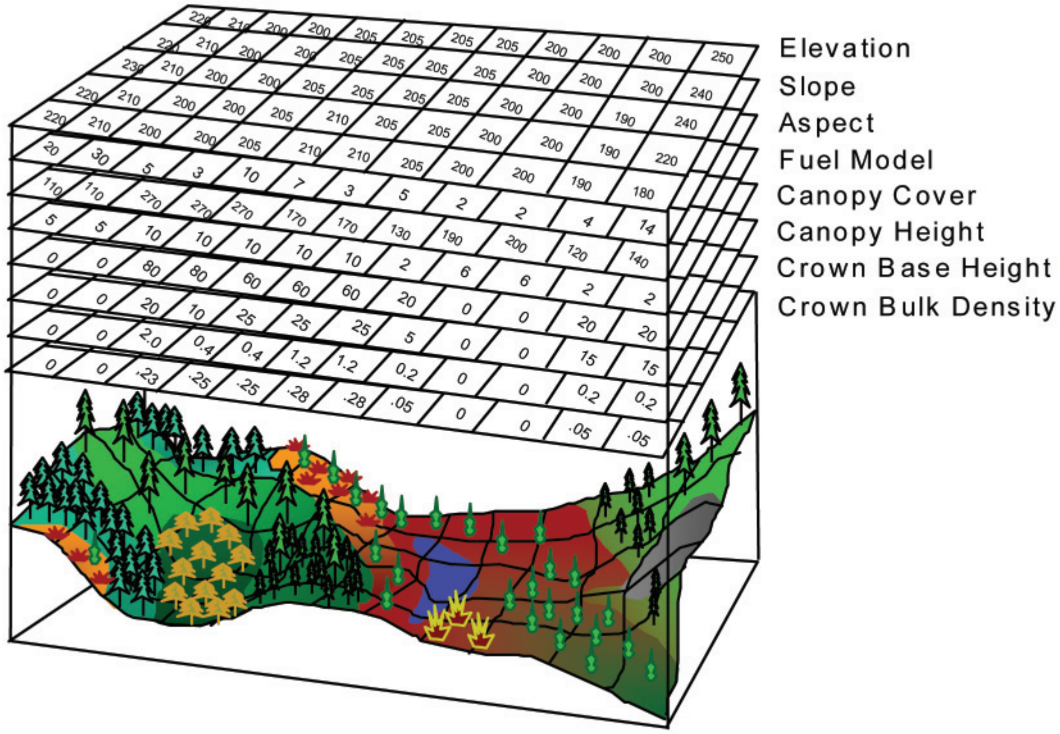

Figure 1—Input data themes required for running FlamMap are the same as those for FARSITE and are contained in a "Landscape" file constructed from ASCII Grid files that are of identical resolution, co-registered, and of equal extent.

Winds are entered as a fixed speed and direction or as spatial wind field grids (separate grids for wind speed and direction) that are generated outside of FlamMap but are useful for examining fire spread in complex terrain where winds are modified by topography.

Ancillary grid and vector themes (besides those in the LCP file or outputs) can also be displayed. All grid and vector themes can be viewed in 2- or 3-dimensions. Outputs can be saved in ASCII Grid or Shapefile format for import and analysis in a GIS.

There are three calculation modes in FlamMap, basic fire behavior, minimum travel time fire growth, and treatment optimization.

Basic Fire Behavior

The simplest use of FlamMap is for use in characterizing fire behavior under a constant set of environmental conditions for an entire landscape. Fire behavior can be generated for all cells on the landscape in a number of ways:

1. For winds blowing uphill, this generates the fastest spread rate because wind will be moving in the same direction as slope.
2. Using a single wind speed and direction combined with the slope to produce the resultant vector for fire spread.
3. Relative to the maximum direction of spread is the default that results in

the heading fire characteristics. A value of 90 calculates fire behavior in the flanking direction and 180 calculates fire behavior in the backing direction.

4. For a direction relative to north (degrees azimuth) allows characterization of the fire behavior in a particular direction and may be useful for looking at fire progress when a specified wind direction is concerned (e.g. winds from west and specifying fire spread rate to the east).

