Adaptation of agricultural production to climate change in Atlantic Canada

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SUMMARY

Agroclimatic indices (heat units and water deficits) were determined for the Atlantic region of Canada for the present-day climate (1961-1990) and for two future time periods (2010-2039 and 2040-2069). Climate scenarios for the future periods were based on outputs from the Canadian General Circulation Model (GCM) that included the effects of aerosols. The GCM assumed greenhouse gas forcing that corresponded to that observed from 1900 to 1996 and increased at a rate 1% per year thereafter. This scenario is equivalent to a doubling of CO_2 by around 2050 compared to the 1980s. Climatic data for all three periods were interpolated to a fine grid of about 10 to 15 km. Agroclimatic indices were computed and mapped based on the gridded data. The potential impacts of climate changes on agriculture were evaluated by comparing the agroclimatic indices to crop yields observed in field trials over a wide range of climates in eastern Canada.

On the basis of the assumed scenarios, Crop (Corn) Heat Units (CHU) would increase by 300-500 CHU for 2010-2039 and between 500-700 CHU for 2040-2069 in the main agricultural areas of the Atlantic region. A decrease in heat units (cooling) is anticipated along part of the coast of Labrador. Anticipated changes in water deficits, defined as the amount by which evapotranspiration exceeded precipitation over the growing season, were generally less than 50 mm for both periods, increasing in some areas and decreasing in others. Greatest increases in deficits were expected in the central region of New Brunswick for the 2040-2069 period.

Statistical comparisons of crop yields with climate indices suggest that yields of grain corn and soybeans could increase as much as 3.8 and 1.0 tonnes per hectare, respectively, by the year 2055, mostly as a result of increased availability of heat units. Yields of barley are not likely to be affected very much by the change in climate. Changes in water deficits are not expected to have a very significant impact on crop yields. However, these estimates do not take into full consideration the potential change in impacts of weeds, insects and diseases under a changed climate. Overall, there will likely be significant shifts away from production of small grain cereals to high energy and high protein crops (corn and soybeans) that are better adapted to the warmer climate. However, small grain cereals will likely remain as important crops as they are very suited for rotation with potatoes and also provide a needed source of straw used as bedding for animals. There is a need to evaluate the potential environmental impacts of these probable shifts in crop production, particularly with respect to soil erosion in the region.

INTRODUCTION

Agriculture is an important sector of the Atlantic region economy that is sensitive to climate change. Projected changes in climate are likely to have both positive and negative effects on agriculture in the region (Bootsma, 1997). The purpose of this study was to evaluate the potential impacts of climate change on the suitability/capability of the Atlantic region of Canada to produce corn, soybeans and barley crops by assessing appropriate agroclimatic indicators. Assessments of the potential impacts of climate change induced by increased concentrations of greenhouse gases (GHG) in the atmosphere are needed by scientists, policy makers, producers and others to make decisions on policies and management practices that will minimize harmful effects of expected changes in climate and take advantage of positive impacts. There is also a need to develop suitable methodologies that will allow for more rapid assessments of the change in production potential of these and other crops as new scenario information becomes available from Global and Regional Climate Models.

Various agroclimatic indices have been used in the past to assess the production potential of crops in Canada. Precipitation Deficit/Surplus (PE - P, where PE and P are the seasonal Potential Evapotranspiration and Precipitation, respectively) and Effective Growing Degree-Days above 5°C (EGDD) are the principal climate variables used to rate the climatic suitability of land for production of spring-seeded small grains (Agronomic Interpretations Working Group, 1995). EGDD are a modification of growing degree-days (GDD) that include consideration of a daylength factor for rating small grain cereal crops, which are sensitive to photoperiod. Corn (or Crop) Heat Units (CHU) are widely used to rate the suitability of various regions for the production of corn and soybeans (Major et al., 1976; Chapman and Brown, 1978; Bootsma et al., 1992; Brown and Bootsma, 1993; Bootsma et al., 1999). These indices were adopted for this evaluation of potential impacts of climate change in the Atlantic region due to their importance on influencing crop performance and because of their common acceptance in the past as indicators of crop suitability. We explored the relationships between these indices and crop yield information obtained from field trials and from farm statistics, and then used these to postulate on potential changes in crop production for the Atlantic region under a changed climate.

METHODOGY

Baseline climate and climate change scenarios

The baseline climate data used for this study was 30-year monthly mean of average daily maximum and minimum air temperature and total precipitation for the 1961-1990 period for available climate stations in the Atlantic region (Environment Canada, 1994). Mean values of each variable for each of the 12 months were interpolated to a grid of 500 arc seconds (approximately 10 to 15 km), using Digital Elevation Model (DEM) data and a thin plate smoothing spline surface fitting technique (Hutchinson, 1995). Interpolations were made using a software package called ANUSPLIN (Hutchinson, 2000). ANUSPLIN is a FORTRAN program that fits multi-dimensional thin plate smoothing splines to noisy multi-variate data. It should not be confused with simple uni-variate cubic splines. It has been used to develop spatially continuous climate "surfaces" to many regions in the world including Canada. For a full description of the mathematics underpinning ANUSPLIN see the references above. For recent Canadian applications see McKenney et al. (2001) or Price et al. (2000).

Climate change scenarios for temperature and precipitation for the periods 2010-2039 and 2040-2069 were based on the output of the first generation coupled Canadian General Circulation Model (CGCMI) (Boer et al., 2000). Results of the first of three ensembles that included the effect of aerosols were extracted from the IPCC Data Distribution Centre (1999) CD-Rom. Greenhouse gas (GHG) forcing corresponds to that observed from 1900 to 1996 and increases at a rate 1% per year thereafter until year 2100. In this scenario, the GHG forcing increase is equivalent to a doubling of CO_2 by around 2050 compared to the 1980s (Boer et al., 2000).

