ASSESSING DISCONTINUOUS FIRE BEHAVIOR AND UNCERTAINTY ASSOCIATED WITH THE ONSET OF CROWNING

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ABSTRACT

Question: How can one integrate the natural variation in the variables influencing fire propagation associated with the prediction of crown fire behavior?

Background: Fire behavior in horizontally or vertically discontinuous fuel complexes, such as found in certain conifer forests, is often characterized by sudden changes in rate of spread and intensity. This discontinuous behavior occurs as discrete events, where small changes in the variables driving the fire, e.g., wind speed, cause large and abrupt increases in rate of spread and energy output of the fire. These features have been observed in wildfires and quantified in experimental and prescribed fires. From a heuristic point of view, the slight changes in the fire environment conditions allow the fire to transition into a new fuel layer where distinct combustion and heat transfer dynamics lead to a higher "steady state" rate of fire spread. A fire burning under a set of environmental conditions in the vicinity (above or below) of the threshold conditions for transition into a new fuel layer can be considered to be propagating in an unstable regime. Besides the sudden changes in fire behavior, which for rate of spread can be up to an order of magnitude higher, fires in this regime present bimodality and hysteresis.

The forecast of fire behavior following the conventional method of "best prediction" based on the best estimate of input variables can lead to large errors when fire is spreading under this unstable regime. We propose an alternative method based on ensemble modeling that aims to incorporate the uncertainty that exists in the input variables. This approach allows one to estimate the uncertainty associated with fire behavior predictions, namely an error term associated with the mean prediction and present probabilistic outcomes (e.g., likelihood or probability of occurrence of a certain event).

Location: Australia, but the general results are deemed universally applicable to conifer forests.

Methods: We apply a fire behavior modeling system that describes surface fire characteristics and crowning potential (e.g., identify the onset of crowning, type of crown fire, and associated rate of spread) through a Monte Carlo ensemble method that considers the uncertainty in the estimation of the modeled weather and fuel inputs. We assess the system outputs through its application to a recently documented wildfire case study in an industrial radiata pine (*Pinus radiata*) plantation in Australia.

Results: The application of the Monte Carlo ensemble method expanded the type of outputs arising from the application of the fire behavior modeling system. The method allowed for 1) quantifying the variability in predicted rate of spread and fireline intensity through measures of variability; 2) an estimate the probability of crowning; and 3) the probability of the fire reaching certain threshold values (e.g., exceeding a fireline intensity level for direct attack suppression tactics).

Comparison between the deterministic and ensemble results indicates departures between the two models when simulations are carried out in similar conditions that lead to the onset of crowning. The ensemble method predicts higher rates of spread when the deterministic method output is below the threshold for crowning and lower rates of spread if the deterministic method indicates crowning. Outside this transitional range, the outputs from both methods are essentially equal as demonstrated through a Taylor series expansion.

The evaluation of the method against selected burning periods of the Billo Road Fire (New South Wales, Australia, 2006) provided insight into its validity to predict fire behavior, namely in quantifying intermittent crown fire behavior (e.g., percentage of crown fire occurrence or flame defoliation) and the variability inherent to such nonlinear phenomena (e.g., coefficients of variation varying between 0.13 and 1.5).

Conclusions: The present work highlights the advantage of incorporating the uncertainty in the estimation of the variables influencing the fire spread process to better assess the effect of nonlinear fire phenomena, such as the onset of crowning on free-burning fire behavior. The ensemble methods used not only enable an improved description of fire potential but also extend the range of questions that can be answered by fire behavior models, namely providing probabilistic outputs that can be linked to quantitative risk analysis.

keywords: crown fire behavior, ensemble methods, Monte Carlo, pine plantations, rate of spread.

Citation: Cruz, M.G., and M.E. Alexander. 2009. Assessing discontinuous fire behavior and uncertainty associated with the onset of crowning [abstract]. Page 20 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.