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The Prediction of Extreme Agrometeorological Indices Using the Canadian Meteorological Centre's Medium Range Forecasts

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1. Introduction

The overarching objective of this work was to develop practical indicators, methods, and procedures for monitoring and analyzing agrometeorological extremes that significantly influence crop and/or livestock production in agricultural regions of Canada. Because of Canada's extreme northern location, agriculture lies at the fringe of ideal conditions. As a result, extreme weather conditions can quickly assume disaster proportions. The economic loss due to extreme weather events is always substantial. In 2001 and 2002 for example, Canada's GDP fell some $5.8B due to extreme drought (Wheaton *et al.* 2005) and in 2010, excessive flooding led to unseeded acres, resulting in insurance claims of about $956 Million (Public Safety Canada 2011). We therefore sought to develop some key indicators that can inform the industry about the weather related risks over time frames associated with managing an agricultural activity. We considered water, heat and wind related extreme events and developed agrometeorological indices that can be linked directly to agriculture operations. This work was partly influenced by the world-wide interest in reporting climate extremes (Peterson and Manton 2008). In total, twelve indices were developed as discussed below. Predictions were made at daily to monthly time frames which closely coincide with the planning window of most agricultural activities during the growing season.

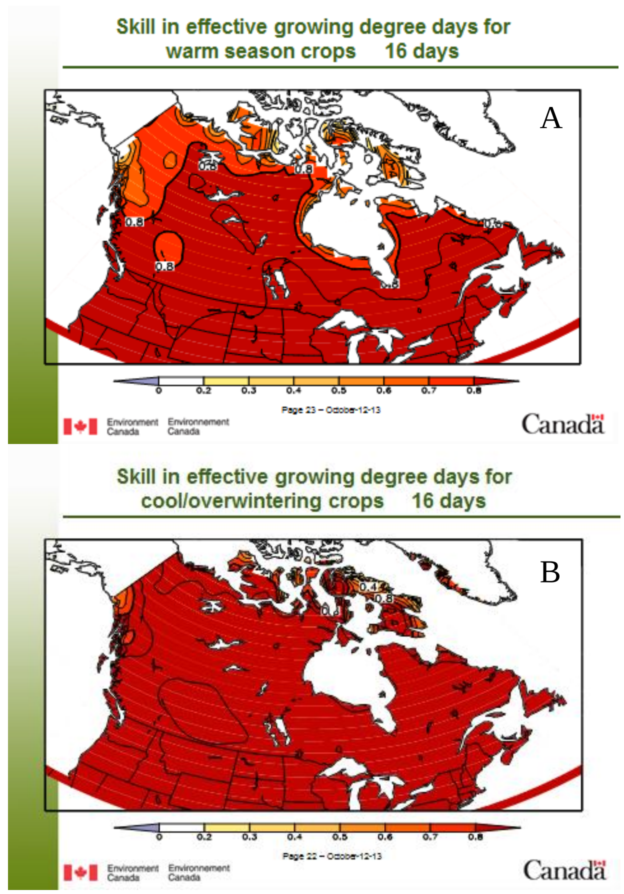

Fig. 1 Skill in predicting the effective growing degree days for A) warm and B) cool season crops across Canada.

2. Methodology and data

A phased approach was taken to develop, test and forecast agrometeorological indices across Canada's agricultural landscapes. In phase 1, the occurrence of extreme agrometeorological indices, their trends and variability were analyzed (Qian *et al.* 2010). In phase 2, improvements were made to the extreme indicators by defining the indices in terms of the critical thresholds by major crops. Phase 3 consisted of calculating and validating the indices in hindcast mode using forecast data sets from the Canadian Meteorological Centre's medium range and seasonal forecasts. This step was critical because it involved assessing the forecast skill. The last step involved communicating the forecast of indices to the agriculture sector on an experimental basis as part of building an integrated agroclimate monitoring system that includes near real time reporting and forecasting of agrometeorological indices.

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In all, twelve agrometeorological extreme indicators from heat, water and wind sub-climatic themes were investigated as follows:

Heat based indices

i) *Effective Growing Degree Days (EGDD)* - Growing Degree Days were calculated using 5^{o}C and 10^{o}C as the baseline for cool and warm season crops respectively. The growing season was defined using the Biometeorological time scale (Baier and Robertson, 1968). Daily EGDD = (Tmax+Tmin)/2.

ii) *Crop Heat Units (CHU)* - Although similar to EGDDs, the maximum and minimum temperature are defined differently. The maximum temperature uses 10ºC as the base and 30ºC as the ceiling. The minimum temperature uses 4.4ºC as the base. Thus, Ymax = (3.33 (Tmax-10)) - (0.084 $(Tmax-10.0)^{2}$) and Ymin = (1.8 x (Tmin - 4.4)). Daily CHU = (Ymax + Ymin)/2.

iii) *Number of Frost-Free Days (NFFD)* - Frequency of days above the frost temperature (-2ºC for cool and 0ºC for warm season crops respectively).

iv) *Number of Ice Free Days (NIFD)* - Frequency count of days with a minimum temperature below the frost temperature (-2ºC for cool and 0ºC for warm season crops respectively). The T thresholds for herbaceous and woody crops are much lower.