Basic fire behavior outputs are generated in raster format for surface and crown fire calculations (Table 1). These can be displayed and saved to a variety image formats (Figure 2a, b). In addition, a combined output can be requested to display spread vectors that show the spread rate and maximum spread direction of the fire.

Minimum Travel Time

The minimum travel time (MTT) algorithm (Finney 2002) is used in FlamMap for computing fire growth between the cell corners at an arbitrary resolution. Fire growth is computed under the same assumptions as the basic fire behavior – holding all environmental conditions constant in time. Thus, the MTT calculations can generate fire growth in the absence of time-varying winds or moisture content which enables analysis only of the effects of spatial patterns of fuels and topography.

To run the MTT algorithm, ignitions (points, lines, polygons), the desired resolution of the calculations (distance between nodes of a square lattice), and the maximum simulation time are required inputs. Alternatively, ignition points can be generated randomly for a specific number of fires. As the name implies, MTT calculates fire growth (Figure 2c) by finding the paths with the minimum fire travel time among the nodes of the grid. The resolution can be selected independently of the input data resolution. This search produces both the arrival time grid which can be contoured at any time-interval to depict fire progression, but also the minimum time paths (Figure 2d). These paths can be sorted by their flow characteristics or prominence in affecting the landscape as measured by the magnitude of the number of nodes that burn as a result of burning through that node (i.e. logarithm of the number).

Table 1—Outputs from FlamMap.

Fire Behavior Value	Output Type	Units
Fireline Intensity	Raster	kW m^{-1} or BTU ft^{-1} sec^{-1}
Flame Length	Raster	meters or feet
Rate of Spread	Raster	M min^{-1} or ft min^{-1} or ch hr^{-1}
Heat per unit Area	Raster	kW m^{-2} or BTU ft^{-2} sec^{-1}
Horizontal Movement Rate	Raster	M min^{-1} or ft min^{-1} or ch hr^{-1}
Midflame Windspeed	Raster	mph or kph
Spread Vectors	Vector	m min^{-1}
Crown Fire Activity	Raster	Index, 0 1 2 or 3
Solar Radiation	Raster	W m^{-2}
1-hr Dead Fuel Moisture	Raster	Fraction (0.0-1.0)
10-hr Dead Fuel Moisture	Raster	Fraction (0.0-1.0)

