10.6 PREDICTING FIRE-WEATHER SEVERITY USING SEASONAL FORECASTS

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1. INTRODUCTION

The Canadian Forest Fire Danger Rating System (CFFDRS) has been an important part of forest protection operations in Canada since 1970 (Stocks *et al*. 1989). The ability to forecast fire-weather conditions associated with the CFFDRS is critical to operational decisions and thus is a routine part of fire management planning.

This paper presents a method to predict fire-weather severity for a fire season. Predictions are based on Environment Canada's seasonal forecasts and information contained in the Canadian Wildland Fire Information System (CWFIS).

1.1 *Canadian Wildland Fire Information System*

The Canadian Wildland Fire Information System (CWFIS) is a computer-based fire management information system that monitors fire danger conditions across Canada (http://cwfis.cfs.nrcan.gc.ca/). Daily weather conditions are collected from across Canada and used to produce fire weather and fire behaviour maps based on the CFFDRS.

1.2 *Severity Rating*

The fire-weather severity outlook is based on the forecasted seasonal severity as calculated by the CFFDRS. The two principal models within the CFFDRS are the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behaviour Prediction (FBP) System. This report focuses on components of the FWI system.

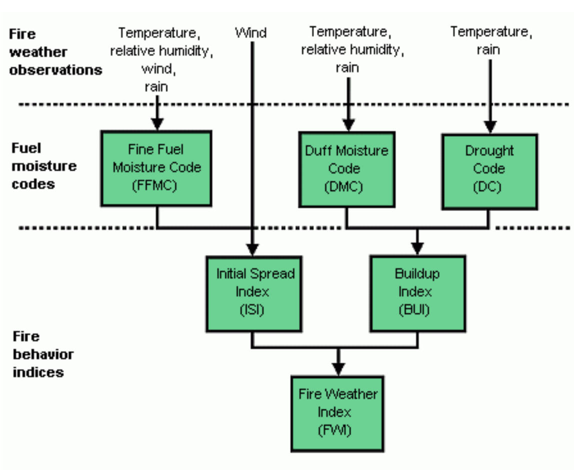

Figure 1. Structure of the Canadian Forest Fire Weather Index (FWI) system.

The FWI System, as shown in Figure 1, consists of six components that account for the effects of fuel moisture and wind on fire behavior (Van Wagner 1987). The first three components, the fuel moisture codes, include the Fine Fuel Moisture Code (*FFMC*), the Duff Moisture Code (*DMC*) and the Drought Code (*DC*). These are numeric ratings respectively of the average moisture content of the litter and other fine fuels, of the loosely compacted organic layers of moderate depth, and of the deep, compact organic layers. High values indicate dry fuels. Only the *DC* is capable of carrying over fall moisture conditions into the spring (Turner and Lawson 1978).

The remaining three components – the Initial Spread Index (*ISI*), the Buildup Index (*BUI*) and the Fire Weather Index (*FWI*) – are fire behavior indices, which respectively represent the rate of fire spread, the fuel available for combustion, and the frontal fire intensity; their values rise as the fire danger increases.

The Daily Severity Rating (*DSR*) and its time-averaged value are extensions of the FWI System. The *DSR* is a transformation of the daily *FWI* value

$$DSR = 0.0272\ FWI^{1.77} \qquad (1)$$

emphasizing higher *FWI* values through the power relation. The *DSR* can be accumulated over time as the cumulative *DSR* (or *CDSR*), or averaged over an entire fire season as the seasonal severity rating (*SSR*)

$$SSR = \sum_{i=1}^{n} DSR_i \ / \ n \qquad (2)$$

where DSR_i is the *DSR* value for day *i* and *n* is the total number of days. This severity rating can also be averaged over a month as the Monthly Severity Rating (*MSR*). Values of 2 or more generally indicate severe fire conditions (Harvey *et al*. 1986).

1.3 Climate and Weather Outlooks

The Canadian Meteorological Centre (CMC) of Environment Canada has been producing seasonal outlooks for Canada since 1995. Based on numerical

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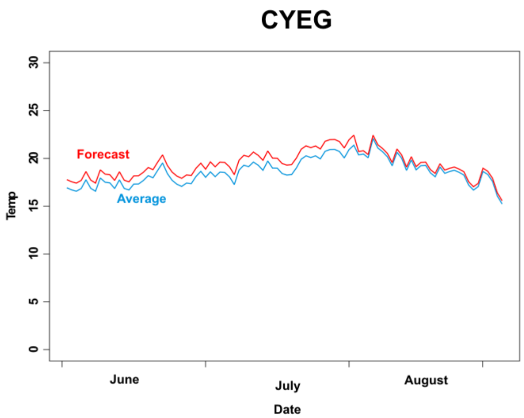

Figure 2. Seasonal forecast of the temperature for Edmonton Alberta for 2007.

weather prediction (NWP) models, these outlooks predict the temperature and precipitation anomalies for the next 12 months.