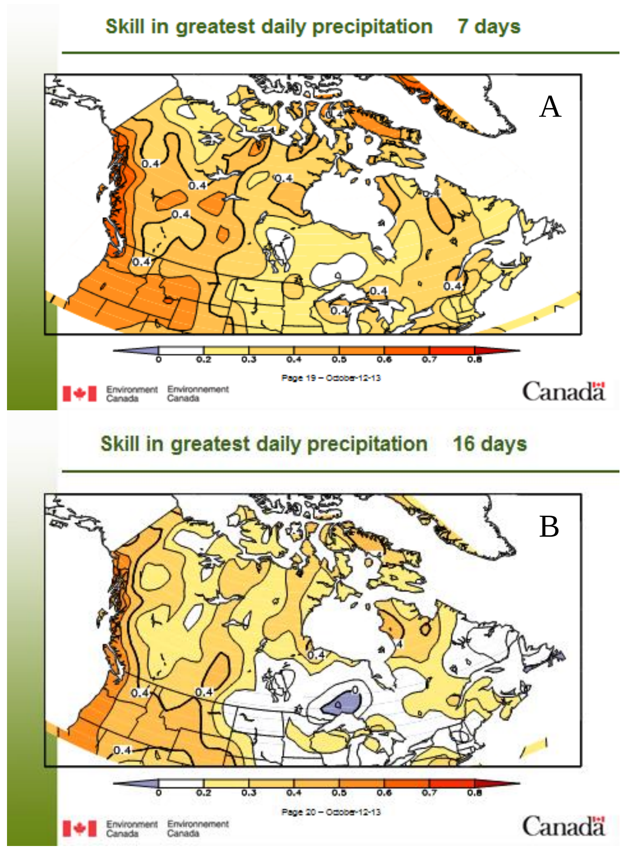

Fig.2 Skill in predicting the greatest 7 –day (A) and 16- day (B) precipitation across Canada.

v) *Days of Cool Wave (DCW)* - A frequency count of days with a minimum temperature below the cardinal minimum temperature (5ºC and 10ºC for cool and warm season crops respectively).

vi) *Days of Heat Wave (DHW)* - Frequency count of days with maximum temperature above the maximum cardinal temperature (30ºC and 35ºC for cool and warm season crops respectively).

Water based indices

i) *Greatest Daily Precipitation (P1D)* - the greatest daily precipitation over the period of analysis.

ii) *Greatest 10-Day Precipitation (P10D)* - the greatest 10 day precipitation total in a 2-week period.

iii) *Seasonal Water Deficit (SWD=P-PE)* - the difference between total precipitation (P) and evapotranspiration (PE).

Wind based indices

i) Maximum Daily Wind speed (MDWS) - the maximum wind speed reached per day.

ii) Number of Strong Wind Days (NSWD) - Frequency of days with an average wind speed > 30km h^{-1}.

iii) Number of Drying Days - Frequency of days with an average wind speed > 30km h^{-1} and maximum temperature > 30ºC.

Homogenized climate data from Environment Canada (Vincent *et al.* 2009) were used to calculate trends, variability and change in agrometeorological indices over a period of 60 to 100 years across Canada (depending on station history length). To calculate the forecast skill, hindcast data were obtained from the Global Ensemble Prediction System (GEPS) covering 2009 to 2011. The GEPS has been in operation since 1996 (with many upgrades) and consists of the Global Environmental Multiscale (GEM) model, a global

Gaussian grid of 600×300 km, 40 levels and top at 2hPa, 30 minute time step, 16 day integration, disturbed physical parameterizations and Kalman Filter initialization (Houtekamer *et al.* 2009).

3. Results

Skill of Agrometeorological Indices - We examined the predictability of the indices by calculating the Heidke Skill Score (HSS) which compares the proportion of correct forecasts to a no skill random forecast Hyvärinen (2014).

Energy based indices - The energy and temperature - based indices were realistically forecast over Canada. At most locations, the skill score was in excess of 70% correct (Fig. 1).

Water (precipitation) based indices - The precipitation based indices exhibit a relatively high forecast skill in western Canada at both 7 and 16- day time frames (Fig. 2). In central and eastern Canada, the skill score drops at the 16-day timeframe and degrades even further at the monthly time frame (data not shown).The temporal drop in skill is caused by the growth of initial errors in the model. Spatially, the difference in skill can be partially explained by the consistency of the forcing factors during the period under study (April to September). It has been shown that western Canada is influenced by the Madden-Julian Oscillation and ENSO-like forcing factors more than eastern Canada during spring through summer (*e.g.*, Lin *et al.* 2010).

