Applying fire spread simulation over two study sites in California

Lessons learned and future plans

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***Abstract* - There is an increasing application for bushfire spread models in planning for prescribed burning and for the generation of fire risk assessment maps in fire prone communities. An evaluation of FARSITE and FlamMap bushfire spread models developed by the Fire Sciences Laboratory at Missoula involved a comparison of fire simulator models over two Californian landscapes representing different terrain and vegetation regimes. The paper includes a discussion on the models, the assumptions and limitations resulting from their application, and also the assembly of data to build landscape files and model outputs over the two test areas. The spatial datasets used in this study are sourced from the USGS EROS Data Center's LANDFIRE database at 30-metre pixel resolution. Information about fuel which has been derived from satellite imagery, terrain modelling and biophysical and local field knowledge was used to build Anderson's 13 Fire Behavior Fuel Models (FBFM13) and Scott and Burgan's 40 Fire Behavior Fuel Models (FBFM40). These were ingested into the FARSITE fire growth simulation model and FlamMap fire potential simulator. The FBFM40 provides a better representation of fuel across the landscape, leading to an improvement in surface fire intensity prediction and increased precision in determining crown fire behaviour. The FARSITE/FlamMap were used to model fire behaviour, and WindWizard simulated wind speed and direction scenarios across the Woodacre and Glen Ellen regions near San Francisco, California. FARSITE and FlamMap are two separate fire simulation models that use the same input datasets (vegetation/ground cover type, crown stand height, crown base height, crown bulk density, temperature, humidity, precipitation, slope, aspect, elevation, wind speed and direction). In this study, the actual fire perimeters were not available to compare the overestimated and underestimated fire growth perimeters/areas after and before using gridded wind data into the fire simulation. However, previous studies [1] demonstrate that incorporation of gridded wind data clearly improves prediction of fire growth perimeters. The preliminary evaluation of FARSITE/FlamMap simulations appropriately predicts fire growth process and assesses resources at risk, suggesting the need for further experiments in areas of different terrain and vegetation, and with varied weather conditions. In future research, it is proposed to evaluate how these models compare with existing Australian fire models by using the example of recent Australian wildfire events.**

Keywords-component; Fire spread simulation, FARSITE, FlamMap, WindWizard, fuel models, GIS

I. Introduction

Wildland fire behavior models predict fundamental fire behavior characteristics using fuel load, weather variables, and topographical information. There are several fire models in use today that are based on fire-spread relationships ([2] and [3] in the US; [4] and [5] in Canada; [6], [7], and [8] in Australia). In the US, bushfire authorities are using several fire-spread tools (eg BEHAVE fire behavior prediction system [9], FIRECAST [10], FARSITE [11], FireFamilyPlus [12], BurnPro [13], FlamMap [14], and FSPro [15]) that are based on the Rothermel's [2] spread model. All the above models and systems incorporate three environmental factors (fuel, weather, and topographical variables) affecting fire behavior. The majority of these models have been developed into Geographic Information Systems (GIS) fire spread modeling tools (eg BurnPro [13], FlamMap [14] and FARSITE [11]) and have led to practical in-the-field tools that require simple point or two-dimensional surface values of meteorological fields such as wind as input [16]. The variability inherent in the parameters controlling and influencing wild land fire behavior in these systems has performed adequately and is accepted as valuable tools in the industry (eg [17], [9], [18] and [11]). Other researchers (eg [19], [20], and [16]) have bridged atmospheric models such as WRF-Fire at the National Center for Atmospheric Research (NCAR)'s Weather Research and Forecasting Model (WRF) to fire behavior spread simulators to explore the mechanism between a fire and the local weather, ranging from small-scale fire whirls to generation of supercell-like circulations affecting regional weather. At the cost of adding computational complexity this approach gives insights into fundamental aspects of fire spread behavior (Coen, 2004). Scientists at NCAR are developing verification metrics to assess forecasted fire/weather model results in comparison to remote sensing data and have indicated release of a beta version of WRF-Fire for community user evaluation in 2007.

