3.5 CANADIAN AGROCLIMATIC SCENARIOS PROJECTED FROM A GLOBAL CLIMATE MODEL

Budong Qian* and Sam Gameda

Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa

1. INTRODUCTION

Agriculture remains a significant component of the Canadian economy, especially in some regions such as the Prairies, southern Quebec and Southwest Ontario. Canadian agricultural production is still subject to failure under disastrous climate extremes, such as droughts on the Canadian Prairies (Wheaton et al. 2005; Qian et al. 2009). Canadian climate records indicate increasingly wetter and warmer conditions throughout the 20th century (Zhang et al. 2000), although there are regional and seasonal differences. A recent study (Qian et al. 2010b) showed a significant lengthening of the growing season in Canada due to a significantly earlier start and a significantly later end to the growing season, together with a significant positive trend in heat accumulation and a decreasing trend in the occurrence of low temperatures during the growing season. It has also indicated that availability of water during the growing season has been increasing but may have been offset by an upward trend in evaporative demand resulting from increasing temperature.

It is of great interest for climate change impact studies and the development of adaptation strategies whether these observed historical trends will continue in the future and how agroclimatic conditions will be. This paper presents a set of projections based on climate change simulations performed by CGCM3 – the third generation global climate model (Flato and Boer 2001; Kim et al. 2002, 2003) developed at the Canadian Centre for Climate Modelling and Analysis (CCCma). The climate change simulations were conducted with four forcing scenarios, i.e., four greenhouse gases emission scenarios: Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A2, A1B, B1 (Nakicenovic et al. 2000) and the so-called "committed" scenario in which greenhouse gas concentrations and aerosol loadings were held fixed at year 2000 levels. Future agroclimatic conditions are presented by a suite of agroclimatic indices for the time period of 2040-2069, in comparison to those in the baseline period of 1961-1990.

2. DATA AND METHODOLOGY

2.1 *Historical Climate Data*

Daily climate data for 1961-1990 were extracted from a climate data set archived at the Eastern Cereal and Oilseed Research Centre (ECORC) of Agriculture and Agri-Food Canada (AAFC). The climate data were originally provided by Environment Canada and quality controlled. Missing data were estimated using nearby stations wherever possible. Daily climate data used in this study include daily precipitation (P), daily maximum temperature (Tmax), daily minimum temperature (Tmin). There were 673 climate/weather stations across Canada with observations for P, Tmax and Tmin in the AAFC archived climate dataset. However, as stations started or closed throughout the 30-yr period, only 424 stations were retained in this study to keep a maximum number of missing data of 5 years during 1961-1990 in order to have more reliable estimation of the statistics.

2.2 *GCM Data*

Climate change scenarios, i.e., possible changes in the statistics of climate variables simulated by GCMs, are the basis for developing future climate scenarios. Daily CGCM3 (T63 version) outputs for P, Tmax, Tmin are on a grid of roughly 2.8˚longitude/latitude, obtained from CCCma. Data for 1961-1990 in the models were used to represent the present-day climate (baseline climate) and 2040-2069 data were employed to represent a future climate under approximately doubled atmospheric CO_2 concentration, although the projected CO_2 concentration level may be different under the four emission scenarios.

2.3 *Stochastic Weather Generator AAFC-WG*

Stochastic weather generators are widely used as a tool to develop future climate scenarios based on GCM simulated or subjectively introduced climate changes for climate change impact models (e.g. Wilks 1992; Mearns et al. 1997; Semenov and Barrow 1997). As Semenov and Porter (1995) stated, a methodologically more consistent approach is to use a stochastic weather generator, instead of historical data, in conjunction with a crop simulation model. A stochastic weather generator allows temporal extrapolation of observed weather data for agricultural risk assessment as well as providing an expanded

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* *Corresponding author address*: Budong Qian, Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa, ON K1A 0C6, Canada; Telephone 613-759-1641; Email Budong.Qian@agr.gc.ca

spatial source of weather data by interpolation between the point-based parameters used to define the weather generators (Hutchinson 1991). Therefore, we employ the method of stochastic weather generators in this study.