The Canadian GCM data is provided on a grid of 3.75° latitude by 3.75° longitude. The area of study and locations of GCM grid points are show in Fig. 1. The location of climate stations used to develop the gridded monthly averages for 1961-1990 are also shown. Mean

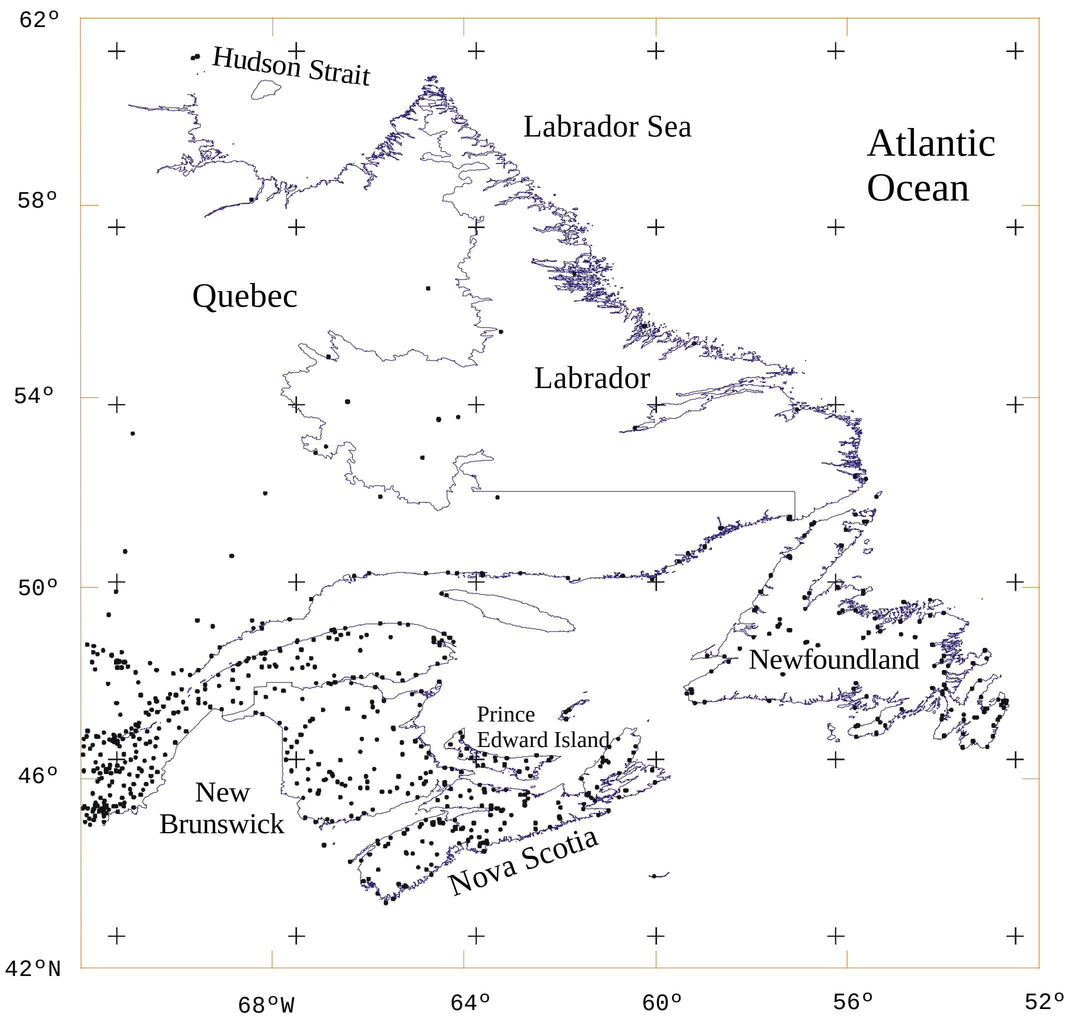


Figure 1. Location of climate stations and GCM grid points in study area.

monthly changes in temperature and in precipitation ratios for the two future time periods compared with 1961-1990 values for the coarse GCM grid were interpolated to the fine grid scale using the thin plate spline method of ANUSPLIN. After several trials of different model settings the interpolations were based on using X and Y (latitude and longitude) only with a fixed signal. The optimization directive was set to 0, so that a single smoothing parameter was set for all surfaces, which minimized the AVERAGE GCV (General Cross Validation statistic) over all 12 months. This enforced somewhat brute force stability between months and reduced the influence of individual data points on the overall surface. This was justified on the basis that: a) differences in temperature and in precipitation ratios were interpolated, not the absolute values of these variables; b) the GCM data is not developed with elevation dependencies and; c) the fixed signal ultimately resulted in a smoother result removing spurious bulleye effects. These changes were then applied to the gridded mean monthly maximum and minimum air temperature and precipitation data for the 1961-1990 period to construct gridded data for the two future time periods.

Calculation of agro-climatic indices

Calculations of Corn Heat Units (CHU), Growing Degree-Days (GDD), Effective Growing Degree-Days (EGDD) and Precipitation Deficits (DEFICIT) were made using the gridded monthly climatic normals for average daily maximum (T_{max}) and minimum (T_{min}) air temperature and total precipitation (P) as input data. All calculations were made using C^{++} programs compiled with a Watcom compiler. Initially, 365 daily average values of T_{max} and T_{min} were generated from monthly average values using the Brooks sine wave interpolation procedure (Brooks, 1943). Average daily values for P were generated by dividing the monthly value by the number of days in the month.

Average daily values of CHU were computed after Brown and Bootsma (1993), using the following formula:

$$Y_{max} = 3.33\,(T_{max} - 10.0) - 0.084\,(T_{max} - 10.0)^2 \qquad (\text{if } T_{max} < 10.0,\ Y_{max} = 0.0)$$
$$Y_{min} = 1.8\,(T_{min} - 4.44) \qquad (\text{if } T_{min} < 4.44,\ Y_{min} = 0.0)$$

where Y_{max} and Y_{min} are the contributions to CHU from average daily maximum (T_{max}) and minimum (T_{min}) air temperatures respectively.

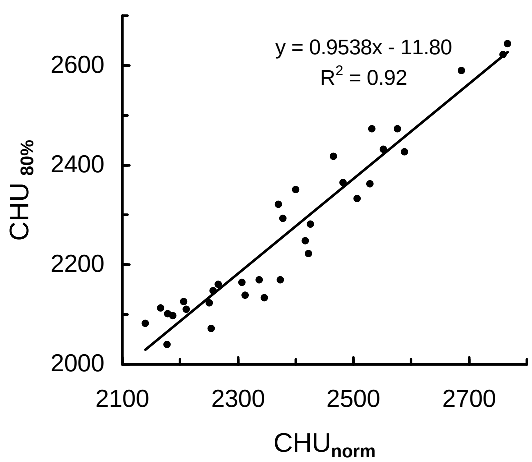
Then, $\quad \text{Average daily CHU} = (Y_{max} + Y_{min}) / 2.0$

