MODELING THE SPREAD AND BEHAVIOR OF PRESCRIBED NATURAL FIRES[1]

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ABSTRACT: A fire growth model, FARSITE (Fire ARea SImulator) is under development for simulating the spread and behavior of prescribed natural fires. The model uses a technique for wave propagation to expand surface fire fronts in 2 dimensions. Points defining the outer edge of a surface fire contain data on the time, direction of spread, and rate of spread. These parameters provide a logical basis for implementing models of crownfire, fire acceleration, and spotting. Preliminary validations of the FARSITE model against surface fire spread patterns from 5 prescribed natural fires suggests good agreement after some adjustment. Observations suggest consistent overprediction of spread rates for each fuel type, necessitating the use of reduction factors by fuel type.

KEYWORDS: fire modeling, fire behavior, Huygen's Principle

INTRODUCTION

The growth of wildland fires has been of interest to fire scientists and managers for many years (Fons 1946). The simplest models consist of a constant fire shape, for example the ellipse (Van Wagner 1969), ovoid (Peet 1967), or double ellipse (Anderson 1983). If burning conditions are uniform, a single shape can be applied to estimate the fire size, area, and perimeter over time (Catchpole et al. 1982, Catchpole et. al. 1992), with the use of fractals to account for smaller-scale variations (McAlpine 1993). Most fires, however, do not burn under constant conditions. There is often considerable spatial variation in fuels, weather, and topography, as well as temporal variation in weather.

Efforts to model the growth of wildland fires can be classified according to two approaches, cellular models and wave-type models. These differ mainly in the way time and space variables are treated. Cellular models use the constant spatial arrangement of a cell or raster landscape to solve for the time of ignition. Wave models, or those based on Huygen's principle, (Anderson et al. 1982) solve for the position of the fire front at specified times.

Wave-type models originated from the ideas of 17th century mathematician Christian Huygen's on the travel of light waves. Huygen's principle essentially posits that a wave can be propagated from points on its edge that serve as independent sources of smaller waves. Anderson et al. (1982) and French (1992) found elliptical waves produced fire growth in good agreement with actual spread patterns. Richards (1990) derived an analytical solution to the propagation of ellipses.

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METHODS

The FARSITE model implements Richards (1990) algorithm. The fire perimeter(s) must be defined by a number of points. The coordinates are registered with a spatial database, so that data from underlying rasters or polygons can be obtained. Data on fuels, weather and topography are required for fire behavior calculations.

The user selects the timestep to be used by the simulation. At every timestep, the suite of fuel moistures for each point on the fire perimeter is computed from initial conditions up to the current time-step (Rothermel et al. 1986, Bradshaw et al. 1987). This has proven faster than generating fuel moisture maps for the entire landscape at each timestep.

Using the fuel and fuel moisture data for a given point, the rate of spread is computed using the Rothermel spread equation with zero wind and slope (Rothermel 1972, Andrews 1986). An effective windspeed and direction is obtained by vectoring wind and slope coefficients in the Rothermel equation. These are used to produce the equilibrium forward spread rate. The actual forward spread rate at the end of the current timestep (and average rate) is determined by accelerating the fire from the previous spread rate toward this equilibrium (Alexander et al. 1992) using coefficients for line source fires interpreted from Johansen (1987). The effective windspeed determines the shape of an elliptical fire burning under constant conditions (Alexander 1985); more eccentric ellipses are produced by stronger effective windspeeds. The average spread rate is used to dimension the size of this ellipse in appropriate distance units (e.g. meters). The resulting elliptical dimensions and effective wind direction are inputs to Richards' (1990) algorithm for computing the new position of a given perimeter point. These points must be corrected for slope, because spread rates are given in units of surface distance by the Rothermel equation.

The surface fire may make the transition to some form of crown-fire (torching trees, active etc.), where crown involvement is determined using the spread rate, fireline intensity, and crown characteristics (Van Wagner 1977, 1993). The spread rate of an active crown fire is determined using the correlation suggested by Rothermel (1991). The entire process is repeated for each point yielding its new location, rate, and direction of spread at each timestep.