A stochastic weather generator (AAFC-WG) developed at Agriculture and Agri-Food Canada (Hayhoe 2000), was improved from Richardson's weather generator (Richardson 1981; Richardson and Wright 1984). AAFC-WG has been evaluated for its capacity to simulate statistical properties of observed weather data for agricultural applications, including a set of agroclimatic indices (Qian et al. 2004), as well as climate extremes (Qian et al. 2008). Methods used to perturb weather generator parameters based on changes in the statistics of daily climate variables simulated by GCMs were also studied (Qian et al. 2005b).

2.4 *Development of Climate Scenarios*

Synthetic daily climate data were generated by AAFC-WG for the baseline period 1961-1990 and the future period of 2040-2069 for 0.5˚×0.5˚ grids in the agricultural regions across Canada. Details on how the synthetic data were generated can be found in Qian et al. (2005a, 2010a). Four scenarios were developed based on the climate change simulations performed by CGCM3 with forcing scenarios of IPCC SRES A1B, A2, B1 and "committed".

2.5 *Agroclimatic Indices*

Agroclimatic indices used in Qian et al. (2010b) were mostly adopted for this study, especially the indices that reflect the start (GSS), the end (GSE) and the length (GSL) of the growing season defined with temperature conditions relevant to the cardinal minimum temperature of three categories of field crops. These three categories are cool season (spring) crops, warm season crops and over-wintering crops. The cardinal minimum temperatures are 5ºC for cool season and over-wintering crops and 10ºC for warm season crops. Heat accumulations and water deficits (i.e., precipitation deficits) were then calculated for the crop growing season. Effective growing degree-days (EGDD) and crop heat units (i.e., corn heat units, CHU) were used to measure heat accumulations during the growing season for cool-season and over-wintering crops, and warm season crops, respectively. Water deficits (WD) were accumulated daily precipitation deficits (P-PE) for the growing season. P is daily precipitation amount and PE the potential evapotranspiration estimated from daily maximum and minimum temperatures (Baier and Robertson 1965). More detailed definitions of the agroclimatic indices can be found in Qian et al. (2010b).

3. RESULTS AND DISCUSSION

In this paper, we present only the mean values of some selected agroclimatic indices for the future climate (2040-2069) under four emission scenarios, compared with the baseline climate (1961-1990). Only the averages across the agricultural regions were discussed since there were not dramatic changes for the spatial patterns of the agroclimatic indices. The spatial patterns could be further examined on the maps for details.

3.1 *Potential Changes to the Growing Season*

At present (1961-1990), the last frost in spring occurs in late May, i.e., the 145th day of the year. It was projected that this date would be 10-15 days earlier in 2040-2069 under the scenarios of B1, A1B and A2; it could be still 5 days earlier even under the "committed" scenario. The first frost in fall occurs on the day 262, i.e., late September under the baseline climate. It could be delayed by 14-17 days under the three SRES emission scenarios. A 6-day delay was projected under the "committed" scenario. The earlier start and the delayed end of the frost-free period resulted in an increase in frost-free days of 24-32 days under the three scenarios. An 11-day increase was still foreseen under the "committed" scenario. The warm effect is strongest under the A2 scenario, then A1B and B1 for most of the temperature related indices.

In correspondence with the projected changes for frost-free days, growing season was projected to start earlier and end later for over-wintering and warm season crops. Growing season starts 11-16 days earlier for over-wintering and cool season crops, and 9-11 days for warm season crops under the A2, A1B and B1 scenarios, compared to the baseline climate. It is 6 and 5 days earlier under the "committed" scenario. Under all scenarios growing season also ends later than the baseline climate for over-wintering and warm season crops, but earlier for cool season crops. The delay for GSE is 7-9 days for over-wintering crops, and 8-11 days for warm season crops. For cool season crops, growing season may end 8-13 days earlier. The projected changes for GSE are smaller under the "committed" scenario. Therefore, the growing season length for all four scenarios is at around 130 days, only about 2-3 days longer than the baseline. The growing season length is 17-24 and 17-23 days longer under the three IPCC RESE scenarios, for over-wintering and warm season crops, respectively. There is still an 8- and 9-day lengthening for these two types of crops under the "committed" scenario.