Average daily CHU were accumulated from starting and stopping dates to obtain seasonal values (CHU_{norm}). Starting dates were based on the date when the average mean daily temperature (T_{mean}) was \$11.0°C in spring. This date corresponds closely to the average planting date for corn in the region (Bootsma, 1991). Stopping dates were based on the date when average mean daily minimum temperature was #5.8°C in the fall, which corresponds closely to the date of 10% probability of occurrence of killing frost (-2°C) in this region. Average accumulated CHU values computed from the normals data (CHU_{norm}) were adjusted to estimate average CHU (CHU_{ave}) and CHU values exceeded at 80% probability ($CHU_{80\%}$) computed from daily climate data by using regression-based algorithms. These algorithms were determined using values for CHU_{ave} and $CHU_{80\%}$ calculated from daily maximum and minimum air temperature data at 33 locations in a previous study for the Atlantic region (Bootsma, 1991) and were as follows:

$$CHU_{ave} = 185.2 + 0.93771*CHU_{norm} \qquad (R^2 = 0.94; \quad S.E.E. = 42.5)$$

$$CHU_{80\%} = -11.80 + 0.95382*CHU_{norm} \qquad (R^2 = 0.92; \quad S.E.E. = 49.1)$$

These relationships are graphically displayed in Figures 2a and 2b.



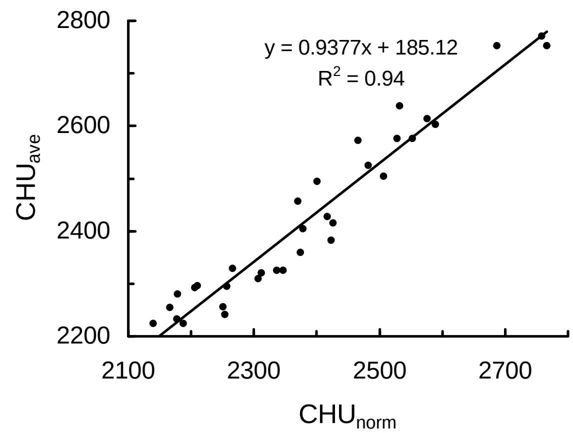


Figure 2a. Relationship between CHU_{norm} and CHU_{ave}

Figure 2b. Relationship between CHU_{norm} and $CHU_{80\%}$

It was assumed that these linear relationships could be extrapolated to higher CHU values under the climate change scenarios. This assumption seemed reasonable since similar relationships based on Ontario data continued to be linear for CHU values exceeding 3500 and since the scenarios used assume no change in variability in temperature (i.e. no change in the temporal distribution of CHU).

Average daily values of GDD > 5°C (GDD) were computed from interpolated mean daily air temperatures (T_{mean}) using the formula:

$$\text{Daily GDD} = T_{mean} - 5.0 \qquad \text{if } T_{mean} \text{ is} < 5.0, \text{GDD} = 0.0$$

Daily GDD values were summed from the time when T_{mean} first exceeded 5.0°C in spring until the last date of T_{mean} >5.0°C in fall. These starting and stopping dates for GDD are generally considered to coincide with the growing period for perennial forage crops (Chapman and Brown, 1978). Calculating GDD from mean daily air temperatures may involve some error in the spring and fall periods, since averages of daily temperatures include days when the temperature was below the base value. However, this procedure has been commonly accepted as being of sufficient accuracy (Chapman and Brown 1978).

Effective Growing Degree-Days (EGDD) were computed by summing GDD from 10 days after $T_{mean} \geq 5.0$°C in spring to the day before the average date of the first fall frost (0°C). These dates are more appropriate for the growing period of spring-seeded small grain cereals. An adjustment is made to compensate for increased effectiveness of GDD for cereal crops due to longer daylengths at northern latitudes. EGDD are used as a primary classifier in the suitability rating system for spring-seeded small grains (Agronomics Interpretations Working Group, 1995). Average fall frost dates were estimated from monthly temperature normals, station elevation and astronomical data as described by Sly et al. (1971). Daylength (N) and solar radiation at the top of the atmosphere (Q_o) were estimated from latitude and time of year using procedures described by Robertson and Russelo (1968). The daylength factor for computing EGDD from GDD was computed from latitude using a fitted regression equation to the graph in Appendix C in the land suitability rating system published by the Agronomics Interpretations Working Group (1995). Since this factor only begins to compensate at latitudes higher than 49°N, the three Maritime Provinces (New Brunswick, Nova Scotia and Prince Edward Island) are not affected by this adjustment.

The precipitation deficit (DEFICIT) was calculated by subtracting average daily precipitation (P) from potential evapotranspiration (PE) and accumulating values over the same period as EGDD. Latent evaporation (LE) (cm^3) was estimated from T_{max}, T_{min} and Q_o using Baier and Robertson (1965) Formula I and converted to PE (mm) by using the conversion factor of 0.086 (Baier, 1971).

Mapping of indices

Computed indices for each grid point were imported into a geographic information system software called ArcView GIS (ESRI, 1996) and overlaid on a base outline map of the Atlantic Provinces. ArcView files were converted into PC compatible formats for printing and inserting into documents. Three maps were generated for each index, one for the baseline climate (1961-1990) and two for future periods (2010-2039 and 2040-2069). Change in indices from the baseline period to the future scenarios were also computed and mapped. To demonstrate those areas where agriculture will be most affected by climate change, a map was prepared showing where significant areas of agricultural land is located in the region.

Assessing potential impact of changes on crop yields

To assess the potential impacts of crop yields and production in the Atlantic Provinces, data on average yields from corn, soybean and barley trials at various locations in Ontario, Quebec and the Atlantic region were assembled from various sources. Yield data from outside the Atlantic Provinces were included to obtain a broader range of climate regimes that might be more typical under the change scenarios. Provincial yield and production statistics were also assembled, to the county level where available. Crop yields were compared to agroclimatic indices computed for climate stations or grid points nearest to the trial locations, or values representative of each county or region in the case of provincial statistics. Linear regression analyses were used to quantify the relationship between crop yields and agroclimatic indices. These algorithms were used to approximate potential impacts of changes in the climate on crop yields and production in the Atlantic region.

a) Grain corn

For grain corn, annual yield averages for all hybrids tested were extracted from the annual reports on Ontario Hybrid Corn Performance Trials conducted by the Ontario Corn Committee or obtained directly from trial co-operators (Table 1) and then averaged for the 1990-2000 period. Hybrids included in the trials varied depending on the CHU zone in which trials were conducted. Hybrids also changed over time, as new ones were introduced and old ones dropped from the field trials. Average yields for location that had years with missing data were adjusted using yield data from neighbouring sites where possible. For the Maritime Provinces, average yields of check hybrids in grain corn trials were extracted from Corn Hybrid Testing Reports published by the Atlantic Corn Hybrid Evaluation Committee for the years 1991-1996

Table 1. Average yields of grain corn from corn hybrid trials conducted in eastern Canada and climate variables.

