P1.12 USING WEATHER GENERATORS AND AGROCLIMATE INDICES FOR CLIMATE CHANGE IMPACT ASSESSMENTS

Henry N. Hayhoe* and David R. Lapen
Agriculture and Agri-Food Canada, Ottawa, Ontario

1. INTRODUCTION

The spatial and temporal resolution of many current climate forecasts and scenarios require that new procedures be developed and implemented to provide the spatial and temporal information required for agricultural adaptation studies. Indices such as crop heat units (CHU), rely on a daily time step which is frequently not available in forecasts of seasonal climate or climate change scenarios. There is growing interest in the potential usefulness of weather generators in climate change studies. Weather generators have been used to downscale large-scale climate change data produced with general circulation models (Hayhoe, 2000). The use of weather generators will be assessed in relation to other approaches that have been used. These approaches frequently make use of historical climate data to derive daily values for climate change scenarios or rely on empirical adjustments to account for daily and monthly variability (Bootsma et al., 2001; De Jong and Li, 2001; McGinn et al., 1999).

2. METHOD

The study was carried out for Ottawa, Ontario, Canada (45E23'N, 75E43'W). Thirty years (1960 to 1990) of observed daily data were used to derive input for the weather data generator (Hayhoe, 2000). Monthly means (MN) and standard deviation (SD) were calculated for input into the weather data generator. Monthly means were interpolated using sine and cosine functions as proposed by Brook (1943) to provide data to calculate agroclimate indices. Daily potential evapotranspiration was calculated based on the Baier and Robertson (1965) methodology.

The climate change scenario was based on the first generation coupled global model CGCM1 (Flato et al., 2000). Data from an ensemble of three 201-year simulations with CGCM1 in which the change in green house gases (GHG) forcing corresponded to that observed from 1900 to 1996 and increased at 1% per year thereafter until 2100. The direct effect of sulphate aerosols (A) was also included (Boer et al., 2000 a,b). Daily maximum (T_x) and minimum (T_n) air temperature and precipitation (P) data from the run labelled GHG+A1 for the period 1975 to 1995 (present climate) and 2040 to 2060 (2xCO_2) were downloaded from the Canadian Centre for Climate Modelling and Analysis web site for the four grid points closest to the Ottawa climate station.

For the four grid points, monthly MN and SD were calculated for T_x, T_n and P. The monthly probability of wet days (pw) was calculated. Changes in monthly MN of T_x, T_n and P between values for 1xCO_2 and 2xCO_2 were determined. The ratios of SD for daily T_x, T_n and P were calculated by dividing values for 2xCO_2 by values for 1xCO_2 to indicate the change in variability. For precipitation, the monthly MN total precipitation was calculated from simulated values for 1xCO_2 and 2xCO_2 and the differences were determined. The ratio of monthly pw for 2xCO_2 was divided by the corresponding pw for 1xCO_2 to provide an estimate of the change in frequency of precipitation. Change parameters for the Ottawa climate station were then calculated using an inverse square distance procedure to weight the change parameters from the four grid points (De Jong and Li, 2001). The change parameters calculated for Ottawa were used to adjust the monthly MN and SD values used as input into the weather data generator. Thirty years of climate data based on change resulting from a doubling of CO_2 were simulated using the weather data generator (Hayhoe, 2000). This is referred to as scenario 1. The simulation was repeated with the assumption that the amount of precipitation remained the same but that the probability of precipitation increased by 20% (scenario 2).

Crop heat units (CHU), the precipitation deficit/surplus (PDEF), last spring frost (0EC) (SPRF), first fall frost (FALLF) and frost free period (FFP) were calculated. CHU were calculated with the following equations:

$$Y_x = 3.33(T_x - 10) - 0.084\,(T_x - 10)^2 \text{ if } T_x \$ 10$$
$$Y_n = 1.8\,(T_n - 4.44) \text{ if } T_n \$ 4.44 \qquad (1)$$
$$Y_x = 0 \text{ if } T_x < 10 \text{ and } Y_n = 0 \text{ if } T_n < 4.44$$
$$CHU = 3\,(Y_x + Y_n)/2$$

where the sum is from the date when average mean daily temperature (T_{mn}) was 11EC in the spring to the date when T_{mn} was 5.8EC in the fall (Brown and Bootsma, 1993). Daily DPEF is defined as potential evapotranspiration (PE) minus precipitation (P). The seasonal value is the sum of daily values from 10 days after T_{mn} equals 5EC in the spring to the day before the first occurrence of 0EC. PDEF,CHU, SPRF, FALLF and FFP were calculated for Ottawa using interpolated thirty year normals, observed daily data and scenario 1 and 2. Using 0EC to calculate frost with smooth normal data does not give realistic results because it does not account for natural variability in T_n. In this case frost was estimated using a temperature of 5.6EC (Sly et al., 1971).