An attempt to simulate spotting is based on work by Albini (1979, 1983) and Morris (1987). Maximum spotting distances from torching trees and surface fires are computed by first solving for the lofting height of different sized embers. Embers are then iteratively transported downwind across the landscape until contacting the ground surface.

In addition to the timestep, the user controls the spatial resolution of the spread calculations. The perimeter point density determines the distance between points that define the perimeter; convex portions of the perimeter are expanding and require additional points to be inserted to maintain the definition of the fire front. The "distance check" affects the timestep by limiting linear spread from any point to less than or equal to a specified distance. This becomes important with rapid spread rates that can cause points to greatly overshoot fuel or topographic boundaries (e.g. rivers, rocks, or fuel changes). Area and perimeter of the fires are computed in horizontal and topologic units, and distributions of fire front characteristics can be derived by area or perimeter.

Although relatively simple in concept, the use of wave-type models has proven to be complicated with heterogeneous landscapes and weather. These models require a series of algorithms to eliminate "cross-overs" on fire perimeters (Richards 1990), calculate mergers between separate fires, and isolate active enclaves. Such efforts are necessary because fire fronts are computed mathematically and cannot distinguish areas already burned. These routines are time and computationally intensive, but are crucial given that FARSITE may process thousands of simultaneous fire fronts.

VALIDATIONS

Some preliminary validations of FARSITE were performed using data from 5 prescribed natural fires (PNFs) in Sequoia National Park, California. Landscape information on topography, surface fuel type (NFFL model), and canopy characteristics (cover, species) was obtained from GIS data themes at 30m resolution. Fuels on most landscapes were a mixture of timber, shrub and grass types. Weather information was obtained from RAWS stations (hourly averages) or from fire weather observations made by fire monitoring personnel. Surface fire spread patterns from the FARSITE model were compared with those mapped by observers stationed on the fires.

During the simulations it was noticed that the spread rate was overpredicted for every fuel type. An explanation may be that the scales of fuels and weather data were too coarse to represent the high frequency variations that actually affect fire spread. Small scale variations in fuels, along with fluctuating wind speeds and directions, probably keep fire spread in a continual state of acceleration or deceleration. The long-term and long-distance averaged spread rates of an actual fire are, thus, less than that generated by average weather and fuels information.

To compensate, fuel-specific reduction factors for the rate of spread were determined; comparisons of predicted and observed spread rates were made for the early portions of the simulations at the head of the fires. This was justified, given that the intent of the validations was to test the spatial extension of fire spread over complex landscapes. The rate of spread reduction factors were then held constant throughout the remainder of the simulation.

Agreement between the observed and predicted spread patterns was assessed simply by computing areas (total, overlapping, overestimated, and underestimated) and perimeters, as well as spread rates radially from the point of origin. Figure 1 and Figure 2 show examples of the validations. Agreement was generally encouraging but tended to worsen with time, presumably since errors are compounded and spread rate reduction factors were based on early portions of the simulations. However, these validations can be interpreted only in a general sense because the accuracy of the data (e.g. fuels, overstorey characteristics etc.) and mapped fire perimeters is not really known. Thus, the adequacy of weather data and suitability of model algorithms cannot be thoroughly tested with these observed fire data.

CONCLUSIONS

FARSITE is intended for use by wilderness fire managers in planning the progress of prescribed natural fires as well as for simulation modeling of landscape dynamics. Wave-type models are a promising means for simulating fire spread and behavior. Information on the time, direction and rate of surface fire spread at points on the fire front enable the incorporation of existing models of fire behavior. Smoke estimates may also be possible, given loading data for duff and large woody fuels, time-dependent models of fuel consumption, and emission factors.

