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A 72-day Probabilistic Fire Growth Simulation used for Decision Support on a Large Mountain Fire in Alberta, Canada

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Introduction

Lightning ignited the Spreading Creek fire in the Rocky Mountain front ranges of west-central Alberta on 3 July 2014. The ignition was in close proximity to an approved prescribed burn planned for the Upper North Saskatchewan River valley. The prescribed burn was to contribute to a 10-year disturbance target for the R11 Forest Management Unit. An overarching forest management plan supported the use of prescribed fire to reduce the threat of large-scale wildfire and create resilient forest ecosystems (Alberta Sustainable Resource Development 2007).

The fire was situated in a complex mountain environment with poor firefighter access. Predominate vegetation included Lodgepole pine (*Pinus contorta*) in valley bottoms, and Engelmann spruce (*Picea engelmannii*) and Subalpine fir (*Abies lasiocarpa*) on steep north-facing slopes. Critically dry fuel moisture conditions contributed to several high-intensity crown fire runs beyond the control of suppression resources. The fire spread east towards the Kootenay Plains Ecological Reserve, south into the Siffleur Wilderness Area, and west into Banff National Park. Incident command had the challenging task of balancing the merits of prescribed fire with aggressive suppression.

The incident command team managing the fire requested a long-range assessment of potential fire spread on 18 July. The team recognized that residual burning left on the landscape could result in additional fire spread. The authors completed a 72-day probabilistic fire growth simulation for the period 21 July to 30 September and presented their results to the incident command team on 22 July. Simulation outputs quantified the likelihood of additional fire spread and supported a strategic fire management plan for the remainder of the fire season.

We discuss our methodology used to assess long-range fire spread potential and present the results of three retrospective analyses. First we evaluated the accuracy of our original modeling approach. Next we investigated what the Spreading Creek fire might have burned in the absence of suppression. Finally, we explored how our long-range assessment may have supported initial response decisions had we completed it on the first day of the fire.

Methods

The Prometheus fire growth simulation model (Tymstra *et al*. 2010) was used to produce deterministic and probabilistic fire growth approximations for the 2014 Spreading Creek fire. All fire growth simulations used noon weather records from the Kootenay Plains automatic weather station (R4) located 18.5 km northeast of the fire's point of origin. The Prometheus model

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requires hourly weather inputs. Noon weather records and FWI System values were therefore replicated 24 times for each historical day.

Deterministic fire growth simulations were based on weather and Canadian Fire Weather Index (FWI) System values (Van Wagner 1987) from 2014. The last organized fire runs were observed on 16 July, and a fire boundary captured during the afternoon of 17 July was within 48 ha of the final area burned (8,961 ha). We therefore simulated fire growth for the period 3 to 17 July to evaluate the accuracy of our modeling approach against observed fire growth. A simulation for the period 3 July to 30 September was used to investigate what the Spreading Creek fire might have burned in the absence of suppression.

Probabilistic fire growth was modeled using weather records from the years 1994 to 2013. Missing records were filled using archived records from weather stations located within a 100 km radius and +/- 400 m elevation of R4. We recalculated FWI System values for each historical weather year using R4 moisture codes reported on 2 July 2014 as starting values (Table 1).

Table 1. Starting moisture codes used to recalculate FWI System values for each historical year of weather from station R4.

Moisture Code	Starting Value
Fine Fuel Moisture Code (FFMC)	93.5
Duff Moisture Code (DMC)	67.5
Drought Code (DC)	561.5

Separate fire growth outputs were generated for each historical weather year. Burn probability was calculated by dividing the number of simulations that resulted in a cell burning by the total number of simulations.

Static Inputs

Fuel data were clipped from the Government of Alberta's 2014 provincial fuel type grid classified according to the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). The primary sources of vegetation information used to create the fuel type grid include the Alberta Vegetation Inventory and Alberta Ground Cover Classification. Several areas of NoData were reclassified based on underlying natural subregion classifications (Natural Regions Committee 2006). NoData values were classified as non-fuel within the Alpine subregion, and as the C-3 fuel type within the Montane and Subalpine subregions. The grass curing parameter for the O-1b fuel type was set at 40 %. A green-up setting was applied to mixedwood and deciduous fuel types to account for deciduous leaf-out.

Elevation data were clipped from Shuttle Radar Topography Mission (SRTM) digital elevation models. Prometheus generated slope and aspect grids from the elevation data provided. WindNinja version 2.5.4 software (Forthofer 2007) was used to approximate the effect of local topography on wind flow based on point initialization inputs for the R4 station location. Wind direction and wind speed grids were provided for each of the eight main cardinal directions.

The starting ignition for all simulations used the discovery time (3 July 21:18) and initial assessment location (51.988983° N, -116.656067° W) for the Spreading Creek fire. Highways 11 and 93 were used as 15 m wide fuel breaks.

Model Parameterization and Calibration
Simulations were limited to four hours of burning per day to compensate for daily FWI System values used throughout each 24-hour period. Daily FWI System values represent peak burning conditions (Van Wagner 1987). We assumed four hours of burning under peak burning conditions equivalent to a day of burning given typical diurnal weather and fuel moisture trends.