The models used and the extent of the forecast have varied over time. Currently, CMC produces a probabilistic forecast for the next four months using an ensemble approach while the 12 month extended-range forecast is based on statistical techniques (Servranckx *et al*. 2000; Plante and Gagnon 2000, Derome *et al*. 2001). The ensemble approach uses six independent runs, referred to as members, of two models: the Global Environmental Multiscale (GEM) model (Côté *et al*. 1998) and the Second Generation Atmospheric General Circulation Model (GCM2) (McFarlane *et al*. 1992). The six members from each model are produced by individual runs with staggered start times (12 hours apart). Through the total 12 members, the ensemble approach produces a probability and confidence of above, below and normal anomalies.

2. METHODOLOGY

For this study, fire-weather severity was evaluated by comparing the forecasted *SSR* (and *MSR*) to the average *SSR* (and *MSR*) as a ratio. This was calculated for 62 representative stations within the CWFIS and mapped for all of Canada.

The average *SSR*s for Canada were based on average weather conditions from 1971 to 2000 as calculated by the CWFIS. In this case, weather conditions were averaged by station and day (e.g. average temperature, humidity, wind speed, and precipitation for April 1, April 2, etc. for Victoria, for Kamloops, etc.) to produce a time series of daily weather observations from April 1 to September 30 used to calculate fire conditions. Precipitation was summed and applied once per week (days evenly divisible by seven) to capture rain's intermittent pattern (otherwise the average weather would produce drizzle amounts for every day). Fire Weather Index system values were then calculated for each station for this artificial year of average weather.

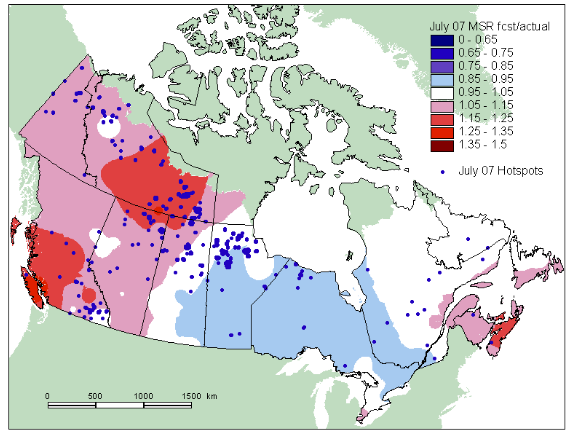

Figure 3. Predicted fire weather for Canada fo July 2007, based upon the predicted monthly severity rating (*MSR*) over the average *MSR*.

Next, Environment Canada's ensemble outlooks of surface temperature and precipitation rate were considered. These products included global grids for each ensemble member for each month at 2.5º resolution. Weather values were interpolated from the grids to the 62 weather station locations. Climatological normals of the temperature and precipitation rates were then used to determine anomalies.

Monthly anomalies of the temperature and precipitation rate were applied systematically to each daily average weather value for each CWFIS station. For temperature, the anomaly was added to each of the daily average values, while for precipitation, the anomaly was applied as a percent change to the weekly-estimated rainfall. By separately applying each ensemble member's anomaly to the average-weather time series, an ensemble of daily weather time series was created for each station. In turn, the FWI system calculations were applied to each time series to produce a ensemble of monthly *MSR* values and final *SSR* values per station.

Figure 2 illustrates the application of the monthly anomalies. In the figure the blue line represents the average daily temperature in Edmonton for each day from June to August. Perturbations are applied systematically to each average daily value to produce the forecasted temperatures, shown in red. In this case, the forecasted temperatures for Edmonton are above-average for the three summer months, though the anomaly varies from month to month, as can be seen on the graph.

Once the time series of forecasted fire-weather conditions were produced, the forecasted and the average severity ratings were mapped for Canada using inverse distance weighting. The forecast map was then compared to the average map as a ratio, showing the regions that are above and below average. These maps were produced for the individual months (*MSR*s) as well as for the season (*SSR*).

Figure 3 shows a typical monthly forecast produced using this method, in this case a single ensemble member of the GEM forecast for July 2007. This prediction shows above-average fire-weather conditions for much of western and northern Canada and the Maritimes while central Canada is below-average. The fires detected by satellite (hotspots) are shown as dots on the map to indicate areas of fire activity that occurred during the forecast period.