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II. DESCRIPTIONS OF FIRE SIMULATORS

The FARSITE and FlamMap fire spread models are briefly described here:

Fire Area Simulator (FARSITE): developed by the Department of Agriculture, Forest Service's Missoula Fire Sciences Laboratory (Finney 1998) is a two-dimensional fire simulator model of fire growth which spatially and temporally simulates the fire spread and its behavior using topography, fuels, and weather data. FARSITE propagates fire across a terrain using the fire behavior models found in the one-dimensional fire model BEHAVE ([9], [21], and [2]). It is a deterministic, equation-driven fire spread simulator that models fire propagation as a wave front spreading from multiple vertices (a series of ellipses) along a fire front, based on Christian Huygens' principle [22] and [24]. This principle has formed the foundations of many existing fire growth models [11]. Every point of an advancing light wave becomes the source of new light waves, and then dimensions of the ellipses are computed from the fire behavior predictions. These collectively generate fire perimeters at specific instances in time. FARSITE then connects all points at the end of the smaller waves using topological algorithms. FARSITE includes a well-developed user interface, and inputs/outputs are GIS-based.

FlamMap: also developed by the Department of Agriculture, Forest Service's Missoula Fire Sciences Laboratory [11] that maps fire behavior across an entire landscape; hence calculations are carried out based on each pixel independently using quantified fuels information for a single point in time. FlamMap uses the same input datasets as FARSITE (vegetation/ground cover type, crown stand height, crown base height, crown bulk density, temperature, humidity, precipitation, slope, aspect, elevation, wind speed and direction).

WindWizard: is based on the FLUENT computational fluid dynamics (*www.fluent.com*) platform. It assumes the atmosphere is neutrally stable and a constant temperature, while wind flow and turbulence is modeled applying turbulence models [25] and [26]. WindWizard is considered as an integral part of fire simulation in which the US bushfire authorities have widely applied it to produce fire forecast spread products [1] and [27]. This tool simulates the effect that terrain has on synoptically driven surface wind flow and generates gridded (cell-based) wind speed and direction at the 100-300 feet horizontal scale, (for which wind information at this spatial detail is not available from the weather service). The WindWizard tool performs simulations of what the wind flow would be under different general (synoptic) wind speed and direction scenarios.

III. METHODOLOGY

An overview of research workflow in relation to data processing and fire spread simulation is shown in Figure 1.

A. *Test sites*

Woodacre: This study area is located approximately 5 miles north of San Francisco, covering a major portion of Golden Gate National Park, Golden Gate Biosphere Reserve and the township of Woodacre and its surroundings just near to the San Andreas Fault, a major rift in the earth's surface. It offers an ideal case study because of particular characteristics of vegetation composition and structure; land cover and land use dynamics, weather, terrain, human activities and practices, and has notably rich biological diversity due to the variety of habitat and unique geology. The changes in bedrock along with microclimatic and topographical differences between tectonic plates make this region unique and highly diverse including coastal redwood forests, the world's tallest tree species. The area has strong spatial heterogeneity, in terms of composition and structure of the ecosystem as well as the spatial distribution and arrangement. Major vegetation consists of mixed evergreen forests, redwood forests, Douglas fir forests, Bishop pine forests, oak forests, woodlands and savannas, coastal scrub, chaparral, coastal dune, coastal strand, grasslands, marshes and their associated animals such as cougars and Tule elk.

Fire spread modeling operates on three major environmental variables that influence fire behavior spread. These include weather, topographical (terrain) and fuel data that are briefly discussed here:

B. *Weather Variables*

Weather Data: For the 2006 fire season, all Western Region Offices offer automatic 7-day FARSITE weather data. The FARSITE weather data consists of a "wind" file (WND file extension) and a "weather" file (WTR file extension) at 2.5 km grid resolution points [28] acquired from Digital Forecast Database of the National Oceanic and Atmospheric Administration's National Weather Service Digital Forecast Database (DFD). Data in the WTR file include month, day, daily precipitation (inches), local time of minimum temperature and maximum relative humidity percentile, local time of maximum temperature and minimum relative humidity, minimum temperature, maximum temperature, maximum relative humidity, minimum humidity and elevation in feet for the forecast location. In the WND files, each line shows month, day, hour (local), wind speed (mph), direction and percentile of cloud cover.