Projected scenarios of the growing season length under different GHG emission scenarios are shown in Fig. 1, in comparison with the baseline climate. Only GSL for over-wintering crops are shown in Fig. 1, as an example.

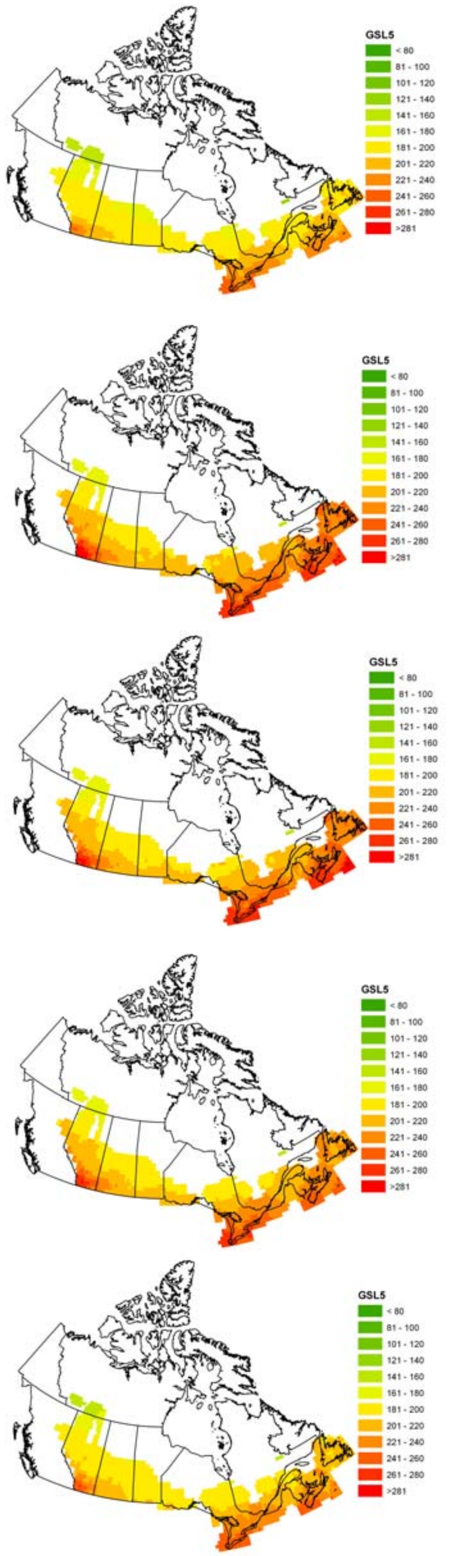

Fig.1 Growing season length (GSL) of over-wintering crops for the baseline (1961-1990) and 2040-2069 projected by CGCM3 under IPCC SRES A2, A1B, B1 and the "committed" scenarios (from top to bottom)

3.2 *Possible Changes in the Amount of Heat*

Growing Degree-Days (GDD) and crop heat units (CHU) are used to measure the amount of heat available for crops to grow. A modified version of GDD, i.e., effective GDD (EGDD), is used to reflect the influence of day length on crop maturity processes at high latitudes (Bootsma 1999). CHU is also called corn heat units, being widely used to rate the suitability of a climate for corn and soybean production in Canada (Major et. 1976, Chapman and Brown 1978, Bootsma et al. 1992, Brown and Bootsma 1993). EGDD is more often used for cool season and over-wintering crops, thus it was accumulated from GSS to GSE for cool season and over-wintering crops, respectively. Daily CHU was accumulated from GSS to GSE for warm season crops. GSS and GSE for the three crop types are estimated from thermal conditions based on different crop cardinal temperature thresholds (Qian et al. 2010b). Therefore, the time period for heat accumulation was different for the three crop types.

