Chisholm/Dogrib Fire Research Initiative
Quicknote 6

November 2004 By: M.E. Alexander, C. Tymstra & K.W. Frederick

Incorporating breaching and spotting considerations into *PROMETHEUS* – the Canadian wildland fire growth model

PROMETHEUS is a spatially explicit deterministic model that simulates fire growth based on fuel type information, fire weather and fire danger data, and topographic characteristics. This is accomplished largely by utilizing the two major modules of the Canadian Forest Fire Danger Rating System, namely the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behaviour Prediction (FBP) System. The wildland fire environments to which *PROMETHEUS* is applied include both natural (e.g., water bodies, rock outcrops, particular fuel types, recent burns) and man-made barriers (e.g., roads, plowed fields, irrigated pastures, planned firebreaks) to fire spread. These discontinuities in the fuel type mosaic are treated as "non fuel" in the model (i.e., unburnable).

Barriers to fire spread either: (1) stop fire growth; (2) hinder fire growth (i.e., fire spreads laterally around an unburnable patch of ground); or (3) temporarily halt or delay maximum fire growth potential (e.g., the development of new, discrete ignition points across a wide water body as result of "mass transport" need time to reach their equilibrium rate of fire spread). Models like *PROMETHEUS* must be capable of dealing with these barriers to fire spread in order to realistically simulate the growth of free-burning wildland fires. *PROMETHEUS* presently handles the first two cases except for roads and narrow water bodies. The breaching or crossing of a barrier can occur by one, all or any combination of the following mechanisms:

- Spotting (i.e., sparks or embers are carried by the wind and start new fires beyond the zone of direct ignition by the main advancing fire front)
- Thermal radiation, either by pilot (firebrand) or spontaneous ignition
- Direct flame contact by the fire's leading edge
- Fire whirls

Whether this happens or not depends on a multitude of factors but principally on the barrier or break width, the level of fire behaviour (i.e., fire intensity, flame size), characteristics of the fuel type (i.e., firebrand material), size of the fire, associated burning conditions (e.g., wind velocity, air temperature, relative humidity, fuel dryness), and terrain features. The mathematical prediction of fire whirl development is beyond the current state-of-the-art with respect to wildland fire growth modeling, although a good deal of general qualitative information exists from operational experiences and experimental fire studies. In regards to the other three breaching mechanisms, varying degrees of predictability exist as a result of observations and measurements of wildfires, prescribed fires and experimental fires, and theoretical work.

The effect of spotting on a fire's overall rate of advance is implicitly accounted for in each of the FBP System fuel type rate of spread functions used in *PROMETHEUS* as a result of the empirical nature of their development. What these sub-models do not do is predict spot fire distances or their distribution/density. High-density, short-range spotting (say 0.1-100 m) is a common feature of many free-burning wildland fires, especially during "critically dry" fuel conditions (e.g., once the Fine Fuel Moisture Code (FFMC) component of the FWI System exceeds ~90). In the case of surface fires, significant spotting begins to occur once frontal intensities exceed ~1500-2000 kW/m. Low-density, intermediate- to medium-range spotting (~100-1000 m) such as observed on the Chisholm and Dogrib fires during the 2001 fire season in Alberta is a common occurrence with high-intensity crown fires. Long-range spotting (e.g., 1.0-10 km) occurs much less frequently. In continuous fuels, short- and medium-range spot fires are normally overrun by the main advancing fire front before they are able to developed sufficiently to increase the rate of advance.