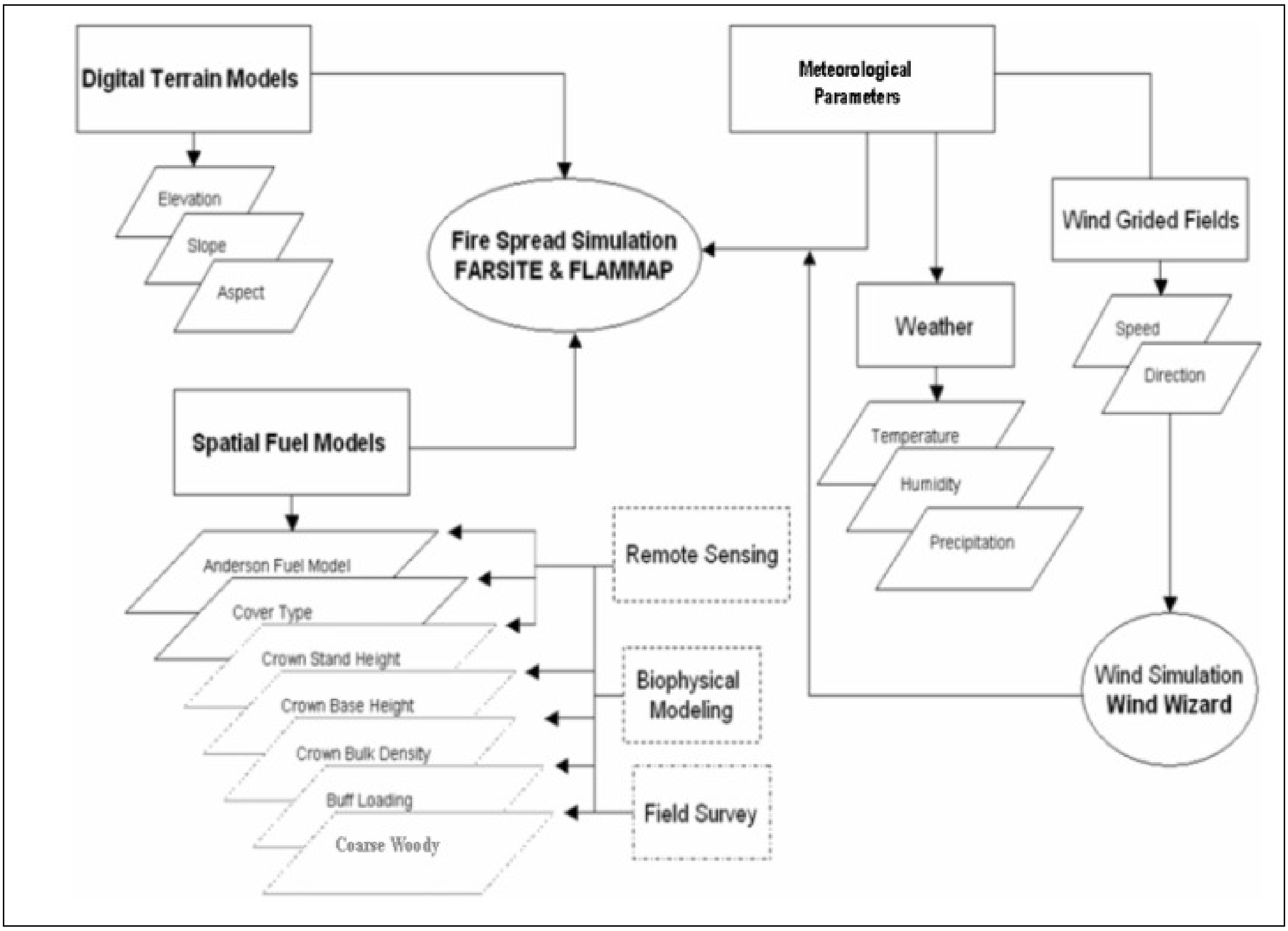

Figure 1. Conceptually represents key components of fire growth and behavior simulation process.

Gridded Wind Data from WindWizard: Digital Elevation Model data was ingested into the WindWizard fluid dynamics predictive tool to simulate surface wind speed and direction at the 100m scale on the terrain surface. In this study, the actual fire perimeters were not available to compare the overestimated and underestimated fire growth perimeters/areas after and before using gridded wind data into the fire simulation. However, previous studies [1] and [27] demonstrate that the incorporation of gridded wind data clearly improves prediction of fire growth perimeters. These types of simulations provide a "…*snapshot at one point in time of what the local surface wind speed and direction would be for a given ridge top or synoptic wind scenario*" [27]. Generating gridded wind data consists of a number of consecutive stages including [29]:

- Collecting/assembling DEM and ingest into WindWizard as an ASCII raster digital elevation data file.
- Building computational mesh grid cells and computing a surface roughness parameter based on user input of the dominant vegetation types such as forest, shrub and grass.
- Solving the Navier-Stokes equations recounting the wind flow based on user input of the ridge top or synoptic wind conditions.
- Displaying and visualizing the wind speed and direction (6m above the terrain surface at a resolution specified by the user) on a GIS software package such as ArcGIS. This aids fire managers and field staff for representing and interpreting the spatial variation of the wind speed and direction particularly to detect high/low wind speed areas across the fire perimeter and the terrain effects.
- Loading the wind vector files into FARSITE/FlamMap for consequence fire behavior simulations and analysis (Figure 3a).

