Linking Dynamic Empirical Fire Spread Models: Introducing Canadian Conifer Pyrometrics

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Introduction

Land and forest managers routinely use fire behaviour prediction tools for decision support in wildfire management and operations. Across Canada, the Canadian Forest Fire Danger Rating System (CFFDRS) has provided standard tools used for fire weather and fire behaviour forecasting by virtually all land managers for several decades (Taylor and Alexander 2006). The CFFDRS consists of two major subsystems – the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) and the Canadian Forest Fire Behavior (FBP) System (Forestry Canada Fire Danger Group 1992, Wotton et al. 2009).

The FBP System is based on the analysis of several hundred experimental burns and wildfires conducted and documented over 30 years of effort. The current list of fuel types was designed to match the dominant fire-prone vegetation communities across Canada, with discrete fuel complexes defined by simple descriptive characteristics similar to forest cover data available to land managers in the latter 20th century (Van Wagner 1990). Fuel consumption and fire spread equations for each fuel type are predicted from a small number of inputs. This simplicity has been important to the use of the system in preparedness and response planning where time and data are scarce. However, the simplicity also limits its application to non-standard fuel conditions. Today, forest cover data is much more readily available and at much higher resolution than in previous decades, and the lack of flexibility of the FBP System fuel structure parameters is sometimes limiting. For instance, using the present version of the FBP System, it is not currently possible to model the effects of hazard mitigation treatments such as thinning and pruning on fire behaviour. This is because the FBP System spread rate and fuel consumption functions are parametrized based on fixed values for each fuel type for canopy base height (CBH), canopy fuel load (CFL), and surface fuel

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load (Forestry Canada Fire Danger Group 1992). In addition, the Fine Fuel Moisture Code (FFMC) component of the FWI System, a required input to the FBP System, is calibrated for a single vegetation model, the 'generalized pine forest' (Van Wagner 1974) and does not reflect the effects of variable stand type or structure on fine fuel moisture.

Objectives and Methods

Since the FBP System was issued and adopted in 1992, additional studies have been completed that offer greater flexibility for the inputs representing both fuel and moisture parameters. Cruz et al. (2003, 2004, 2005) developed crown fire initiation and spread models by reanalyzing the experimental burns and wildfires of the FBP System. These new models introduced a number of dynamic fuel moisture and stand structure inputs, while maintaining the empirical convention and local relevance of the observations comprising the FBP System database. In addition, a large and historic dataset of Canadian test fire and moisture content observations has also been analyzed (Beverly and Wotton 2007, Wotton and Beverly 2007). These studies showed that stand characteristics, season, and duff moisture were significantly influential in determining litter moisture content and offered notable improvements to the FFMC model commonly used as part of the FWI System.

This project introduces a conceptual scheme, tentatively called 'Canadian Conifer Pyrometrics' (CCP), that combines four separate modelling components into a coherent system for predicting wildfire behaviour in conifer forest fuel types. A simple estimate of surface fire spread was fitted using aggregated observations from the FPB System database. The Wotton and Beverly (2007) equations for estimating fine fuel moisture content were then used in a reanalysis of the Cruz et al. (2004, 2005) crown fire models. This allowed for stand-sensitive estimates of fuel moisture content and stand-specific crown base height and crown bulk density measures to be linked with the process of crown fire initiation and spread for conifer forests. The result is a fire behaviour modelling system built on empirical data that potentially offers much greater flexibility with respect to conifer fuels than the existing FBP System.

Results and Discussion

Integral to understanding and communicating the CCP concept in its present form is an interactive software tool, called FuelGraph (Figure 1), that allows users to compare predicted rate of spread (ROS) and type of fire under different fuel and weather scenarios. The FWI System components, season, and stand characteristics are user inputs that resemble the existing FBP System inputs for conifer stands. Wind speed is shown on the X-axis, and ROS and type of fire (i.e. surface, passive crowning, or active crowning) are shown on the Y-axis as outputs. The effects of fuel structure on moisture content, crown fire initiation and ROS are evident, although the additional input requirements will demand some investment in measuring or estimating certain parameters (e.g. canopy bulk density (CBD) and surface fuel consumption (SFC)).