2.1 *Validation Study*

A validation study was conducted using data available from Environment Canada. These data sets included 6 member ensembles runs for each of the GEM and GCM models for 2007 as well as hindcasts produced from historical analyses from 1969 until 2000 for the GEM and from 1969 until 2003 for the GCM. Data for the CWFIS dates back to 2000 so the only common sets included 2000 and 2007 for the GEM and 2000-2003 and 2007 for the GCM (5 years and 7 sets in total).

The June 1 model runs were used to predict for June, July and August. This avoids any issues with the fire season start-up conditions within the FWI system as most indices would have stabilized by June 1.

Both observed and forecasted values of the *MSR* were compared to the average conditions to judge whether fire weather conditions were above or below average. Comparisons were conducted for each day and each station on a monthly basis. A 2x2 contingency table was created and standard skill scores were calculated as a measure of model skill (Stanski *et al*. 1989). Note that the table nomenclature is based on above-average conditions as the event being forecast, hence a correctly predicted above-average condition is a “Hit” while a correctly predicted below-average condition is a “Zero”. The table can be reconstructed to the below-average perspective, resulting in minor changes in the skill scores.

Table 1. Contingency table used in validation study.

	Above-average prediction	Below-average prediction
Above-average observation	**Hit** (correct)	**Miss** (incorrect)
Below-average observation	**False alarm** (incorrect)	**Zero** (correct)

Based on this contingency table, the following skill scores are used:

$$Bias = \frac{Hits + False\ Alarms}{Hits + Misses} \quad (3)$$

$$PC\ (probable\ correct) = \frac{Hits + Zeros}{Total\ observations} \quad (4)$$

$$POD\ (probability\ of\ detection) = \frac{Hits}{Hits + Misses} \quad (5)$$

$$FAR\ (false\ alarm\ rate) = \frac{False\ alarms}{Hits + False\ alarms} \quad (6)$$

$$CSI\ (critical\ success\ index) = \frac{Hits}{Hits + Misses + False\ alarms} \quad (7)$$

With the exception of the *FAR*, the ideal score for each skill score would be 1.0 while the ideal *FAR* would be zero. It is worth noting that a totally random prediction would derive equal values in each box, resulting in a *Bias* of 1.0; *PC*, *POD* and *FAR* values of 0.5; and a *CSI* of 0.33, given an equal number of above and below-average occurrences. Likewise, always predicting above-average conditions would result in a *Bias* of 2.0; a *POD* of 1.0; and a *FAR* and *CSI* of 0.5.

3. RESULTS AND DISCUSSION

Table 2. Validation study results

			Bias	PC	POD	FAR	CSI
GEM	2000	Jun	1.47	0.64	0.96	0.35	0.64
		Jul	1.80	0.52	0.95	0.47	0.51
		Aug	1.83	0.49	0.86	0.53	0.43
GEM	2007	Jun	1.44	0.62	0.91	0.37	0.59
		Jul	1.54	0.65	1.00	0.35	0.65
		Aug	1.97	0.51	1.00	0.49	0.51
GCM	2000	Jun	1.16	0.51	0.71	0.39	0.49
		Jul	0.90	0.43	0.41	0.54	0.28
		Aug	1.49	0.47	0.66	0.56	0.36
GCM	2001	Jun	1.02	0.69	0.80	0.22	0.65
		Jul	0.70	0.53	0.43	0.38	0.34
		Aug	0.70	0.53	0.54	0.23	0.46
GCM	2002	Jun	0.92	0.66	0.74	0.19	0.63
		Jul	0.91	0.44	0.49	0.47	0.34
		Aug	0.77	0.61	0.65	0.16	0.58
GCM	2003	Jun	0.94	0.62	0.72	0.23	0.59
		Jul	0.89	0.54	0.53	0.40	0.39
		Aug	0.73	0.56	0.57	0.22	0.49
GCM	2007	Jun	1.23	0.61	0.79	0.36	0.55
		Jul	0.70	0.49	0.46	0.34	0.37
		Aug	1.67	0.55	0.89	0.47	0.50

Table 2 shows the results of the validation study conducted for 5 study years using the GCM model and 2 study years using the GEM model.

