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A comparison of geospatially modeled fire behavior and fire management utility of three data sources in the southeastern United States ☆

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A B S T R A C T

Landscape-scale fire behavior analyses are important to inform decisions on resource management projects that meet land management objectives and protect values from adverse consequences of fire. Deterministic and probabilistic geospatial fire behavior analyses are conducted with various modeling systems including FARSITE, FlamMap, FSPro, and Large Fire Simulation System. The fundamental fire intensity algorithms in these systems require surface fire behavior fuel models and canopy cover to model surface fire behavior. Canopy base height, stand height, and canopy bulk density are required in addition to surface fire behavior fuel models and canopy cover to model crown fire activity. Several surface fuel and canopy classification efforts have used various remote sensing and ecological relationships as core methods to develop the spatial layers. All of these methods depend upon consistent and temporally constant interpretations of crown attributes and their ecological conditions to estimate surface fuel conditions.

This study evaluates modeled fire behavior for an 80,000 ha tract of land in the Atlantic Coastal Plain of the southeastern US using three different data sources. The Fuel Characteristic Classification System (FCCS) was used to build fuelbeds from intensive field sampling of 629 plots. Custom fire behavior fuel models were derived from these fuelbeds. LANDFIRE developed surface fire behavior fuel models and canopy attributes for the US using satellite imagery informed by field data. The Southern Wildfire Risk Assessment (SWRA) developed surface fire behavior fuel models and canopy cover for the southeastern US using satellite imagery.

Differences in modeled fire behavior, data development, and data utility are summarized to assist in determining which data source may be most applicable for various land management activities and required analyses. Characterizing fire behavior under different fuel relationships provides insights for natural ecological processes, management strategies for fire mitigation, and positive and negative features of different modeling systems. A comparison of flame length, rate of spread, crown fire activity, and burn probabilities modeled with FlamMap shows some similar patterns across the landscape from all three data sources, but there are potentially important differences. All data sources showed an expected range of fire behavior. Average flame lengths ranged between 1 and 1.4 m. Rate of spread varied the greatest with a range of 2.4–5.7 m min^{-1}. Passive crown fire was predicted for 5% of the study area using FCCS and LANDFIRE while passive crown fire was not predicted using SWRA data. No active crown fire was predicted regardless of the data source. Burn probability patterns across the landscape were similar but probability was highest using SWRA and lowest using FCCS.

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1. Introduction

Federal and state land management agencies with fire programs strive to plan fuels treatments and wildland fire response based on best available fire behavior science. Numerous systems have been developed to model fire behavior for a point or landscape to determine ecological effects and risk to resources, vegetation,

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infrastructure, personnel, and communities (Peterson et al., 2007). Point fire behavior analyses often rely on specific data collected within a defined plot using established protocols. For a broader perspective, geospatial fire behavior analyses can be completed for an entire landscape of interest. A landscape includes multiple interacting ecosystems composing a heterogeneous land area (Forman and Godron, 1986). In this case, the landscape is defined as the study area and is equivalent to the administrative boundary.

Standard systems used in the United States to model geospatial fire behavior include FARSITE, FlamMap, FSPro (Fire Spread Probability), and Large Fire Simulation System. While these systems provide the ability to model fire behavior across a landscape, they do not provide the means to track vegetation and fuels trends at the scale of a stand or plot. Conversely, systems that rely on plot data do not readily allow for spatial fire behavior analyses without imputing plot data to the stand and landscape.

The Fuel Characteristic Classification System (FCCS) provides the ability to build custom fuelbeds including detailed vegetation and fuels structure and species composition based on each fuelbed component (Ottmar et al., 2007). The FCCS was designed to be inclusive of all fuelbed categories including canopy, shrubs, non-woody fuels, woody fuels, litter-lichen-moss, and ground fuels stratums (Ottmar et al., 2007). The FCCS uses a reformulation of Rothermel's (1972) surface fire spread model to calculate surface fire behavior including reaction intensity, flame length, and rate of spread (Sandberg et al., 2007a), crown fire (Schaaf et al., 2007), and fire potential ratings scaled on an index from 0 to 9 (Sandberg et al., 2007b). The FCCS has been used for point fire behavior analyses and to explore fire effects, carbon assessments, and wildfire smoke emissions (Sandberg et al., 2007; Ottmar et al., 2012). This system provides detailed plot-based vegetation and fuels inventory data which must be transformed to spatial data to perform geospatial fire behavior modeling using available programs such as FlamMap and FARSITE.

Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) is a multi-agency effort that provides consistent vegetation and fuels data across all land ownerships for the US at a resolution of 30 m (Reeves et al., 2009; Rollins, 2009). The data were derived from Landsat Enhanced Thematic Mapper and Thematic Mapper satellite imagery acquired from 1999 to 2003 and informed by field data (Reeves et al., 2009). LANDFIRE data include all fields and layers requisite for spatial fire behavior modeling (Rollins, 2009). In addition, LANDFIRE includes numerous spatial vegetation classifications based on existing and potential vegetation and fire regimes.

The Southern Group of State Foresters along with cooperators from federal and state agencies responded to the need for seamless data to evaluate fire potential and related values for the southern portion of the US by creating the Southern Wildfire Risk Assessment (SWRA). SWRA data include canopy cover and surface fire behavior fuel models derived from vegetation data developed during the US Geological Survey Gap Analysis Program which relied on 30 m satellite imagery acquired in the early 1990s from Landsat Thematic Mapper (Buckley et al., 2006). Additional SWRA data include community risk rating and an index that measures wildfire risk. SWRA lacks canopy data required by the fire behavior systems to model crown fire activity. Unless canopy data are provided from another source, the systems use one value for each canopy attribute across the entire landscape.

This paper compares modeled fire behavior from FlamMap using these three data sources and compares various characteristics of systems that may help managers determine which may be most effective to address land management objectives.

2. Methods

2.1. Study site

The Southern Atlantic Coastal Plain encompasses the area between the Atlantic Ocean and the Piedmont Plateau in the southeastern US. The study area is approximately 80,000 ha and lies along the Savannah River in South Carolina. Dominant vegetation types include loblolly pine (*Pinus taeda* L.), longleaf pine (*Pinus palustris* P. Mill.), hardwoods, slash pine (*Pinus elliottii* Engelm.), hardwood/pine mix, and baldcypress–water tupelo (*Taxodium distichum* (L.) Rich.–*Nyssa aquatica* L.) forests of various age and size classes. Elevation ranges from 19 to 150 m above sea level with maximum slopes of 28%. The area has a rich history of farming, grazing, and timber extraction (White and Gaines, 2000). Many of the forested stands are less than 60 years old. Current management focuses on forest products, conservation of flora and fauna, fire as an ecological process, and human safety. Fourteen fires occur on average per year in the study area with the vast majority of these fires being less than 5 ha (USDA Forest Service, 2009). Approximately 30% are caused by lightning and 70% are caused by humans (USDA Forest Service, 2009). Due to the flat terrain, fire spread is primarily a factor of available fuels, moisture, and wind.

2.2. FlamMap

FlamMap is a spatial fire behavior model that burns an entire landscape of interest using fuel moistures that are fixed or conditioned by wind and weather streams as well as winds that utilize either spatial wind grids or fixed speed and direction (Finney, 2006). FlamMap was utilized in order to provide a comparison of fire behavior including flame length, rate of spread, crown fire activity, and burn probabilities between the data sources. FlamMap provides both deterministic and probabilistic fire behavior results and therefore was determined to satisfy the study area objectives.

Eight input themes are required to model surface fire, crown fire, and burn probabilities. Topographical themes include slope, aspect, and elevation. Canopy data themes include canopy cover, canopy bulk density, canopy base height, and stand height; the final theme is surface fire behavior fuel models (FBFM). Landscape files for use in FlamMap were developed using these themes. Topographic themes were developed from Digital Elevation Model (DEM) data while canopy and FBFM data were developed from each of the three data sources. The extent for all simulations included a buffer around the study site boundary to minimize the edge-effects from random ignitions while computing burn probabilities; all outputs were clipped to the study area boundary once simulations were complete.

FlamMap supports the 40 FBFM described by Scott and Burgan (2005) and the 13 FBFM described by Anderson (1982) as well as custom fuel models developed by the user. Local data were used to refine accuracy of FBFM for all data sources to ensure that non-burnable areas were consistent between the data sources. Developed areas were reclassified as FBFM 91, water bodies including lakes and rivers were reclassified as FBFM 98, all non-burnable roads were reclassified as FBFM 99, and 2-track roads consisting of grassy medians were reclassified as FBFM 101 (refer to Scott and Burgan, 2005 for descriptions).

Fuel moisture values, wind speed, and wind direction were kept constant for all simulations to provide a comparison between the modeled data. The fuel moisture file specifies fuel moisture values for 1-, 10-, and 100-h timelag fuels, live herbaceous, and live woody fuels. Analysis of historic recorded weather data from the Savannah River Remote Automated Weather Station (RAWS) was completed using FireFamilyPlus (Bradshaw and Tirmenstein, in