The prediction of spot fires in terms of barrier breaching is an inherently difficult problem in part because two distinct phases are involved in the spotting phenomenon, the first being the transport distance of a "live" firebrand downwind of the flaming source and secondly whether the surface fuels are receptive to ignition once a firebrand has landed. Mathematical models have been developed by Dr. Frank A. Albini to predict the maximum distance a firebrand will be transported from four different sources: single or group tree torching, burning piles of woody debris, wind-driven surface fires in open fuel types (e.g., grass, shrubs, slash), and active crown fires. The latter model is deemed applicable only to flat, uniformly forested terrain whereas the other three models have been developed to consider some simplifications of complex terrain. These

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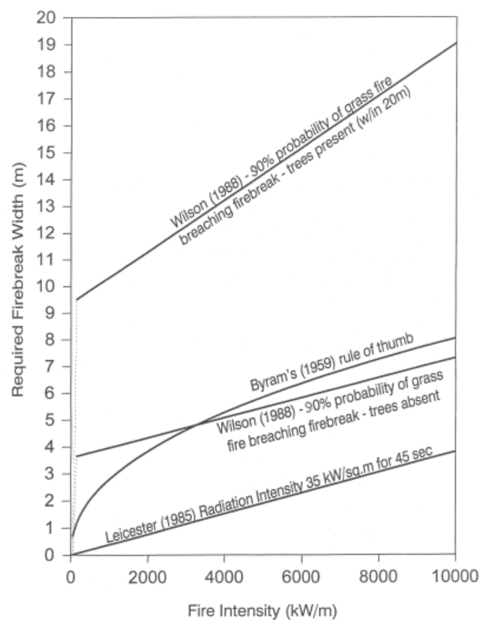
models involve many assumptions, the principal one being that firebrands are assumed to be sufficiently small to be carried some distance, yet large enough to still be able to cause an ignition once they reach the ground. Although these models have not been rigorously tested or validated they are widely used by fire behaviour analysts in the U.S. Perhaps the biggest limitation to the use of these models in *PROMETHEUS* is that the "worst case" situation is always predicted -- i.e., if a flaming source produces 100 firebrands, 99 of which fall within 100 m of the source and one travels 1.0 km, it's the "one" that these model are attempting to predict. The other aspect limiting the direct application of these models in *PROMETHEUS* is the realization that the existing guidelines for predicting the probability of ignition in FBP System fuel types is based on flaming firebrands (i.e., matches) and not glowing or smouldering firebrands.

One simple rule of thumb for assessing the likelihood of breaching a barrier to fire spread advocated many years ago still appears to have merit: in the absence of severe spotting, a firebreak needs to be 1.5 times the expected flame length. As a result of an extensive field study carried out in northern Australia, models have been developed to predict the probability of firebreak breaching by grass fires as a function of fire intensity, firebreak width, and whether trees or shrubs are present within 20 m of the firebreak (this latter variable influences the availability of optimum firebrand material). Interestingly, there is good agreement between the existing rule of thumb regarding breaching and the Australian model for trees and shrubs absent within 20 m of the firebreak. The simple rule of thumb could be easily implemented into *PROMETHEUS* using the fire intensity output for the various fuel types found in the FBP System and converting it into an equivalent flame length using an accepted fire intensity-flame length relationship. To gauge the chance of a barrier being breached by thermal radiation a critical threshold value must be determined based on an assumed duration of exposure. Unfortunately, the research in this field is largely limited to urban or structural materials as opposed to forest or wildland fuel complexes. Given a relationship between radiation intensity versus fire intensity and distance from the flame front, it is possible to derive the minimum barrier or firebreak width required to prevent breaching. These two concepts are illustrated in the accompanying graph.

Spotting ahead of main fire

Breaching of barrier to fire spread



A workshop was held at the Provincial Forest Fire Centre in Edmonton on September 23, 2004 where wildland fire research and fire operations personnel (T. Van Nest, D. Quintilio, J. Beverly, D. Cousin, G. Baxter and authors) reviewed and discussed the currently available knowledge with respect to incorporating spotting and other breaching considerations into *PROMETHEUS*. The following conclusions were reached:

- The simple rule of thumb for firebreak breaching should be incorporated immediately.
- Albini's maximum spot fire distance models could possibly be implemented, with appropriate Canadian modifications, in the form of an auxiliary calculator or as tabulated output, thereby allowing the user the option to add new ignition points when and where appropriate.
- Additional research is needed in order to derive the rules of thumb based on an analysis of existing wildfire case studies and/or an expert opinion for determining barrier or firebreak breaching by massive spotting (i.e., "area ignition") for those situations not covered by the simple rule of thumb.

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