C. *Terrain Derivatives*

The USGS regular gridded 30m x 30m DEM is used to derive elevation, slope and aspect parameters utilizing the ArcGIS's Spatial Analyst tool. The above three layers were input directly to fire simulation, and DEM data were also used to generate wind variables in WindWizard.

D. Fuel Datasets

Fuel includes live fuel and dead fuel (eg forest floor needles, cured grasses, and twigs and branches) that play critical role in fire behavior. NASA's LANDFIRE database (*http://www.landfire.gov*) contains fuel variables at 30m resolution that are derived from satellite imagery, terrain modelling and biophysical and local field knowledge. These datasets were used to build Anderson's 13 Fire Behavior Fuel Models (FBFM13), Scott and Burgan's 40 Fire Behavior Fuel Models (FBFM40) detailed in [30] and [31]. These fuel models were ingested to the FARSITE fire growth simulation model and FlamMap fire potential simulator. The FBFM40 provides a better representation of fuel across the landscape, leading to an improvement in surface fire intensity prediction and increased precision in determining crown fire behaviour.

E. Assembly of Data to Build Landscape Files

The raster GIS datasets acquired and processed over the study area include all of the fuel and vegetation layers (FBFM13 and FBFM40, canopy bulk density, height to base of live canopy, canopy cover, and stand height described in [30] and [31]) and terrain data (elevation, slope, aspect) and weather data. Fuel load data were converted into raster grid, then to ASCII files for input to the FARSITE and FlamMap, which makes landscape (.LCP) file. The inputs should have a common projection, format, cell size and origin (the same min X and Y coordinates/spatial extent) prior to conversion to ASCII files [29]. There are a number of user-defined parameters such as the perimeter resolution of the fire front that FARSITE requires. To determine appropriate FARSITE and FlamMap parameters, several simulations were conducted in consultation with Fire Sciences Laboratory associates.

F. Fire Spread Simulation Outputs

FARSITE and FlamMap generate several spread modeling scenarios and outputs; a couple of generated fire behavior maps are reported in this paper (Figure 3a-c). Fire growth perimeters were generated using FARSITE, and maximum spread direction, flame length and fireline intensity were the outputs from the FlamMap model.

Determining simulation parameters (fine-tuning) is important in the fire modelling process. Once the model parameterisation was established, FARSITE was run over the two study areas to predict fire growth under given inputs (weather, terrain and fuel). For example, a fire simulation using FARSITE over Woodacre (wind direction =180°, wind speed = 15 mph, temperature = 35°; and humidity = 15%) revealed that a wildfire could spread quickly throughout the central and central-east part of study areas respectively. The fire simulation estimated that 1567 acres of national park lands would be burnt in the first 18 hours in the Woodacre experiment, while about 1987 acres of vegetation would be burnt in the first 23-hour in the Glen Ellen area. A spread rate adjustment factor of 1.0 was utilized for all fuel models.

Critical fire behaviour assessment requires comparing these outputs with field observations. However, these observations can be undertaken using the example of recent Australian wildfire events.

In addition to the above outputs, graphics of total fire area (for all fires) over time of horizontal and topologic values of fire area, fire characteristics in terms of spread rate and heat density (heat per unit area) were generated. These aid interpretation of fire behavior in relation to temporal and spatial changes for each fuel type input since different fuel models can result in distinct clusters of points and have their own envelope of fire response to environmental conditions.