In addition to predicting ROS in natural forest stands, CCP will potentially allow for predicting ROS in stands that have undergone hazard reduction treatments. However, additional testing is still needed at this stage, as the current models are assembled based on data from natural stands. For example, Figure 1 shows predicted fire behaviour and type of fire in a dense pine stand under high fire danger conditions (FFMC 92, Duff Moisture Code (DMC) 90). Under these conditions, crown fire initiation (> 50% probability) would be reached at 15 $km \cdot h^{-1}$. Following a hypothetical fuel reduction treatment, the new stand structure would reach the threshold of passive and active crowning behaviour (with 50% probability) at 25 km·h^{-1} and 35 km·h^{-1}, respectively.

Using FuelGraph, CCP outputs can easily be compared with existing FBP System outputs. An FBP System fuel type line can be overlaid on the FuelGraph output screen (not shown) to compare model predictions between the FBP System and CCP. This can help facilitate training and understanding within the fire management community.

At the present time, the CCP is presented as a concept and a modelling scheme in development. Additional work is in progress to refine the various statistical models; these include a reanalysis of the logistic regression of crown fire initiation (Cruz et al. 2004) as well as a re-fitting of the non-linear model of crown fire spread (reanalysis or calibration of Cruz et al. 2005). The FuelGraph tool will be distributed to interested researchers and fire managers for proper feedback and evaluation and may be modified prior to release as an operational forecast product.

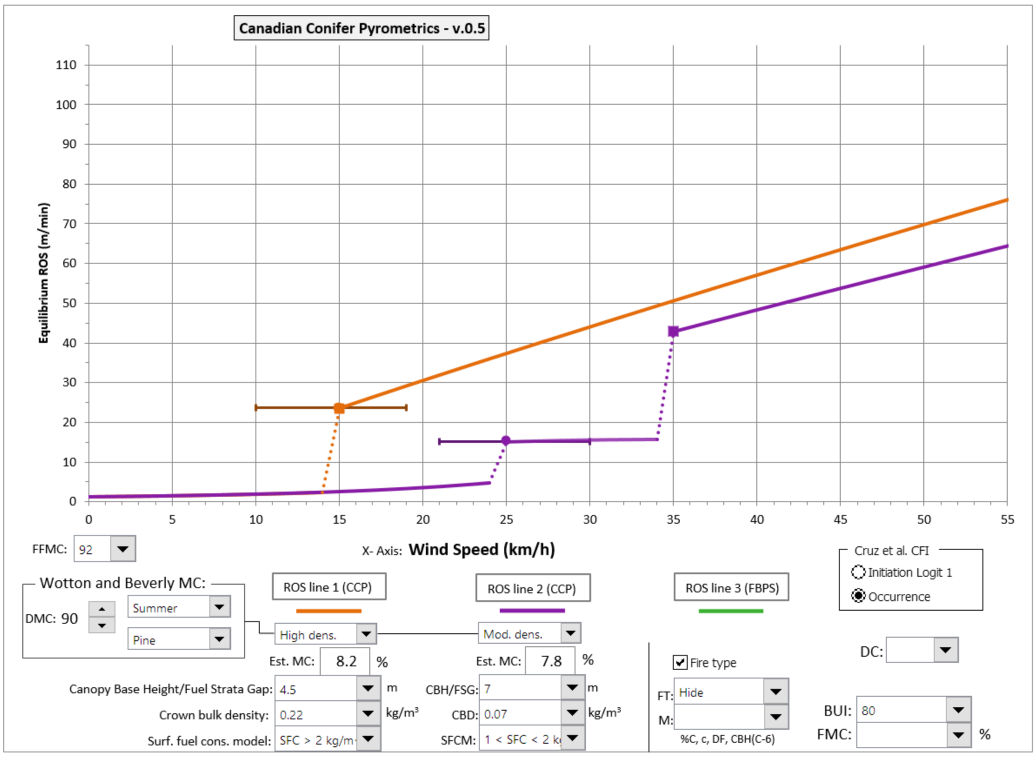

Figure 1. Screen capture of Canadian Conifer Pyrometrics-FuelGraph tool, showing examples of predicted fire behavior in two stands with varying structure under similar weather and fuel moisture conditions. Circle symbol indicates the initiation of passive crown fire behaviour and square symbol indicates the initiation of active crowning. Whiskers show the 70% confidence band (+/- 35%) for crown fire initiation. Wotton and Beverly MC refers to the Wotton and Beverly (2007) moisture content estimate; FFMC, DMC, DC, and BUI refer to the common acronyms representing indices of the Canadian Fire Weather Index System (Van Wagner 1987).

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