

Creating a Dynamic, Large-Scale Fire Danger Index

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ABSTRACT. The combination of forest fuel maps with real-time atmospheric data enables dynamic and comprehensive assessments of fire danger. The goal of this study was to combine fuel maps, based on data from the Forest Inventory and Analysis (FIA) program of the USDA Forest Service, with real-time atmospheric data to create a more dynamic index of fire danger. Fuel loadings and moisture were estimated for points on a meteorological modeling grid (4 x 4 km) (based on FIA's strategic scale fuel inventory and atmospheric data) enabling the current assessment and 1- to 2-day prediction of fire danger as well as refined understanding of fire danger across forest ecosystems.

KEYWORDS. fire danger, fine woody fuels, Forest Inventory and Analysis, mesoscale

INTRODUCTION

Fire danger is defined in terms of factors affecting fire inception, spread, resistance to control, and subsequent damage (NWCG, 1996). It is usually expressed as an index based on component variables and is quantified using fire danger rating or prediction systems such as the U.S. National Fire Danger Rating System (Deeming et al. 1977) and the Canadian Forest Fire Danger Rating System (Stocks et al. 1989). Fire behavior models use fuel loading and fuel moisture information to predict fire behavior that contributes to the development of fire danger rating systems (Andrews 1986, Finney 1998). Fuel loadings are often static for time scales of hours and days, while fuel moisture is variable across time scales of an hour or less. Fuel loadings and fuel moisture vary at small spatial scales (e.g., stand-level), but fuel moisture is difficult to measure accurately due to high variability over short time scales. As a result, spatially averaged fuel moisture observations are generally used in fire danger assessments over large areas. To better mesh the collection and integration of fuel loadings and moisture in fire behavior prediction models, the National Fire Danger Rating System (NFDRS) classifies fuel loadings by fuel-hour classes (Deeming et al. 1977). To determine the fire danger of any forest area, estimates of its fuel loadings and moisture need to be assessed in real time and incorporated into a fire danger index.

Despite extensive work over the past decades to quantify fire behavior and subsequent fire danger, inadequate data and technology have impeded real-time assessments of fire dangers. Modern fuel inventories and recent meteorological advances provide opportunities to determine 1- to 2-day predictions of fire danger.

FUELS INFORMATION

The Forest Inventory and Analysis program (FIA) of the USDA Forest Service conducts a three-phase inventory of forest attributes of the United States (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into approximate 6,000-acre hexagons with at least one permanent plot established in each hexagon. In phase 1, the population of interest is stratified and plots are assigned to strata to increase the precision of estimates. In phase 2, tree and site attributes are measured on plots established in the 6,000-acre hexagons. In phase 3, a 1/16 subset of phase 2 plots are measured for forest health indicators such as down woody materials. Down woody components observed by the FIA program are: coarse woody debris, fine woody debris, litter, herb/shrubs, slash, duff, and fuelbed depth. As defined by the FIA program, fine woody debris (FWD) are downed woody materials with transect diameters of less than 3.00 inches. FWD are sampled on each FIA subplot along one transect. One-hour and 10-hour FWD (transect diameters between 0-0.25 and 0.26-1.0 inches, respectively) are sampled along a 6-foot transect while 100-hour fine woody fuels (1.0-3.0 inches) are sampled along a 10-foot transect (Woodall and Williams, 2005).

The FWD sampled by FIA match the fuel classification system (1-hour, 10-hour, and 100-hour) of the NFDRS, allowing creation of strategic-scale fuel maps that may be used to assess fire danger (Woodall et al. 2004). Due to the relatively sparse sample intensity of the FIA fuels inventory, inverse distance weighting interpolation techniques may be used to predict fuel loadings between sample plots. After fuel interpolation, nonforested areas are masked out of the fuel maps using classified imagery such as the National Landcover Dataset (NLCD) (Vogelmann

et al. 2001). Numerous techniques are available for creating large-scale fuel maps ranging from relatively simple interpolation techniques of FIA fuels data to more sophisticated efforts demonstrated by Rollins et al. (2004) and the USDA Forest Service's LANDFIRE program (www.landfire.gov).

METEOROLOGICAL INFORMATION

Estimates of surface fuels and real-time weather data are both necessary to estimate fuel moisture conditions and fire danger. Numerical weather prediction models produce daily simulations of atmospheric conditions such as temperature, winds, relative humidity, and rainfall for regions ranging in size from continents to counties. One such model, the Penn State University/National Center for Atmospheric Research Mesoscale Model (MM5), simulates the weather conditions for areas of about one-third the size of a continent down to state and county levels (Grell et al. 1994). The MM5 mesoscale model can be run daily, using observations collected and processed at the beginning of each day, to produce a sequence of 24-hour simulations of weather conditions across a region.

The Eastern Area Modeling Consortium (EAMC) is a multi-agency coalition of researchers, fire managers, air quality managers, and natural resource managers conducting research and developing new products to improve fire-weather and smoke transport predictions in the north central and northeastern United States. The EAMC runs the MM5 daily for the north central and northeastern United States in support of fire-weather research and applications. One application of this atmospheric data uses the Canadian Fire Weather Index System (CFWI) (Van Wagner 1987) to estimate fuel moisture variations across the model geographic domains based on simulated temperature, relative humidity, and rainfall information. These estimates use the Fine Fuel Moisture Code in the CFWI system to generate daily values for fuel moisture that roughly correspond to the expected variations in 1-hour and 10-hour fuels, as defined by the NFDRS. Fine fuel moisture estimates from the EAMC's mesoscale models may be produced for any forest ecosystem on any given day.