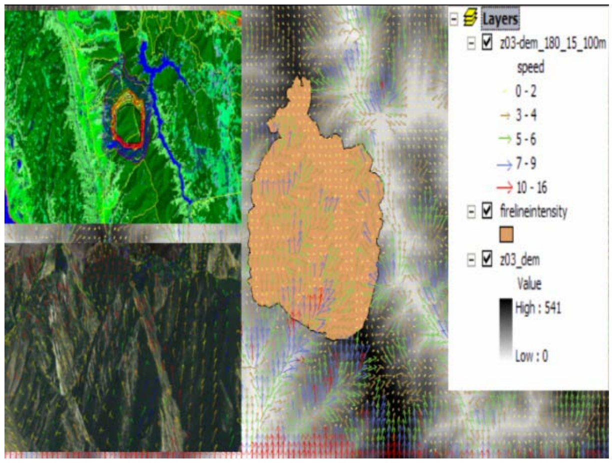

Figure 3a FARSITE displays the simulation over Woodacre, during 3-5 August 2006. The successive perimeters and the ignition are superimposed on the FBFM40 (green map), final fire perimeter is overlaid on the wind vectors (right) and wind vectors superimposed on Google map (left), then superimposed on over DEM of the Woodacre (middle). The blue vectors represent wind direction and other vectors show different wind speed categories (0-16mph). Fire simulation over Woodacre assumes uniform wind speed and direction from the south to north of the study area.

IV. CONCLUSIONS AND REMARKS

The research shows different fire spread scenarios over the study areas that produced various rates of spread and intensity under the same fuel conditions when weather variables changed. Also higher or lower spread rates compared to the actual fire spread rate may be due to deficiencies in the fuel models used [11] and [27]. The assessment of FARSITE, FlamMap and WindWizard simulations revealed that these technologies offer appropriate capabilities to predict fire growth process which hold promise for simulating wind-driven wildland fires. Field data, local knowledge, and historical fire information is critical to calibration of the fire spread model. Calibration involving comparison of predicted fire growth with observed fire was not achievable for this project due to availability of real fire data. Future studies should compare and validate FARSITE, FlamMap and Phoenix models over local fuels and weather regimes for Australian landscapes such as 2006 Grampians bushfire, the Long Plain Range Fire Complex of 3 February 2007, and the 2002 Sydney bushfire. A prerequisite of the above type of comparison is to build fuel load maps that are fundamental base information for many fire spread/behavior simulations and fire risk modeling systems. The project methodology then can be replicated to produce a national map of fire fuel “AUSFIRE”.

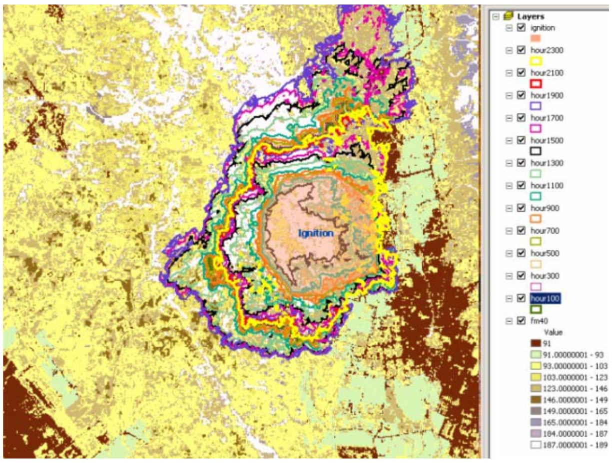

Figure 3b Presents FARSITE’s simulation over Glen Ellen. The successive perimeters and the ignition are draped over the FBFM40 fire behavior fuel models.

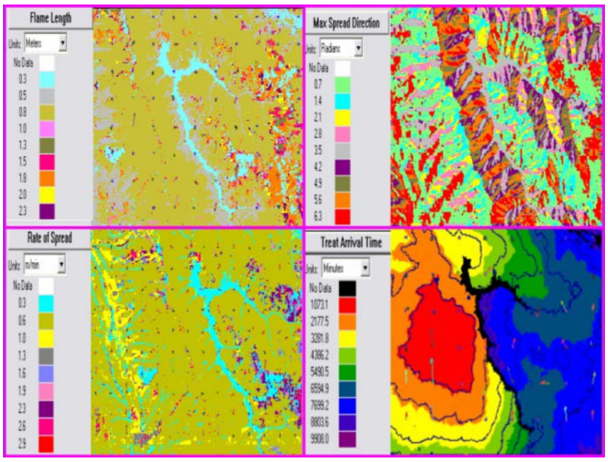

Figure 3c. Presents FlamMap fire behavior outputs such as flame length, rate of spread, maximum spread direction, and treat arrival time over Woodacre.

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