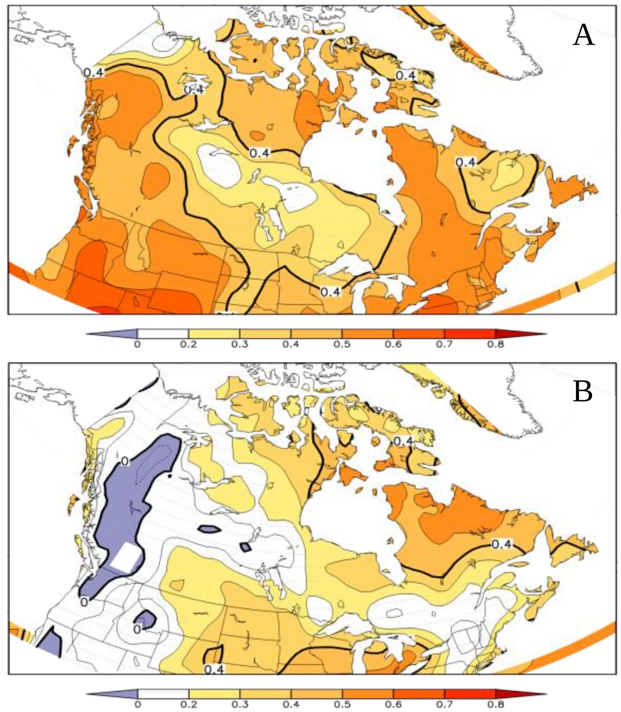

Fig.3 Skill in daily maximum wind speed (A) and the number of strong winds (B) at the 7-day time frame.

Wind based indices -The skill of predicting the wind-based indices has significant spatial differences: the maximum daily wind speed is best forecast in western and eastern Canada, with a relatively low skill in central Canada; the number of strong wind days is more reliable in eastern and central Canada, with a low skill in western Canada (Fig.3). Like the water based indices, the skill in the wind based indices drops at longer time frames in the future.

Real time reporting of the extreme agrometeorological indices - The 12 grometeorological indices are updated daily and e-posted on a public website: http://collaboration.cmc.ec.gc.ca/science/rpn/sages/.

The weekly and bi-weekly forecasts have a spatial resolution of 60 km while the monthly forecasts have a resolution of about 200 km. The intent for posting these products is to encourage the evaluation of the evolving weather related risks so that corrective actions can be taken. In some instances, the products may show opportunities which those involved in activities that are sensitive to the mapped extreme indices may react to. In the examples (Fig. 4) drawn from the 2013 growing season, the greatest 10-day precipitation total between October 14 and 27 (A) and the Number of Frost Free Days (B) between October 14 and 20, were showing ideal harvesting conditions and this information is timely to make plans to take machinery in the field.

Similar maps exist for other indices at the time frames discussed above.

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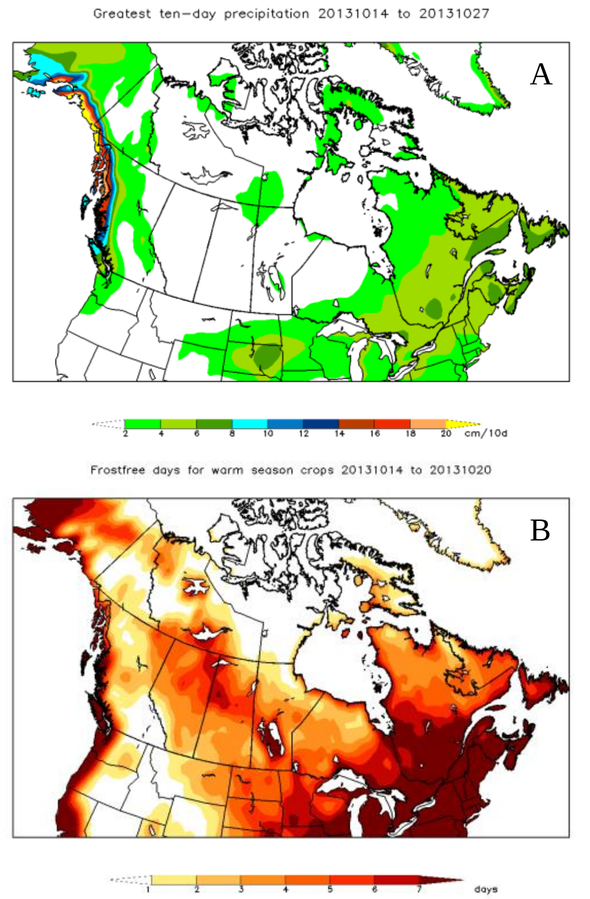

Fig 4 Predicted greatest 10-day precipitation total (A) and number of frost free days for warm season crops (B) on October 1, 2013.