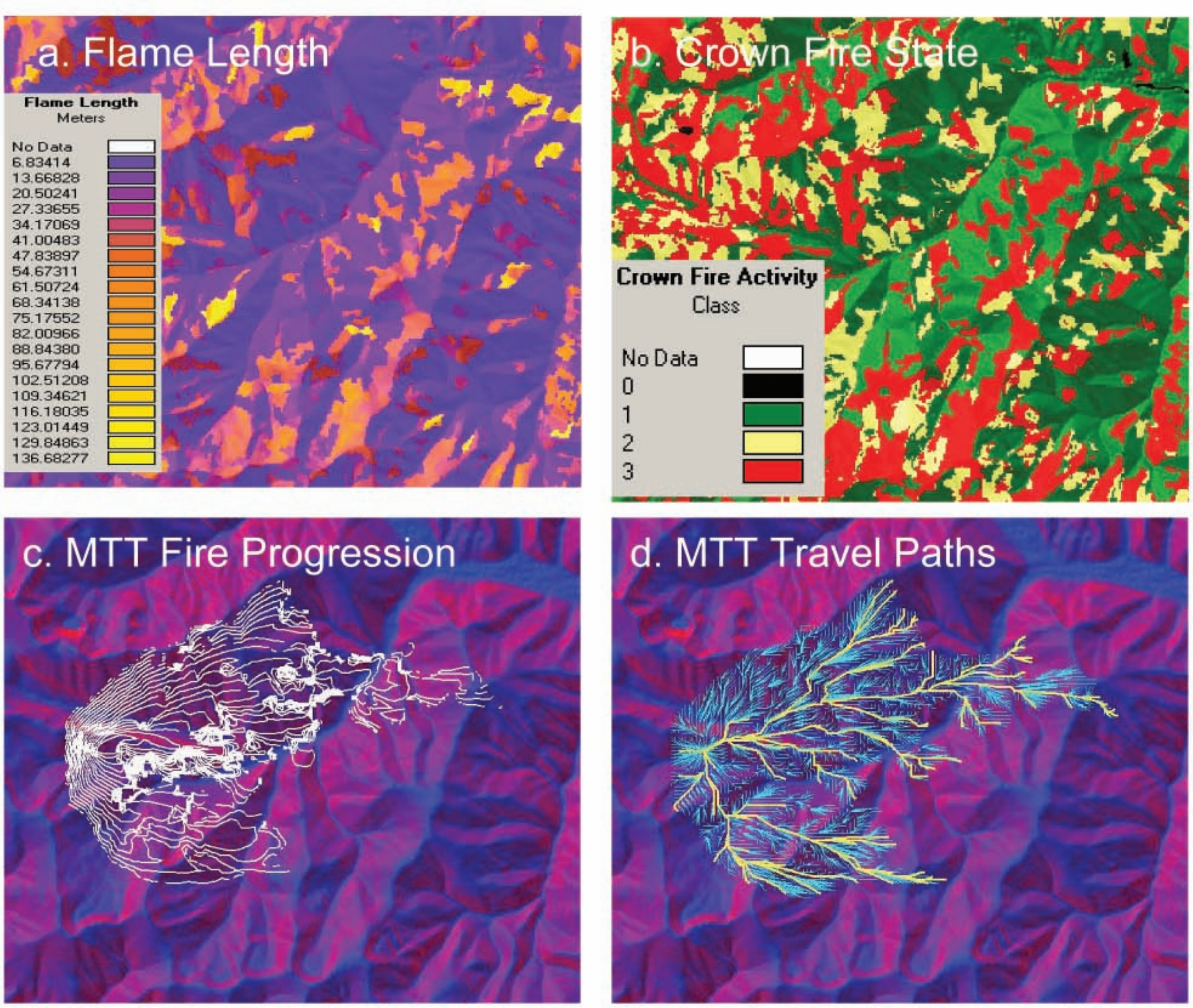

Figure 2—Example outputs from FlamMap for (a) fire spread rate, (b) crown fire activity (0=none, 1=surface fire, 2=torching trees or passive crown fire, and 3=active crown fire), (c) fire progression (white perimeters) simulated using the Minimum Travel Time (MTT) method, and (d) the fire travel paths produced by MTT (bold yellow lines distinguish major paths from all paths in light blue).

A different suite of outputs is generated from the MTT calculations than for the basic FlamMap products (Table 2). These outputs are produced only for the area within the spreading fire and are affected by the direction of fire movement, revealing heading, flanking, and backing spread. They will, therefore, be different from the values that are generated for outputs listed in Table 1. All fire growth calculations across the landscape are performed assuming independence of fire behavior among neighboring cells (e.g. the travel time across a cell does not depend on the behavior in adjacent cells). If random ignitions are selected, then the only output will be a burn probability map (0.0-1.0). These probabilities are properly interpreted as conditional probabilities, since they are <u>conditional</u> upon large fires occurring.

Table 2—Fire behavior outputs from the Minimum Travel Time feature of FlamMap.

Fire Behavior Value	Output Type	Units
Rate of Spread	Raster	m min^{-1} or ft min^{-1} or ch hr^{-1}
Influence Grid	Raster	Index (logarithm of nodes burned after this node)
Arrival Time Grid	Raster	minutes
Fireline Intensity Grid	Raster	kW m^{-1} or BTU ft^{-1} sec^{-1}
Flow Paths	Vector	
Major Paths	Vector	
Arrival Time Contour	Vector	Interval 1/10th range
Burn Probabilities	Raster	0.0-1.0

Fuel Treatment Optimization

Fuel treatment optimization is accomplished using an algorithm that attempts to block the major MTT pathways with fuel treatments that are designed to slow large fires (Finney 2004). Several major assumptions must be met before this process can be attempted:

1. The specific objective of the optimization is to find fuel treatment locations that retard the growth rate of large fires. There are many objectives for fuel treatment, some of which are to provide local benefits only to the area treated. However, the major assumption here is that reduction in large fire growth is obtainable through the collective effect of many units occurring on the landscape (Finney 2001).
2. Wildfires are larger than the fuel treatment units – this allows the analysis to focus on the directions fires move rather than their start locations.
3. Treatments are targeted to perform under a specific set of weather conditions – target conditions must be specified to contrast fire behavior between the current landscape and the ideal landscape. These are often taken from the extreme weather and fuel moisture conditions associated with historic large fire events for which fire suppression is ineffective.