Location	Average Yield @ 15 to 15.5% moisture (t ha^{-1})	CHU	DEFICIT (mm)	Nearest Climate Station(s)
Ridgetown ON	12.0	3310	157.4	Ridgetown
Croton ON	11.3	3229	160.0	Dresden
Grande Pointe ON	11.7	3228	147.5	Dresden
Inwood ON	10.4	3190	157.7	Petrolia Town
Kerwood ON	10.5	3087	164.0	Strathroy
Ailsa Craig ON	9.6	3079	160.5	Ilderton Bear Creek
Ilderton ON	10.1	3079	153.0	Ilderton Bear Creek
Pakenham ON	9.5	2973	213.2	Chats Falls
Woodstock ON	10.1	2884	136.2	Woodstock
Cobden ON	8.1	2855	229.4	Chenaux
Winchester ON	9.7	2837	164.1	South Mountain
Elora ON	8.7	2670	139.8	Fergus Shand Dam; Glen Allan
Alma ON	7.3	2638	120.3	Fergus Shand Dam; Glen Allan; Arthur
Centreville NS	7.2	2668	93.5	Sheffield Mills
Woodside NS	7.6	2668	53.3	Sheffield Mills
Waterville NB	6.8	2556	71.9	Woodstock
Sussex NB	6.5	2457	64.8	Sussex
Nappan NS	6.0	2411	50.1	Nappan
Stewiacke NS	6.6	2385	31.0	Upper Stewiacke
Harrington PEI	4.6	2305	-7.1	Charlottetown A

<u>Notes:</u>
For Harrington, available CHU were reduced by 150 units as CHU are known to be less effective in maturing corn on PEI (Smith et al. 1982).
Average CHU available at Fergus Shand Dam and Glen Allan were used for Elora.
Average CHU available at Fergus Shand Dam, Glen Allan and Arthur were used for Alma.
DEFICIT values are based on nearests grid point.
Ontario yields were based on averages for all hybrids contained in trials.
Maritime yields were based on averages for check hybrids only.

<u>Acknowledgements for sources of yield data from hybrid trials:</u>
Byron Good, University of Guelph, Guelph, Ontario
Scott Jay, University of Guelph, Ridgetown College, Ridgetown, Ontario
Jeff Horn, Huron Research Station
Cheryl Wightman, University of Guelph, Kemptville College, Kemptville, Ontario

and by the Cultivar Evaluation Task Group for Forage and Corn for the years 1997 and 1999 (Table 1). In most years, there were six check hybrids grown at each location. Checks were the same at all trials in a given year, but could vary from year to year as new hybrids were introduced and old ones dropped. Yields were adjusted for missing years as in the Ontario data except for 1998, which was omitted, as data were not available from a large number of the locations. Average CHU and DEFICIT values were computed for the nearest climate station with the same methodology used to compute the indices from the gridded climate data, using 1961-1990 monthly climatic normals.

Statistics on grain corn yields and production from farms were obtained from Statistics Canada (Table 2). Yields were available on a county basis for Ontario. In the Maritimes, only provincial yields were available for Nova Scotia. Average CHU and DEFICIT values for each county in Ontario were estimated visually from published maps (Bootsma et al., 1992; Brown and Bootsma, 1993; Agronomics Interpretations Working Group, 1995). Values for Nova Scotia

Table 2. Average yields of grain corn from farm statistics and climate variables (Source: Statistics Canada, Field Crop Reporting Series 22-002-XPB).

Counties & Districts	Average Yield ($t\ ha^{-1}$) 1990-1999	Average CHU (1961-90)	DEFICIT (mm)
ONTARIO			
Brant	6.8	2900	200
Elgin	7.5	3050	200
Essex	7.4	3450	200
Haldimand-Norfolk	6.7	3025	200
Hamilton-Wentworth	6.5	3000	200
Kent	8.2	3300	200
Lambton	7.5	3100	200
Middlesex	7.8	2950	200
Niagara	6.1	3150	200
Oxford	7.7	2900	200
Bruce	6.7	2650	175
Dufferin	6.4	2450	150
Grey	6.3	2550	150
Halton	6.2	2825	200
Huron	7.4	2800	175
Peel	6.8	2750	200
Perth	7.7	2750	150
Simcoe	6.7	2650	225
Waterloo	6.8	2750	150
Wellington	6.6	2600	165
Durham	6.6	2825	220
Hastings	5.8	2800	240
Northumberland	6.1	2800	225
Peterborough	5.6	2725	240
Prince Edward	5.4	2950	200
Victoria	6.0	2700	225
York	6.1	2800	225
Dundas, Glengarry, Stormont	7.1	2800	200
Frontenac	6.0	2825	220
Grenville and Leeds	6.4	2775	220
Lanark	6.7	2625	250
Lennox & Addington	5.9	2875	200
Ottawa-Carleton	7.3	2725	225
Prescott and Russell	6.8	2700	210
Renfrew	5.9	2550	225
NOVA SCOTIA	5.3	2500	140

Table 3. Average yields of soybeans from variety trials conducted in eastern Canada and climate variables .

Location	1996-1999 Average Yield @15 to 15.5% moisture ($t\ ha^{-1}$)	CHU	DEFICIT (mm)
Malden ON	4.2	3532	128.6
Woodslee ON*	3.6	3369	133.9
Tilbury ON*	3.3	3369	143.8
Chatham ON	4.2	3310	152.2
Ridgetown ON	4.1	3310	157.4
Inwood ON*	3.1	3190	157.7
Dutton ON*	3.6	3062	145.1
Talbotville ON	3.8	2979	158.6
Ottawa ON	3.3	2939	183.7
Exeter ON	3.7	2933	144.2
Woodstock ON	3.3	2884	136.2
Winchester ON	3.3	2837	164.1
Brussels ON	2.8	2788	110.5
St. Pauls ON	3.6	2739	120.2
Elora ON	3.2	2670	139.8
Truro NS	3.2	2603	50.4
Woodstock NB	2.9	2556	71.9
Harrington PEI	2.2	2613	-7.1

Notes:
*These locations had clay soils and were excluded from the analyses.
Truro NSAC monthly temperature normals were adjusted to 1961-90 period before computing station CHU

Acknowledgements for sources of yield data from variety trials:
Ron Guillemette/Elroy Cober, Eastern Cereal and Oilseed Research Centre, Otttawa
John MacLead/Dave Grimmett, Agriculture and Agri-Food Canada Research Centre, Charlottetown, P.E.I.