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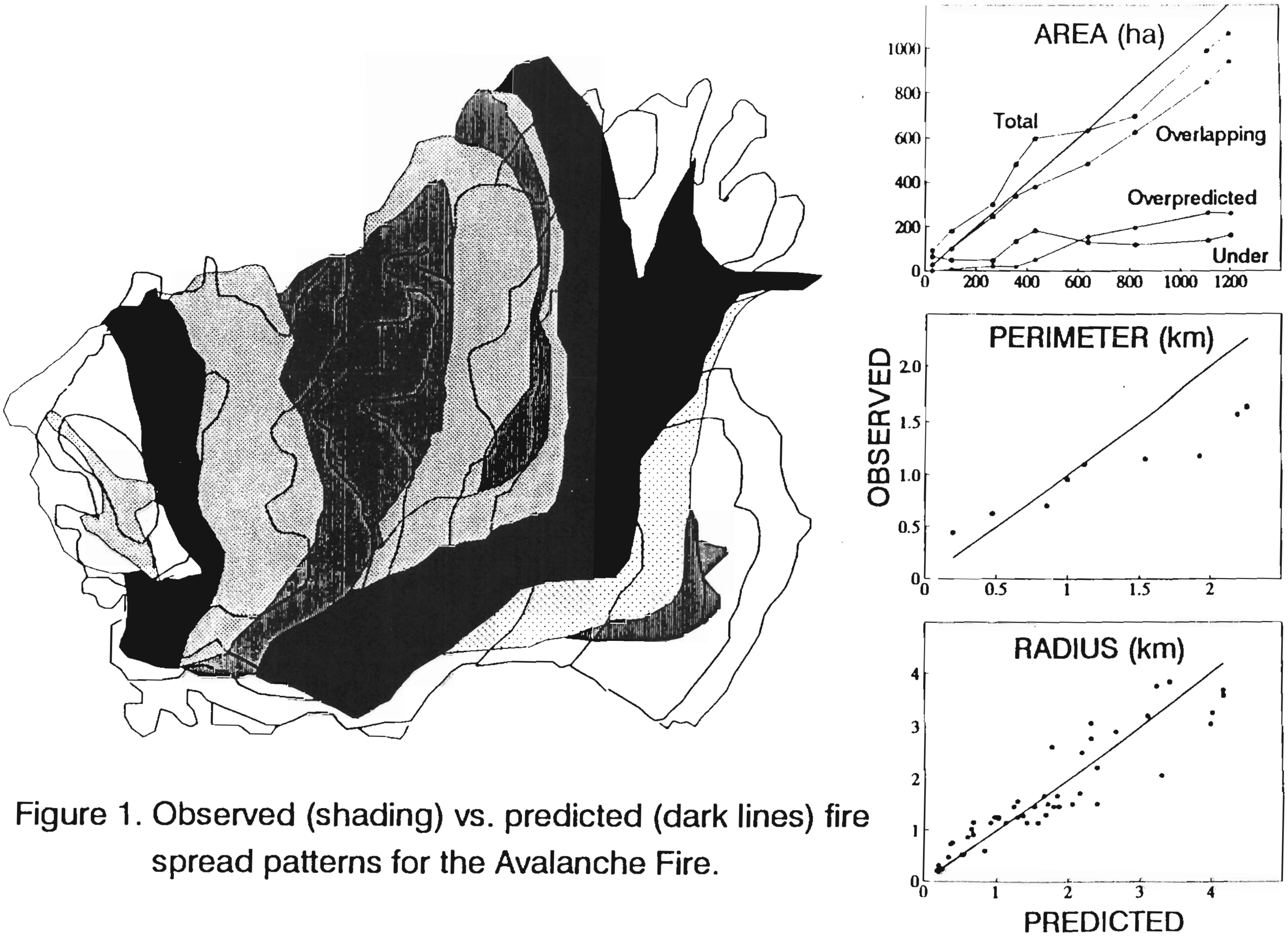

Figure 1. Observed (shading) vs. predicted (dark lines) fire spread patterns for the Avalanche Fire.