3. RESULTS

Table 1 provides a summary of the simulated climate

Corresponding author address: Henry N. Hayhoe, Agriculture and Agri-Food Canada, Research Branch, Eastern Cereal and Oilseed Research Centre, Ottawa, ON, Canada, K1A 0C6; e-mail: hayhoeh@em.agr.ca

TABLE 1. Change parameters for doubling CO_2 for Ottawa calculated from the output from CGCM1

Variable		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
P (mm)	pw_2/pw_1	1.01	1.01	1.06	1.02	1.03	1.01	1.00	0.98	0.99	1.08	1.03	0.93
	MN_2-MN_1	11.3	4.5	11.0	10.0	22.5	-3.4	-24.2	-9.8	-8.2	2.5	5.2	-7.9
	SD_2/SD_1	1.32	1.19	1.08	1.07	1.26	1.15	0.82	0.98	1.03	1.18	1.05	1.08
T_x (EC)	MN_2-MN_1	1.62	2.97	1.07	1.71	2.00	2.08	1.83	1.70	1.90	2.42	2.98	0.61
	SD_2/SD_1	0.58	0.41	0.80	1.69	0.87	1.08	1.01	1.12	1.06	1.09	1.21	1.46
T_n (EC)	MN_2-MN_1	4.62	10.1	4.57	1.02	1.94	2.38	1.87	1.59	1.98	2.52	1.55	0.48
	SD_2/SD_1	0.52	0.79	0.70	1.01	0.96	1.03	0.97	1.03	1.02	1.10	1.47	0.95

TABLE 2. Agroclimate indices based on observed (1960 to1990) and simulated data from scenario 1 and 2

Index	Observed		$2xCO_2$		$2xCO_2$ and 1.2xpw	
	MN	SD	MN	SD	MN	SD
CHU	3135	144	3715	206	3719	186
PDEF	132	112	146	128	172	85.2
SPRF	125	12.3	116	8.1	117	8.8
FALLF	278	8.0	290	12.7	284	11.1
FFP	153	14.3	174	16.7	167	12.8

Figure 1a. Cumulative Distribution of Crop Heat Units

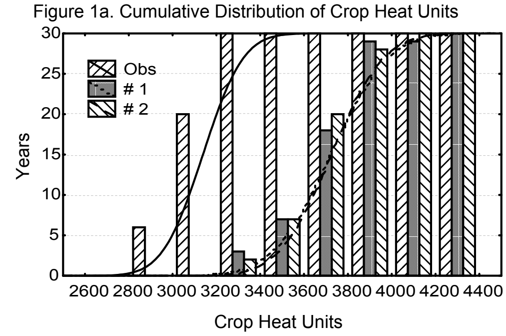


Figure 1b. Cumulative Distribution of Precipitation Deficit

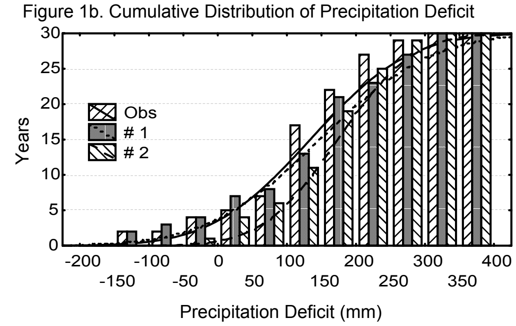
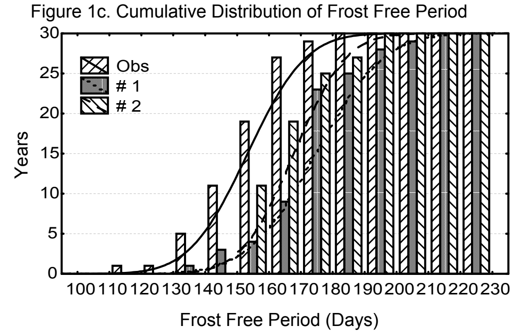


Figure 1c. Cumulative Distribution of Frost Free Period



change from the period 1975 to 1995 (present climate) to the period 2040 to 2060 ($2xCO_2$). There was very little change in the frequency of precipitation. Changes in the MN and SD depended on the season, with increases in P occurring in the winter and spring and decreases occurring in the summer. The largest increase in mean monthly P was 22.5 mm which occurred in May and the largest decrease was 24.2 mm which occurred in July. Mean T_x and T_n consistently increased, with the largest increases occurring during the winter for T_n. The average value of T_n increased by 10.1EC in February.