Table 4. Average yields of soybeans from farm statistics and climate variables. (Source: Statistics Canada, Field Crop Reporting Series 22-002-XPB)

Counties & Districts	Average Yield ($t\ ha^{-1}$) 1996-1999	Average CHU (1961-90)	DEFICIT (mm)
ONTARIO			
Brant	2.27	2900	200
Elgin	2.69	3050	200
Essex	2.68	3450	200
Haldimand-Norfolk	2.20	3025	200
Hamilton-Wentworth	2.18	3000	200
Kent	2.90	3300	200
Lambton	2.82	3100	200
Middlesex	2.84	2950	200
Niagara	2.18	3150	200
Oxford	2.74	2900	200
Bruce	2.49	2650	175
Dufferin	2.31	2450	150
Grey	2.31	2550	150
Halton	2.20	2825	200
Huron	2.75	2800	175
Peel	2.41	2750	200
Perth	2.88	2750	150
Simcoe	2.51	2650	225
Waterloo	2.47	2750	150
Wellington	2.56	2600	165
Durham	2.45	2825	220
Hastings	2.43	2800	240
Northhumberland	2.38	2800	225
Peterborough	2.30	2725	240
Prince Edward	2.35	2950	200
Victoria	2.30	2700	225
York	2.26	2800	225
Dundas,Glengarry, Stormont	2.88	2800	200
Frontenac	2.38	2825	220
Grenville and Leeds	2.58	2775	220
Lanark	2.52	2625	250
Lennox & Addington	2.43	2875	200
Ottawa-Carleton	2.72	2725	225
Prescott and Russell	2.86	2750	210
Renfrew	2.03	2550	225
PEI*	2.22	2550	115

were estimated on the assumption that the statistics were based mostly on the Annapolis Valley region where most of the grain corn is produced. For Ontario, estimates were based on the portion of each county considered suitable for cultivated crops i.e. Class 1 to 3 on the Canada Land Inventory (CLI) (Environment Canada, 1972).

b) Soybeans

Soybean yield data were obtained for the year 1996-2000 from variety trials conducted in Ontario and in the Maritime provinces. Average yields for all varieties included in the trials were used. Yield averages were adjusted for years with missing data using neighbouring trials as was done for corn. Data were obtained from Ontario Soybean Variety Trials Reports conducted by the Ontario Oil & Protein Seed Crop Committee, from the Canadian Soybean Coop Registration Trial Reports published by Eastern Cereal and Oilseeds Research Centre, Agriculture and Agri-Food Canada, Ottawa, and from some trial co-operators (Table 3).

Statistics on farm level yields and production of soybeans are shown in Table 4. Yields were averaged for the 1996-1999 period. Ontario data were available at a county level, while only provincial data were available for Prince Edward Island in the Maritime Provinces. Average values for climate variables were obtained in a manner similar to that for corn for both the variety trials and the farm statistics.

c) Barley

Barley yields were obtained from field variety trials conducted at various locations in Ontario, Quebec and the Maritime Provinces. Results from these trials were available in a series of unpublished reports (Table 5). Averages were based on data from the years 1994-1999 for Ontario (1994-1998 for 6-row) and Quebec and for 1994-2000 for the Maritime Provinces. Data

Table 5. Average yields of barley from variety trials conducted in eastern Canada and climate variables.

Location	Trial*	Yield (t ha^{-1})		EGDD	EGDD/GSL	DEFICIT	GSL
		2-row	6-row				
ONTARIO							
Nairn/Alsa Craig	A	3.1	3.5	2015	11.45	160.5	176
Woodstock	A	3.6	4.7	1933	11.31	133.9	171
Winthrop	A	3.9	4.5	1874	10.83	117.7	173
Ottawa	R	3.6	4.3	1788	11.54	188.0	155
Ottawa	A	3.9	4.3	1788	11.54	188.0	155
Elora	A	4.4	4.7	1719	10.54	139.8	163
Harriston/Palmerston	A	4.2	4.4	1702	10.38	106.3	164
Emo	E		5.7	1506	10.60	151.1	142
New Liskeard	R	4.4	5.8	1350	10.15	135.8	133
New Liskeard	E		6.0	1350	10.15	135.8	133
Thunder Bay	E		5.7	1163	9.30	141.5	125
Kapuskasing	R	3.8	4.5	1115	9.45	124.7	118
Kapuskasing	E		4.6	1115	9.45	124.7	118
QUEBEC							
St-Anne-de-Bellevue	R	4.6	4.5	1932	11.85	115.6	163
Ste-Rosalie	R	4.9	5.8	1832	11.45	68.4	160
Ste-Simone	R	4.1	5.0	1814	11.48	93.5	158
Deschambault	R	4.2	5.3	1577	10.88	42.8	145
Pintendre	R	3.1	3.4	1576	10.72	-38.9	147
LaPocatiere	R	5.0	6.2	1337	9.83	40.2	136
Normandin	R	5.3	6.2	1245	9.80	99.1	127
MARITIME PROVINCES							
Charlottetown PEI	R	3.8	4.2	1563	10.02	15.6	156
Nappan NS	R	4.2	5.4	1498	9.98	50.1	150
Hartland NB	R	4.3	5.0	1443	10.38	74.4	139
Average for Maritimes:		4.1	4.9	1501	10.13	46.7	148

Yields were adjusted for years with no data when possible, and may be averages from more than one trial at a location. Barley trial reports were kindly provided by Drs. T.M. Choo and K.M. Ho, Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa.

* R = Registration trials, 1994-1999 averages, except 1994-1998 period for 6-row barley in Ontario and 1994-2000 period for Maritimes; A = Advanced and screening trials, 1994-99 averages; E = Early trials, 6-row barley only, 1994-99 averages.

were not available for all years for some locations, and in these cases averages were adjusted based on comparisons with neighbouring trials were possible. Yields were averaged for two to three check varieties in each trial. Check varieties sometimes changed over time but were consistent for all trials conducted in a region. Yields for 2-row and 6-row barley varieties were determined separately, as significant differences in yield could be expected (Jui, et al. 1997). Yields were compared with average climate variables for the 1961-1990 period for the grid point nearest to each trial's approximate location, as computed from gridded monthly climate normals in this study. The climate variables selected for comparison were EGDD, DEFICIT, and EGDD/day (REGDD) over the growing season length (GSL), where GSL is the number of days over which the EGDD were accumulated.