Under current climate, EGDD for over-wintering crops, averaged over all agricultural regions, is 1513. An increase of over 400 degree-days was projected by CGCM3 for three scenarios, reaching to 2059, 2047 and 1914 for A2, A1B and B1, respectively. It could also reach 1696 under the "committed" scenario. EGDD for cool season crops is currently at 1199, but this could increase to 1395, 1394, 1368 and 1292, for the A2, A1B, B1 and the "committed" scenarios. CHU is currently at an average of 2283 for the baseline climate. The average CHU could reach 3053, 3038, 2864 and 2557 under the A2, A1B, B1 and the "committed" scenarios, respectively. All these changes indicate that a larger amount of heat would be available for crop growth, no matter whether they are over-wintering, cool season crops or warm season crops.

EGDD for over-wintering crops and CHU for warm season crops are shown in Fig. 2 and Fig. 3, respectively. Scenarios under the four GHG emission scenarios for the time period of 2046-2069 were shown, in comparison to their corresponding baseline distributions.

A greater amount of available heat for crop growth does not, however, necessarily imply an increase in crop yields. For example, an increasing trend in heat accumulations may be more favourable for corn and soybean production but less favourable for barley production (Bootsma et al. 2005).

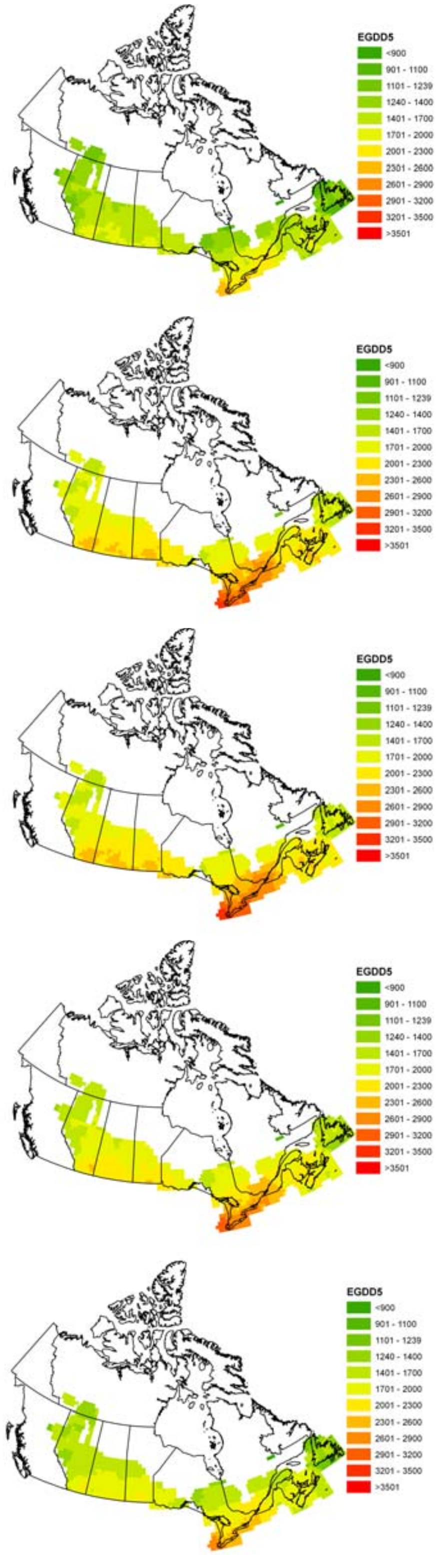

Fig.2 Effective growing Degree-days (EGDD) of over-wintering crops for the baseline (1961-1990) and 2040-2069 projected by CGCM3 under the A2, A1B, B1 and the “committed” scenarios (from top to bottom)