The treatment optimization model (TOM) process requires the user to provide several sets of input data besides the target weather conditions:

1. Ignition location – this is generally a line fire or large ignition source at the upwind edge of the landscape. This ignition configuration allows fire movement to be calculated through the entire landscape for identifying major travel routes.
2. An ideal landscape is required that identifies the fuel conditions everywhere on the landscape where fuel treatments are possible. The changes to the five fuel layers of the LCP file (Figure 1) can vary across the landscape depending on the appropriateness of the treatment prescription. Areas where treatments are not possible remain the same as the current landscape.
3. The resolution of the calculations has the same effect on treatment optimization as on the execution of the minimum travel time algorithm. Finer resolutions require more computations but permit greater detail in identifying treatment unit locations.

4. The maximum treatment dimension is the maximum length dimension that the treatment can be, although multiple treatments may be located adjacent to one-another and form a combined area with a longer dimension than this constraint. Practically, this value should be set no finer than 5 or 6 times the resolution of the calculations (i.e. #3 above) in order to allow the treatment unit to be delineated with several cell widths.
5. The maximum fraction of the landscape that can be treated.

The process begins by dividing the landscape into parallel strips beginning with the upwind edge. Fire growth is calculated using MTT to identify the major fire movement routes and then identifies intersections with areas of the landscape where the treatments change fire behavior favorable to slowing the fire. If such intersections are found, an iterative procedure identifies the collection of grid cells that efficiently blocks each fire travel route (Finney 2004) subject to the constraint on treatment size and total area treated.

The outputs from TOM are similar to those from MTT (Table 2) with the addition of the treatment opportunities grid, which shows the areas where treatments spread faster, slower, or the same as the untreated landscape (values of -1, 0, or 1, respectively), and the final treatment grid which indicates the cells which were selected for treatment (flagged as 0 for untreated and 1 for treated).

Discussion

The basic fire behavior calculations in FlamMap are intended for characterizing fuel hazard in fire management planning. Data on fire spread rate, crown fire activity, and flame length can be quickly calculated and displayed to spatially compare fire behaviors under given weather conditions. FlamMap was used near Flagstaff, Arizona (http://forestera.nau.edu/tools_firemodeling.htm) and in the Sierra Nevada Mountains of California (http://ssgic.cr.usgs.gov/Pages/mapping_nj.htm) for this purpose.

Fire behavior calculations are at the heart of risk assessment as well because risk assessment requires an assessment of probability of fire behavior occurring. Approaches to quantitative risk assessment have incorporated fire behavior from FlamMap for ranges of weather conditions. Examples of such uses include the Florida Risk Assessment (http://www.fl-dof.com/wildfire/wf_fras.html), and the CRAFT risk assessment process (http://www.fs.fed.us/psw/topics/fire_science/craft/craft/introduction.htm).

FlamMap is also useful in the verification process of spatial data. The fire behavior calculations can easily be compared with expected behaviors for the particular fire environment at each cell (i.e. fuels, weather, topography). Display of the landscape, and wind vectors, and various outputs in two- and three-dimensions is often helpful for evaluating reasonableness of the fire behavior calculations.

For fuel treatment analysis the MTT and TOM calculations allow effects of treatment on fire movement to be analyzed. These capabilities are relatively new, however, and have only recently been applied beyond the research phase. However, the basic calculations in FlamMap for comparing effects of fuel treatments on fire behavior have been used to illustrate the stand-level fire behavior changes resulting from treatment (Stratton 2004).

Summary

Version 3.0 of FlamMap has capabilities of 1) calculating surface and crown fire behaviors and moisture of fine dead fuels over an entire landscape, 2) simulating fire growth for constant conditions using a minimum travel time (MTT) algorithm, and 3) fuel treatment optimization modeling (TOM) for delaying the growth of large fires. The basic features are useful for characterizing fuel hazard or potential behavior under specified environmental conditions. New features of MTT and TOM have potential for analyzing fire movement and fuel treatment interactions.

Acknowledgments

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