Statistics on barley yields were obtained from Statistics Canada on a county basis for Ontario and for the whole province for each of the Maritime Provinces (Table 6). In this case, no distinction could be made between 2-row and 6-row barley. Average yields for the 1990-1999 period were compared to average climate variables (EGDD, DEFICIT) estimated from maps

Table 6. Average yields of barley from farm statistics and climate variables. (Source: Statistics Canada, Field Crop Reporting Series 22-002-XPB).

Counties & Districts	Average yield ($t\ ha^{-1}$) 1990-1999	EGDD	DEFICIT (mm)
ONTARIO			
Brant	3.0	1850	200
Elgin	3.1	2100	200
Essex	3.1	2250	200
Haldimand-Norfolk	2.6	1950	200
Hamilton-Wentworth	3.0	1900	200
Kent	2.9	2200	200
Lambton	3.1	2150	200
Middlesex	3.3	2000	200
Niagara	2.3	2100	200
Oxford	3.5	1850	200
Bruce	3.3	1725	175
Dufferin	3.4	1450	150
Grey	3.1	1575	150
Halton	3.2	1800	200
Huron	3.5	1950	175
Peel	3.3	1750	200
Perth	3.5	1700	150
Simcoe	3.2	1700	225
Waterloo	3.3	1725	150
Wellington	3.4	1650	165
Durham	3.3	1800	220
Hastings	2.9	1850	240
Northumberland	2.9	1900	225
Peterborough	2.9	1750	240
Prince Edward	2.7	2050	200
Victoria	3.1	1700	225
York	3.1	1800	225
Dundas, Glengarry, Stormont	3.2	1850	200
Frontenac	2.8	1900	220
Grenville and Leeds	2.9	1900	220
Lanark	3.1	1600	250
Lennox and Addington	3.0	1950	200
Ottawa-Carleton	3.3	1700	225
Prescott and Russell	3.2	1700	210
Renfrew	3.1	1750	225
Algoma	2.8	1400	150
Cochrane	3.0	1100	125
Kenora	2.6	1300	150
Manitoulin	3.3	1450	150
Nipissing	3.1	1300	175
Rainy River	2.9	1300	150
Sudbury	3.0	1200	150
Thunder Bay	3.5	1200	130
Timiskaming	3.4	1300	150
MARITIMES			
NEW BRUNSWICK	3.0	1450	125
NOVA SCOTIA	3.0	1450	135
PEI	3.1	1500	120

provided by the land suitability rating system for small grain cereals in Canada (Agronomics Interpretations Working Group, 1995). The CLI ratings were used again to establish approximate extent of soils suitable for cultivated crops in each province/county for which the climate variables were estimated.

RESULTS AND DISCUSSION

Climate change scenarios

Monthly changes in temperature and precipitation projected by the Canadian GCM for the grid points used in this study (Figure 1) are summarized in Appendix 1. Change in monthly mean maximum (T_{max}) and minimum (T_{min}) air temperatures were greatest for the 2040-2069 period. Changes for T_{max} ranged from an increase of 5.5°C in March in northern Quebec to a decrease of -6.3°C in May off the Labrador coast. Changes in T_{min} were even greater, ranging from an increase of 8.1°C in February to a decrease of -6.4°C in May. In general, greatest temperature increases occurred over the northern part of Quebec and Labrador over land. Largest decreases in temperature were generally off the Labrador coast in the Labrador sea, between 53.8 and 57.5°N. Temperature changes averaged over all GCM grid points and months were 1.3 and 1.6°C for T_{max} and T_{min} respectively for the 2040-2069 period. For the 2010-2039 period, these averages were 0.8 and 1.0°C, respectively. Increases in temperature were generally largest in the December to April period, partly due to a positive feedback with albedo as snow cover is reduced (F. Zwiers, Canadian Centre for Climate Modelling and Analysis, personal communications). Negative temperature changes tended to be greatest during the period from April to August.

Changes in precipitation were generally small, i.e. the ratio (average monthly precipitation for the future scenario divided by the value for baseline period) was frequently close to 1. Average ratios for all grid points and months were 1.0 (no change) for the 2010-2039 period and 1.04 for the 2040-2069 period. Ratios were highest at most northerly grid points in September (1.4) for both periods. Lowest ratios were in August (0.67) for the 2010-2039 period over the New England states and in February (0.74) for the 2030-2069 period north of Labrador in the Hudson Strait. For both periods ratios were predominantly low at 42.7°N over the Atlantic Ocean and New England states.

Impacts of climate change scenarios on agroclimatic indices

A map outlining major areas of agricultural production in the Atlantic Provinces that are most likely to be affected by climate change is shown in Figure 3. The map is based on all Soil Landscape Polygons (Agriculture and Agri-Food Canada, 1994) which had at least 2.5% of the land area (1% in Newfoundland and Labrador) under cultivated crops or improved pasture, based on 1996 Census data.

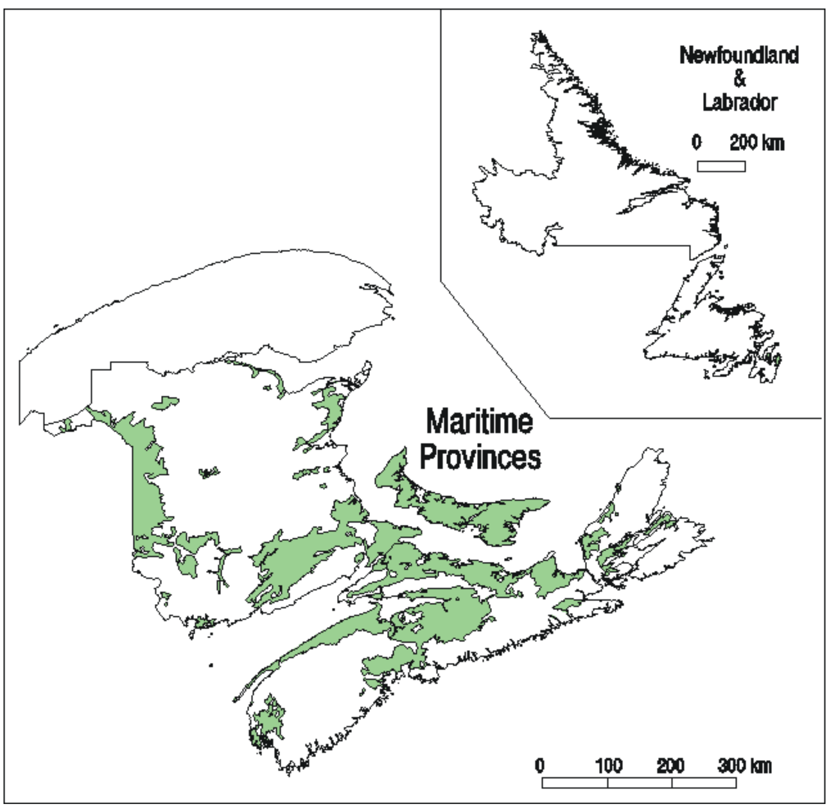


Figure 3. Areas in Atlantic region with soil landscape polygons with at least 2.5%of land areas (1% in Newfoundland and Labrador) under cultivated crops or improved pasture. (based on 1996 Census data)