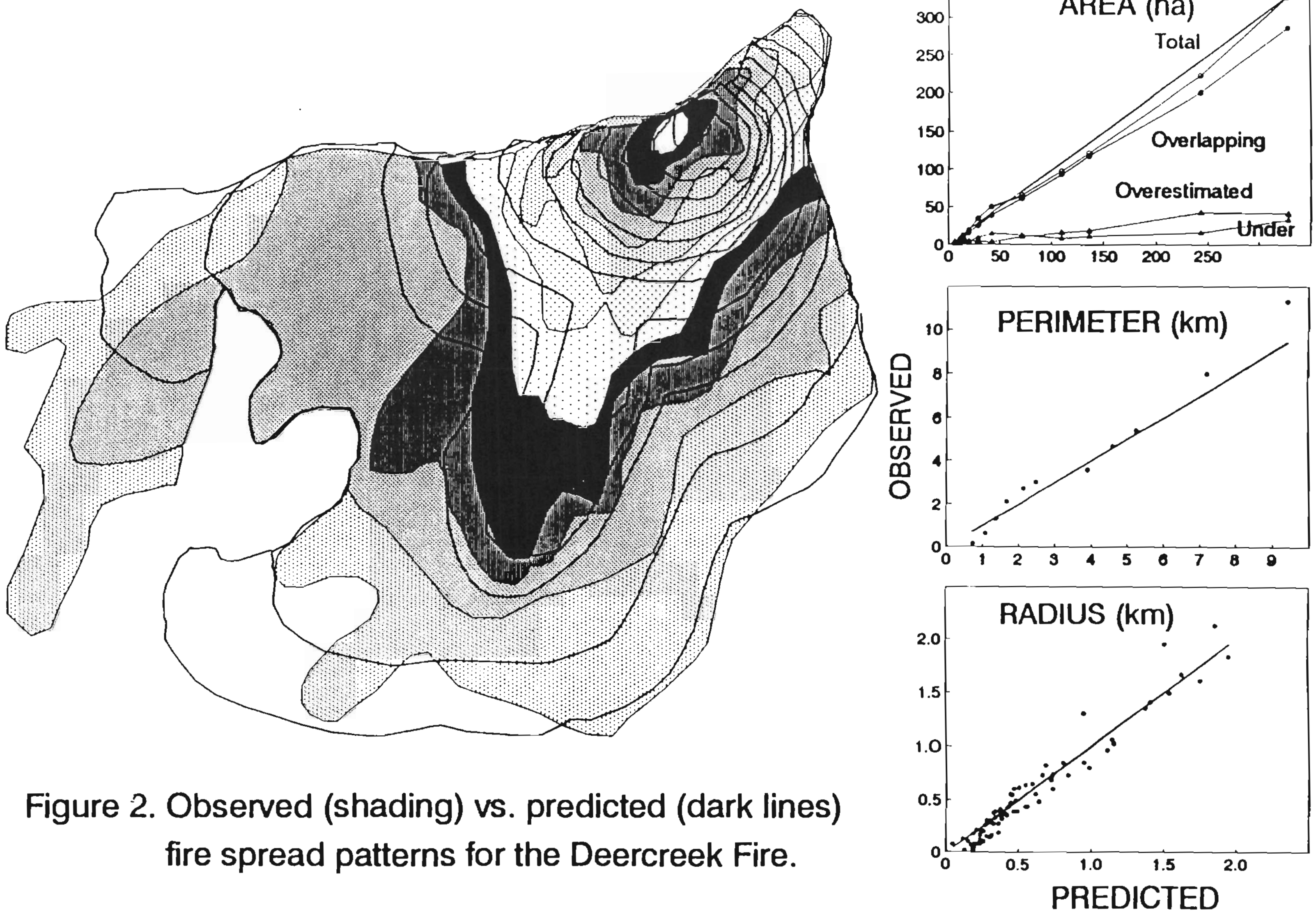

Figure 2. Observed (shading) vs. predicted (dark lines) fire spread patterns for the Deercreek Fire.

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