Fire growth was additionally constrained to days when station R4 reported a FWI > 29. Podur and Wotton (2011) recommended a threshold of FWI > 19 for modeling the growth of large fire over a multi-day period. However, their study focused on fires that occurred in the boreal regions of Ontario and Alberta. Fire behavior observations validated that a threshold of FWI > 19 was too low for predicting the difference between spread and non-spread days for this mountain fire. Fire growth predictions during the incident were more reasonable using the FWI > 29 threshold.

Prometheus does not model fire extinguishment. Xianli *et al*. (2014) used Duff Moisture Code (DMC) < 20 to identify substantial rain events (eg. 10-20 + mm) that effectively extinguish a fire. We used this DMC threshold to specify the earliest end date for each simulation.

Breaching was applied to all simulations. This parameter allows a simulated fire to cross a vector fuel break or non-fuel grid cell whenever the width is less than 1.5x flame length. Fire control lines and air tanker drops that took place during the Spreading Creek fire were not incorporated into any of the simulations. However, we ended the deterministic simulation used to evaluate accuracy of our modeling approach on 17 July to account for suppression activities prematurely extinguishing portions of the fire perimeter.

Results

Evaluation of Modeling Approach
The Spreading Creek fire burned 8,961 ha. Our modeling approach which used daily fire weather inputs and several fire spread thresholds over predicted fire growth by 6,798 ha on the east and west ends of the fire (Figure 1a). The simulation did not predict the 200 ha excursion that occurred on the north side of Highway 11.

Potential Area Burned in the Absence of Suppression
Deterministic simulation outputs for the period 3 July to 30 September suggest the Spreading Creek fire might have burned 112,778 ha in the absence of suppression. The irregular fire shape in Figure 1a highlights strong topographic channeling on fire spread.

Probabilistic Assessment of Long-Range Fire Spread
Fire growth simulations for 20 years of weather records produced fire sizes from 0 to 129,795 ha. Burn probabilities from 0.51 to 0.90 aligned best with the final fire perimeter (Figure 1b). Burn probabilities from 0.05 to 0.10 aligned best with our 2014 simulation that assumed no suppression. The simulation that used weather records from 2003 produced the largest area

burned and accounts for the 0.5 to 0.10 probability contour . The 2003 simulation was most similar to our 2014 simulation with respect to fire size, shape, and extent. A repeating 8 to 10 year gap was observed between R4 weather records conducive to large fire growth.

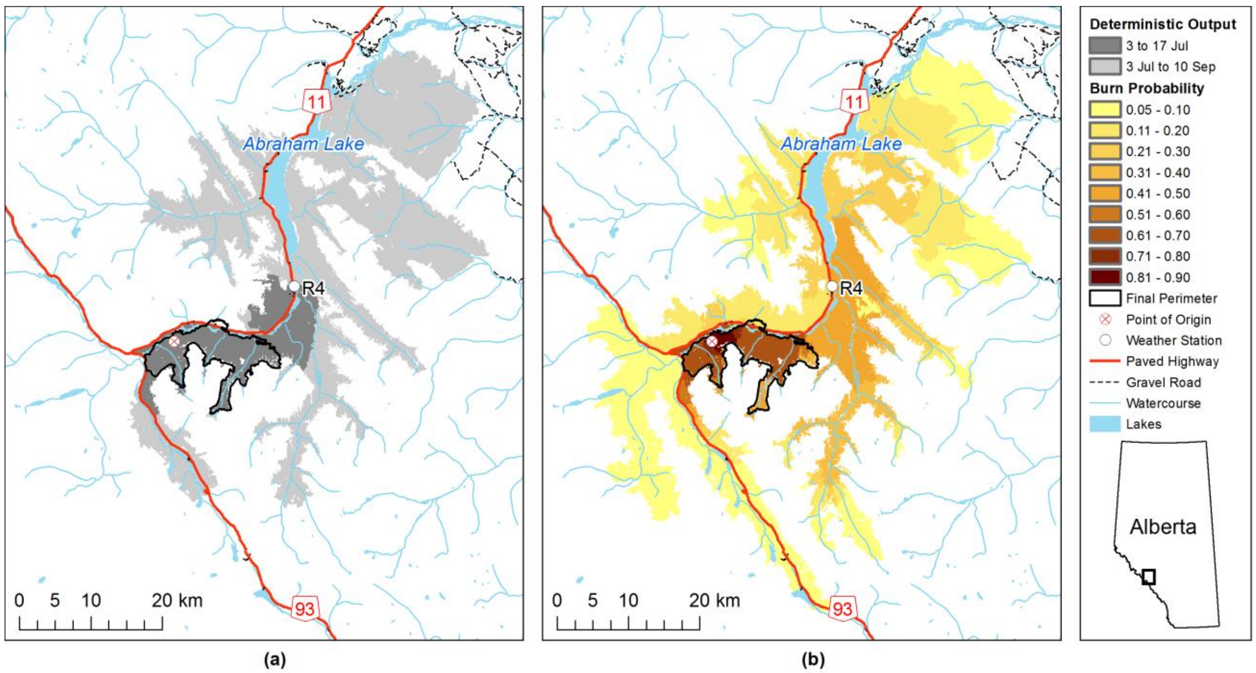

Figure 1: Deterministic (a) and probabilistic (b) fire simulation outputs for the 2014 Spreading Creek fire.