The CHU for the observed normal data was 3133 and the PDEF was 64 mm. When a critical temperature of 5.6EC was used with the observed normal data, the SPRF was day 128, the FALLF was day 273 and the FFP was 145 days. The CHU for the interpolated monthly averages of simulated climate change output from the weather generator was 3765 and the PDEF was 94 mm. Using a critical temperature of 5.6EC with the simulated climate change, the SPRF was day 122, the FALLF was day 290 and the FFP was 168 days.

The advantage of using daily data rather than smoothed data derived from interpolating normals is that it provides more realistic estimates of the average value of indices as well as providing for estimates of variability and risk levels. Table 2 gives agroclimate indices for Ottawa based on observed data for 1960 to 1990, and for scenario 1 and 2. Average results were similar to the values derived using interpolated monthly normals for CHU, SPRF, FALLF and FFP. The FFP were slightly lower using daily data (Table 2), which may suggest that the empirical criteria of 5.6EC for frost requires some adjustment for application at Ottawa. The largest discrepancies occurred in the average PDEF. This indicates the benefit of accounting for the variability in climate data when calculating this index. The simulated results for scenario 2, illustrate the capacity of the weather generator approach to examine the sensitivity of agroclimatic indices to a range of climate change scenarios, including changes in both the frequency and the amount of precipitation. It is possible to assess the potential impact of an increase in average temperature or in the quantity of precipitation without using a weather generator (McGinn et al., 1999), but a weather generator facilitates an assessment of more complex scenarios involving changes in the frequency of weather events. Based on the simulated data from scenario 2, the PDEF increased from 146 mm to 172 mm and the FFP deceased by 7 days to 167 days. Table 2 also indicates as expected that MN as well as SD of CHU, PDEF and FFP all increase with the predicted climate change resulting from doubling CO_2.

Figure 1 shows the cumulative probability distribution for CHU, PDEF and FFP for the observed data and data simulated in scenario 1 and 2. Agroclimatic indices used for zonation or for farm management decisions are most useful if they are expressed as a function of risk rather than simply as an average value. Empirical equations have been developed to estimate the value of agroclimatic indices at specified risk levels, when the probability distribution is not known (Bootsma et al., 2001). The use of weather generators eliminates the requirement for empirical estimates of indices at a given risk level as is illustrated in Fig. 1. For the 30 years of observed data, CHU had a minimum of 2847 and 80% of the years it was greater than 3010 (Fig. 1a). The corresponding values for scenario 1 were 3323 and 3533 and for scenario 2 were 3333 and 3574 respectively. For the 30 years of observed data, PDEF had a maximum of 327 mm and 80% of the years it was less than 225 mm. The corresponding values for scenario 1 were 342 mm and 275 mm and for scenario 2 were 313 mm and 234 mm respectively. For the 30 years of observed data, FFP had a minimum of 111 days and 80% of the years it was greater than 143 days (Fig. 1c). FFP was significantly longer for the climate change scenarios simulated with a weather generator. The corresponding values for scenario 1 were 138 days and 164 days and for scenario 2 were 151 days and 158 days respectively. Fig. 1c indicates that there is a reduction in the variability in FFP for scenario 2 as well as an increase in the length of the minimum FFP.

4. DISCUSSION AND CONCLUSIONS

Indices such as CHU, PDEF and FFP require data with a daily time step. Weather data generators provide a tool for the calculation of these indices for data, which provide only monthly parameters. This study confirms the applicability of weather data generators as a tool to estimate agroclimate indices for selected climate change scenarios. Traditional methods of calculating these indices frequently rely on interpolation algorithms and empirical adjustments, which have a limited range of applicability and may not be valid for different climate regimes. Approaches based on simply adjusting MN and SD of observed climate data to generate climate change scenarios lack the flexibility to simulate complex changes, particularly in the frequency of precipitation events. Weather data generators can produce long series of daily weather data which correspond to modeled or hypothetical climate change scenarios, including precipitation frequency. These data can then be used to assess not only the mean value of agroclimate indices but also their probability distribution.

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