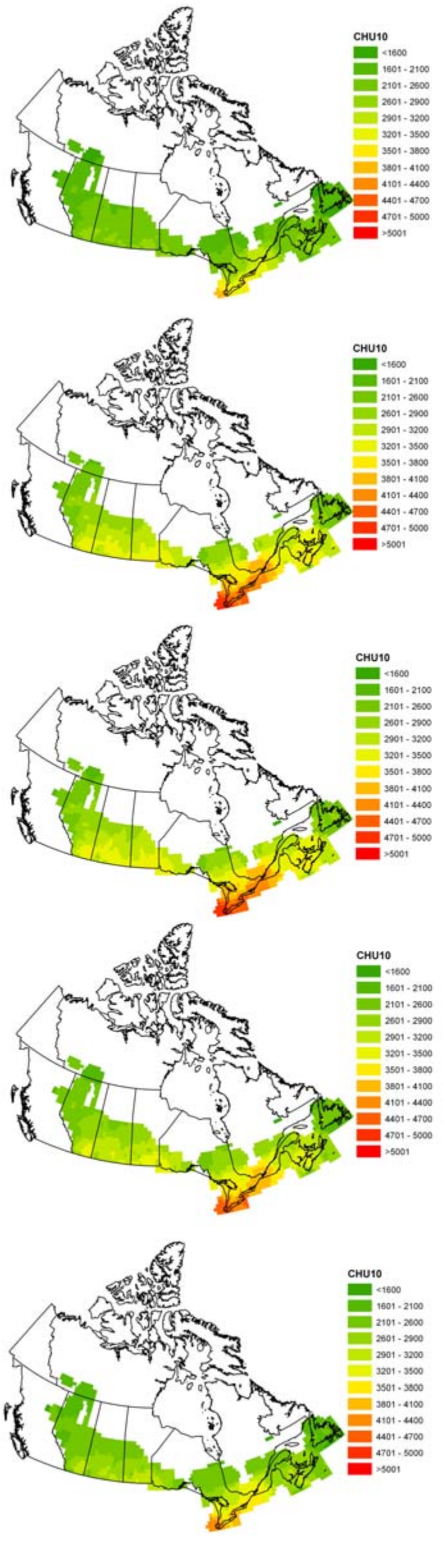

Fig.3 Crop heat units (CHU) of warm season crops for the baseline (1961-1990) and 2040-2069 projected by CGCM3 under the A2, A1B, B1 and the “committed” scenarios (from top to bottom)

3.3 *Possible Changes in Water Deficit*

Water deficit (WD) in this study is the accumulated daily precipitation deficit over the crop growing season. Depending on the timing of precipitation and crop growth, the average values of WD are quite different for over-wintering, cool season and warm season crops. They are 59, 148 and 103mm, respectively for the three types of crops under the baseline climate. As the simulated precipitation changes are not as consistent as the simulated temperature changes in climate models, the projected water deficit does not show consistent changes, in average values, under different emission scenarios. In addition to regional averages, actual spatial distribution may be more important to investigate because of large regional discrepancies in precipitation. We only focused on the overall averages across the agricultural regions in this paper. For over-wintering crops, notable change is only found under the A1B scenario, it reaches 80mm. The deficit is 65, 59 and 58mm under the A2, B1 and the “committed” scenarios, respectively. For cool season crops, the average value of water deficit remains more or less the current level, i.e., 150, 152, 150 and 141mm under the A2, A1B, B1 and “committed” scenarios. However, water deficit for warm season crops is notably larger under all future scenarios than in the baseline. The average values are 137, 152, 120 and 110mm, under the A2, A1B, B1 and the “committed” scenarios, respectively. There is a 50% increase in water deficit for warm season crops under the A1B scenario. As we emphasized before, these are average values across all agricultural regions in Canada. Regional difference may imply a more severe situation in some regions, such as the prairies.