Potential fire spread days (FWI > 29) that occurred in the 20 historical weather years were summarized by month to provide insight as to when large fire growth is more likely. The greatest number of potential spread days were expected in July, and the least in September (Figure 2a). The number of potential spread days in 2014 were above average in both July and August. The distribution of potential spread days suggests there are typically 0 to 10 days conducive to large fire growth between 3 July and 30 September (Figure 2b). Station R4 reported 34 potential spread days in 2014.

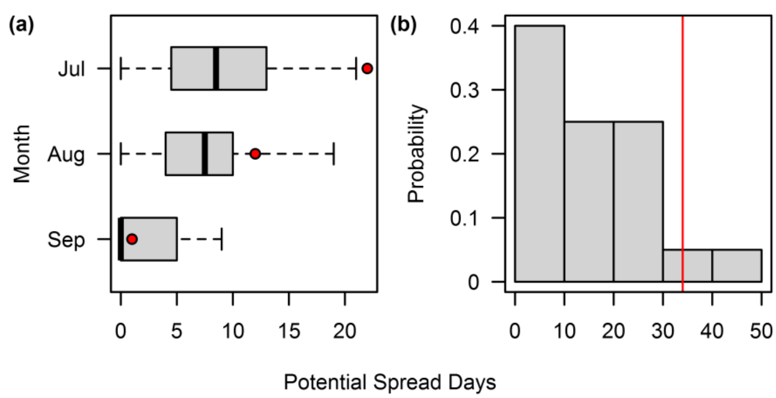

Figure 2: Monthly box and whisker plots (a) and distribution (b) of potential fire spread days (FWI > 29) for the period 3 July to 30 September based on 20 years of weather records from station R4. The red dots and vertical line show the number of potential spread days reported in 2014.

The median date of fire-ending events (DMC < 20) used in our analysis was 17 Aug (Figure 3). The first fire-ending event reported by station R4 in 2014 did not occur until 10 September.

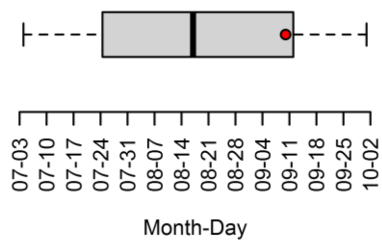

Figure 3: Box and whisker plot of fire-ending events applied to probabilistic fire growth simulations. The red dot is the expected date of extinguishment for the 2014 Spreading Creek fire in the absence of suppression.

Discussion

Deterministic simulation outputs suggest that our modeling approach overestimates area burned. There are several factors that likely explain this result. First, we did not account for suppression activities that slowed or extinguished parts of the fire perimeter. Second, we did not account for minimal fire growth from 11 to 15 July due to heavy smoke trapped in the valley. Finally, aerial ignition operations conducted in Banff National Park on 9 July created a large smoke column that shaded and calmed fire behavior at the east end of the fire. We suggest that our modeling approach provides realistic predictions of fire spread direction. Area burned predictions are more likely representative of a free burning fire with no suppression influence. Assuming no suppression, the 2014 Spreading Creek fire had potential to burn 112,778 ha. A fire of this magnitude would have impacted numerous values located along Highways 11 and 93. Yet our results suggest a low probability (0.05 to 0.10) of fire growth > 100,000 ha.

Original model outputs were presented to the incident management team 19 days after the fire was detected, and six days after the last organized fire run. Strategic fire management decisions were supported by nearly one month of fire behavior observations, model outputs, and certainty in established control lines. What if model outputs were available on the date of detection when little was known about the fire? Maguire and Albright (2005) describe mental shortcuts that commonly lead to overly risk-averse fire management decisions that appear inconsistent with an organization's stated goals. We speculate that incident management would have focused on worst case outputs despite their low probability of occurrence resulting in a similar initial response. However, this information may have also supported the early formation of a strategic suppression response by drawing attention to locations well ahead of the active fire perimeter.

There are no standards or guidelines regarding how best to incorporate probabilistic model outputs into real-time fire management decisions. The best way to develop such standards or guidelines is regularly provide probabilistic model outputs to incident management shortly after fires are detected. This statement is perhaps most relevant to escape fires located in areas with prescribed fire objectives. Mountain fires are rare in Alberta. Organization knowledge and experience to effectively manage infrequent mountain fire regimes is difficult to obtain. Alexander and Thomas (2003) describe case studies, field experience, and computer modeling as the best learning combination for fire practitioners. We hope this retrospective analysis contributes to your learning.

Acknowledgments
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