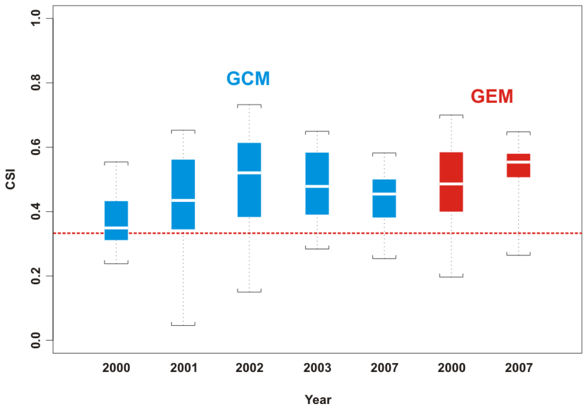

Figure 4. Critical success index (CSI) score results per year for the individual model ensembles.

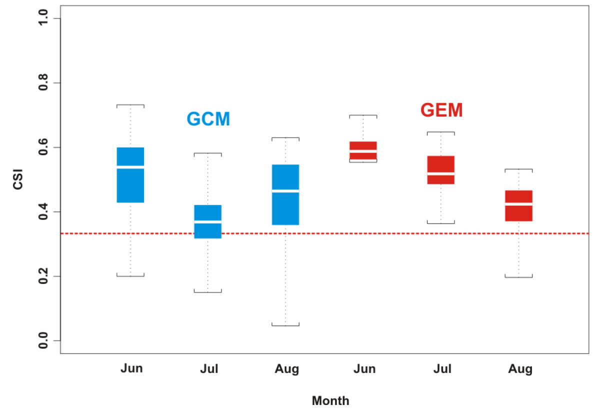

Figure 5. Critical success index (CSI) core results per month for the individual model ensembles.

It appears that the GEM model is consistently over-predicting the fire-weather conditions, as evident from the *Bias* term. For the two study years, the GEM model is predicting 40 to 90% higher values of the *MSR* than observed. This is reflected in the other scores with 0.90 to 1.0 *POD* and *FAR* approaching 0.50.

While the GCM model appears to be predicting the correct range of *MSR* values, with an average *Bias* value of 0.98, the remaining skill scores are lower than those for the GEM model. The average *CSI* value is 0.56 for the GEM model and 0.47 for the GCM.

Figures 4 and 5 show the *CSI* values of the individual model ensembles by year and by month. The box plots show the median, quartile and the extreme values of all ensemble predictions for each category (e.g. the left-most box in Figure 4 includes the June, July and August predictions of each of the six ensemble member of the GCM model for 2000). These figures show the GEM model in general preforming better than the GCM model both in terms of median skill score. On the other hand, the range of the GEM predictions are greater than the GCM predictions for the same years.

Another interesting observation is that the GCM model is performing poorly for July. This is seen in Figure 5 as well as in all of the five years of GCM results as shown in Table 2. This is counterintuitive as one would expect the skill at predicting would generally drop with the forecast length (as evident in the GEM results). Closer examination (not shown) indicates this is due to the temperature anomalies. There may be a physical process within the model that hinder the July forecasts or there may be another element, such as wind speed or humidity, which is not part of this anomaly approach but is more significant in the fire-weather calculations than temperature and precipitation.

There may be other issues outside of the GEM and GCM models that could be affecting results. For example, the application of rain every seventh day was arbitrarily chosen. This may have an impact on fire-weather calculations by eliminating the possibility of extended drought conditions. Another issue is the non-linear nature of the FWI system calculations, with above-average temperatures contributing more to severity values than below-average. It may be assumed that these non-linear tendencies are averaged out through the ensemble approach.

Overall, the scores of both model results are not strong. On the other hand, the scores indicate that there is some skill in seasonal prediction; in its current state the predictions are consistently doing better than chance (*CSI* = 0.33 shown as dashed line on Figures 4 and 5). Still, the study is based on seven data sets covering five years and one cannot draw too many conclusions from this limited set.

Environment Canada is undertaking a difficult task in producing seasonal outlooks and any skill is an encouraging step. One may choose to use other available long-range products but they are likely to produce similar results. Also, as models improve, the quality of long-range outlooks may improve and thus increase our skill at forecasting the fire-weather severity.

4. CONCLUSIONS

This paper presents a method to predict fire-weather severity for a fire season. Predictions are based on Environment Canada's seasonal forecasts and information contained in the Canadian Wildland Fire Information System (CWFIS).

While the results are not strong, they show there is some skill in this long-range outlook, suggesting there is value in the approach presented in this paper. This system is still in development and it is our intention is to conduct more detailed validations with more data years. In the future, there may be ways to improve the predictions, but for now we may continue to use seasonal outlooks in fire management decisions, but with a degree of caution.

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