Water deficits for warm season crops under different scenarios are shown in Fig. 4, in comparison to the baseline value. Regional differences are significant, for example, the projected water deficit on the prairies is much larger than in other regions. This implies higher water stress for warm season crops in the region. However, warm season crops are not commonly planted in the region. Nevertheless, water stress may remain a major limiting factor to crop production in the future as water deficit remains at the current level or increases in all projections, in terms of average values across all agricultural regions.

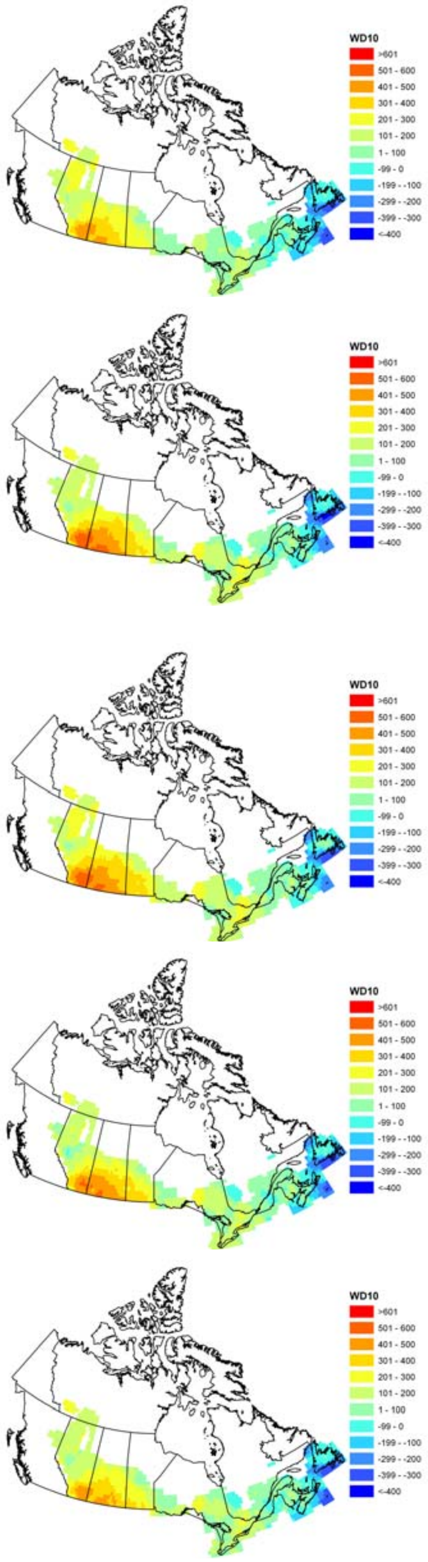

Fig.4 Water deficit (WD) for warm season crops in the baseline (1961-1990) and 2040-2069 projected by CGCM3 under the A2, A1B, B1 and the “committed” scenarios (from top to bottom)

4. CONCLUSIONS

Daily climate scenarios developed in this study can be used in many areas of climate change impact studies. To demonstrate their application, daily climate scenarios were used to study potential changes in agroclimatic conditions for Canadian agriculture in terms of a series of agroclimatic indices. Various agroclimatic indices, which have been used to assess crop production potentials and to rate the climatic suitability of land for crops in Canada, were computed from synthetic daily climate data both for the baseline climate of 1961-1990 and the future climate of 2040-2069 under a set of four GHG emission scenarios. Climate changes under these emission scenarios were simulated by CGCM3.

Agroclimatic conditions, represented by agroclimatic indices, imply that notable changes would occur in the future. For example, an extended growing season and a greater amount of heat accumulated in the growing season, were projected, regardless of which GHG emission scenario was taken into account, including the "committed" scenario. However, water deficit may remain as a major limiting factor for crop production as it was projected to be at the current or higher levels varying under different emission scenarios. Daily climate scenarios developed in this study will be used as input to crop models (e.g., DSSAT, Jones et al. 2003; EPIC, Williams 1995) for a better evaluation of climate change impacts on crop production; and furthermore, adaptation strategies can be developed.

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