The impacts of the climate change scenario on CHU for the Atlantic Provinces are shown in Figures 4 to 6. Average CHU for the baseline climate are typically in the 2400-2600 CHU range in the main agricultural areas of the Maritime Provinces (Fig. 4). These increase to the 2600-3000 range for the 2010-2039 period, and to the 3000-3200 CHU range for 2040-2069. The increases are in the 300-500 and 500-700 CHU category, respectively, for the two future time periods (Fig. 5). Only the eastern tip of Labrador indicated a significant decrease in CHU. A similar pattern for CHU available at the 80% probability level is shown in Fig. 6, although values are typically about one

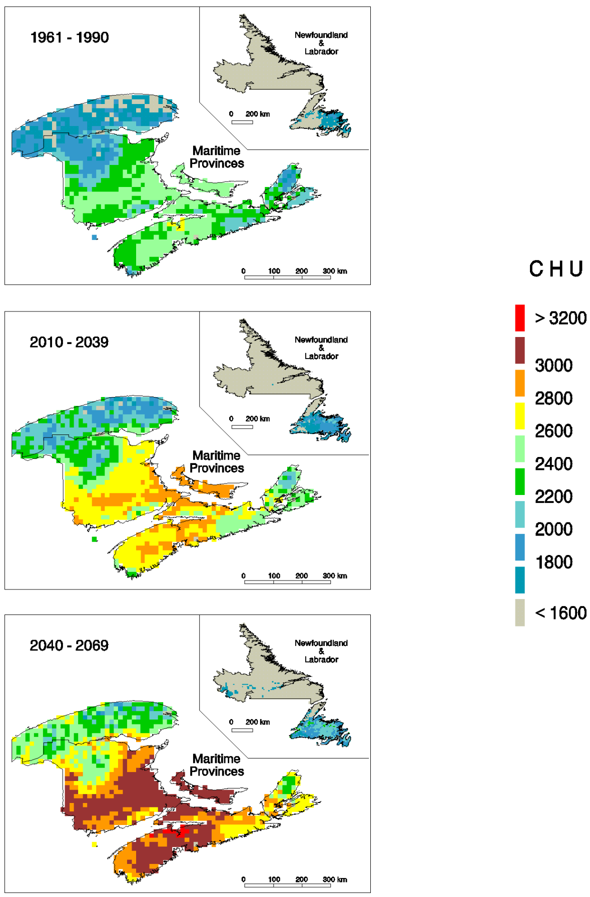


Figure 4. Average Crop Heat Units (CHU) for baseline period (1961-1990) and two future time

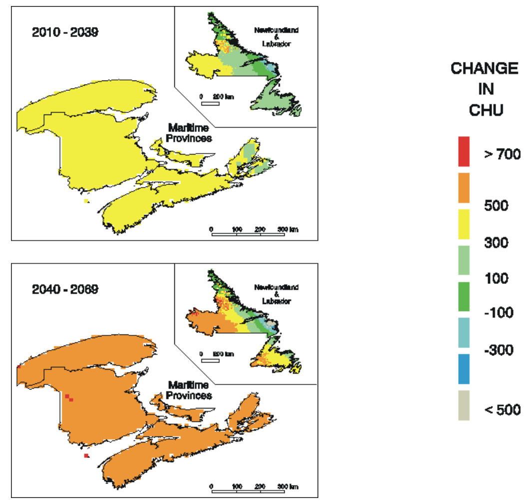


Figure 5. Change in CHU for two future time periods compared to 1961-1990 baseline period.

class interval lower. Previous work has shown that CHU at 80% probability are typically 150 units lower than the average CHU value for the Maritime provinces (Bootsma et al. 1992). Differences between the baseline and future periods for CHU at 80% are similar to differences for average CHU in Fig. 5, since the climate change scenarios assumed no change in variability.

Patterns for changes in GDD and EGDD (Figures 7 to 9) were very similar to each other and to the pattern of change for CHU. Absolute values for EGDD (Fig. 7) are lower than GDD (Fig. 8) by about 100 degree-days, mainly due to later starting dates and earlier stopping dates for accumulating EGDD. GDD are designed to represent the growth period for perennial forage crops (Chapman and Brown 1978), while EGDD are specifically designed to be more applicable to the growth period for spring-seeded small grain cereals (Agronomics Interpretations Working Group 1995). EGDD typically increase by 200-300 units for the 2010-2039 period and over 400 units for the 2040-2069 period in the main agricultural regions of the Maritime provinces (Fig. 9). Only the eastern part of Labrador indicated a decrease in EGDD. Changes in GDD were almost identical and hence are not shown.

Water deficits (PE-P) for the baseline period varied from over 100 mm in central New Brunswick to a surplus (negative value) in excess of 100 mm in the more humid regions such as south-western tip of Nova Scotia, Cape Breton Island and south-eastern parts of Newfoundland and Labrador (Fig. 10). Patterns for deficits/surpluses remained very similar for the future time periods. Greatest increases in deficits were in New Brunswick, with a large region in the interior