CREATING A NEW FIRE DANGER INDEX: CFIA

To create a more dynamic regional view of fire danger, we combined maps of regional fuel loadings and fuel moisture for the upper Great Lakes. First, fuel loading estimates (1-hour and 10-hour FWD) were obtained from FIA's interpolated fuel maps for a 4 x 4 km grid (EAMC mesoscale model grid, 13,136 forested grid points) across the upper Great Lakes. Second, the fuel loading and fuel moisture estimates were combined into a single meaningful quantity applicable to operational fire activities. Woodall et al. (2005) proposed an initial index combining meteorological and fuel loading information called the Burnable Fuels Index (BFI). This "engineered" index was adequate as a first attempt, but could be misleading with some fuel loading and moisture combinations because it is not based directly on atmospheric physics. An index based on atmospheric physics, rather than an empirical equation such as BFI, may more accurately describe the interaction between the atmosphere and fuels during fire events.

Convective Available Potential Energy (CAPE) is an index of atmospheric instability often used to parameterize the likelihood of convective activity (i.e., thunderstorm events) (Holton 1992). In terms of fire weather, CAPE has been used to describe plume dynamics above forest fires. However, when fuels burn, they release heat and moisture that affect the plumes above a fire.

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Thus, a feedback loop is created between burning fuels and the atmosphere above a forest fire (modified CAPE). In this study the real-time CAPE was modified to account for the inclusion of heat and water vapor from burnt fuels (FIA fuel maps). This new index of potential fire danger, CFIA, may more accurately describe the real-time potential for extreme fire behavior based both on atmospheric stability and fuel loadings. To illustrate, CFIA was computed for the Lake States study area for one day (Fig. 1). Higher CFIA appear in bands across southern Minnesota and central Wisconsin demonstrating the potential for extreme fire behavior in those locations at that point in time.

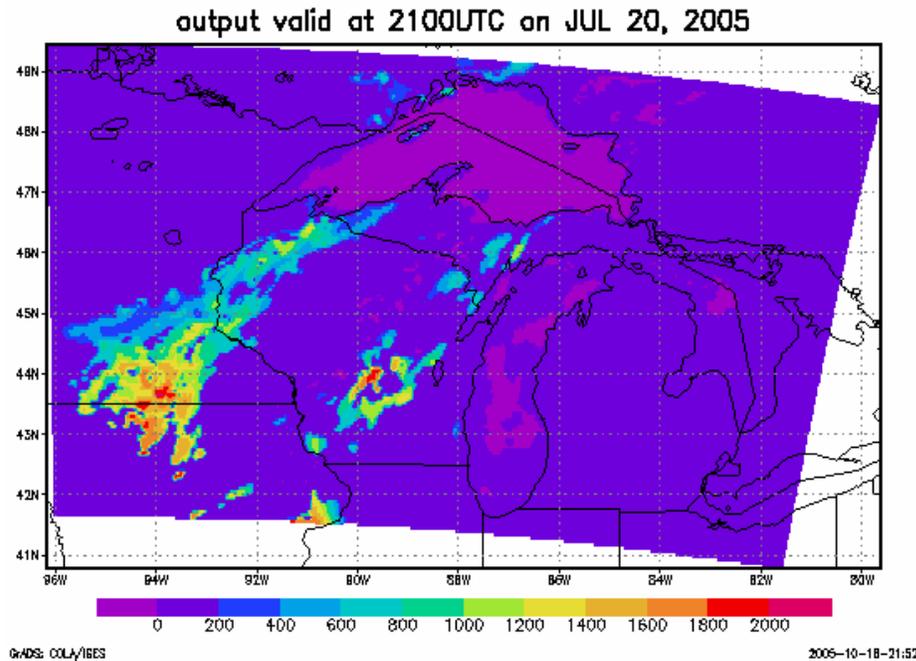


Fig. 1. Modified CAPE (CFIA index) for Lake States on July 20, 2005.

THE FUTURE OF DYNAMIC OUTPUTS

Regardless of the sources for strategic-scale fuel loading and moisture maps (i.e., LANDFIRE, FIA inventories, or EAMC mesoscale models), these fuel attributes can be combined to create real-time outputs such as CFIA to estimate regional fire danger. On a daily time step, counties or other polygons with hazardous FWD may be identified. Because the hazardous nature of FWD may vary on such a short time step, relaying safety information to the public and fire control information to firefighting crews is crucial.

Because this study served as an initial examination of the techniques and outputs of merging strategic-scale fuel maps with real-time weather data, numerous refinements need to be

developed to allow widespread application. First, the CFIA index needs to be tested for a variety of real-world weather/fuel scenarios. Second, the CFIA index needs to be validated using field observations. Third, data dissemination techniques that facilitate real-time web updates of CFIA maps are necessary to incorporate them into fire season activities. Overall, the results of this study indicate opportunities exist to refine understanding of the dynamic nature of forest fire dangers.

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