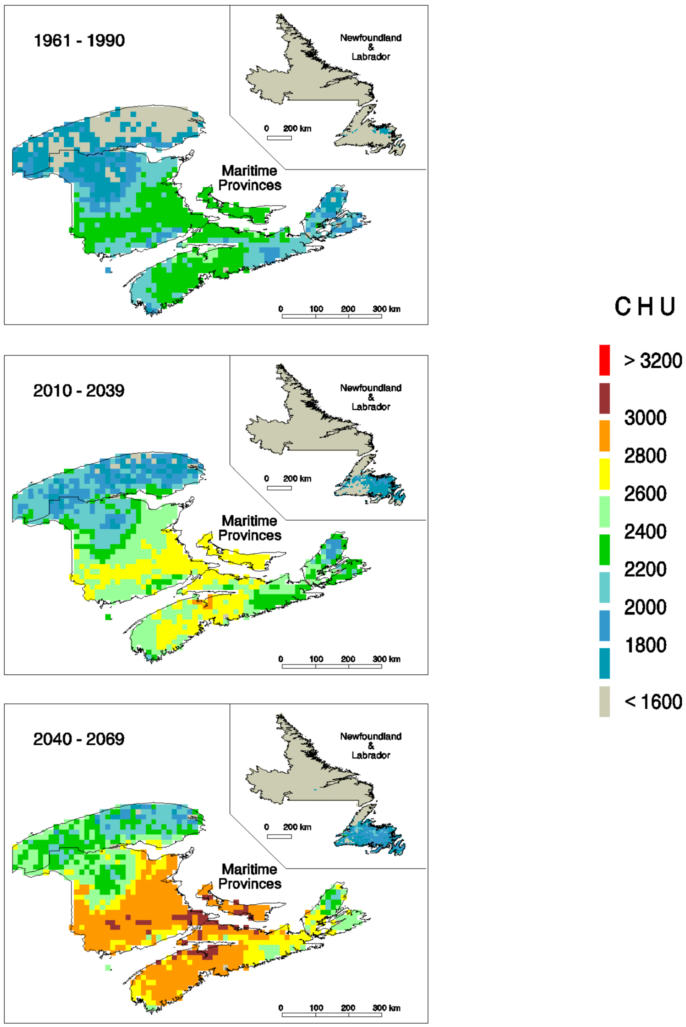


Figure 6. Crop Heat Units (CHU) at 80% probability for baseline period (1961-1990) and two future time periods.

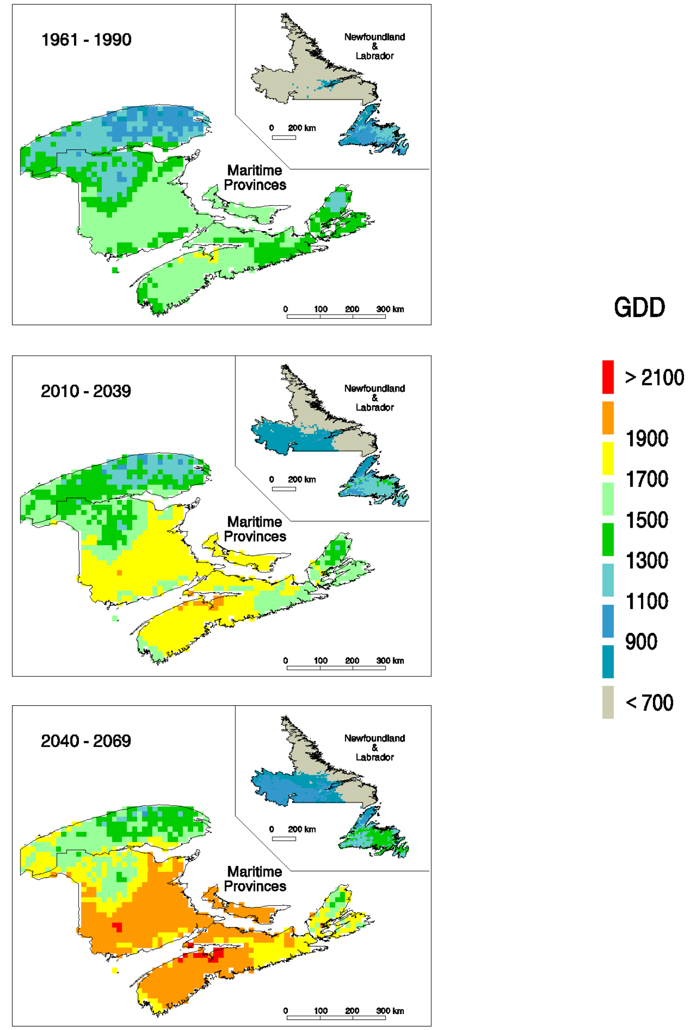


Figure 7. Average Growing Degree-Days above 5EC (GCC) for baseline period (1961-1990) and two future time periods.

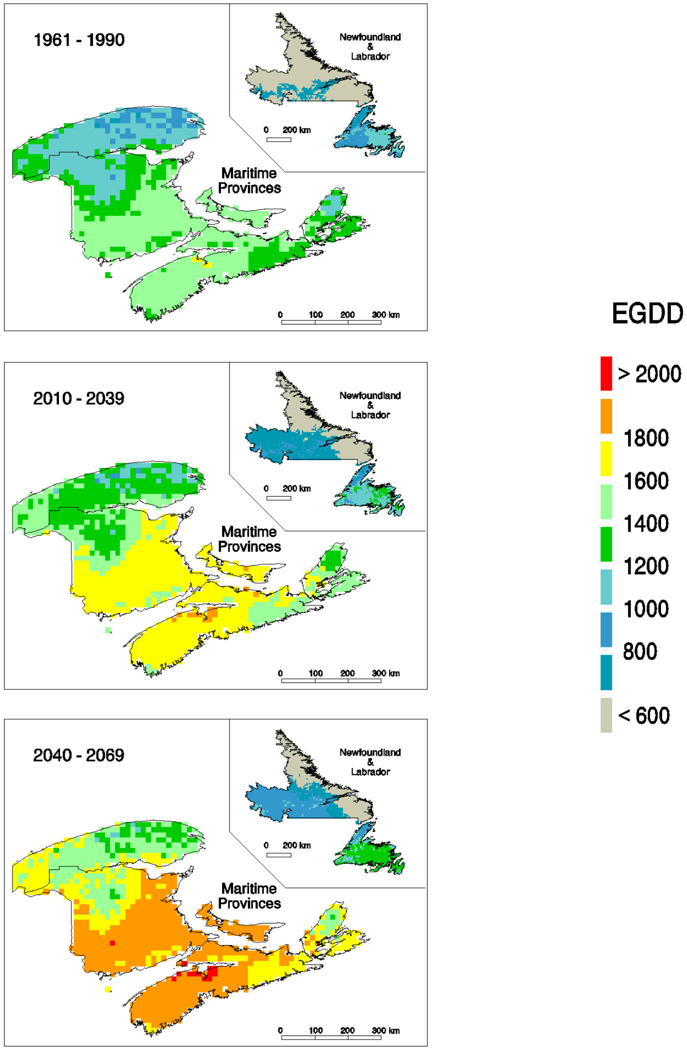


Figure 8. Average Effective Growing Degree-Days (EGDD) for baseline period (1961-1990) and two future time periods.

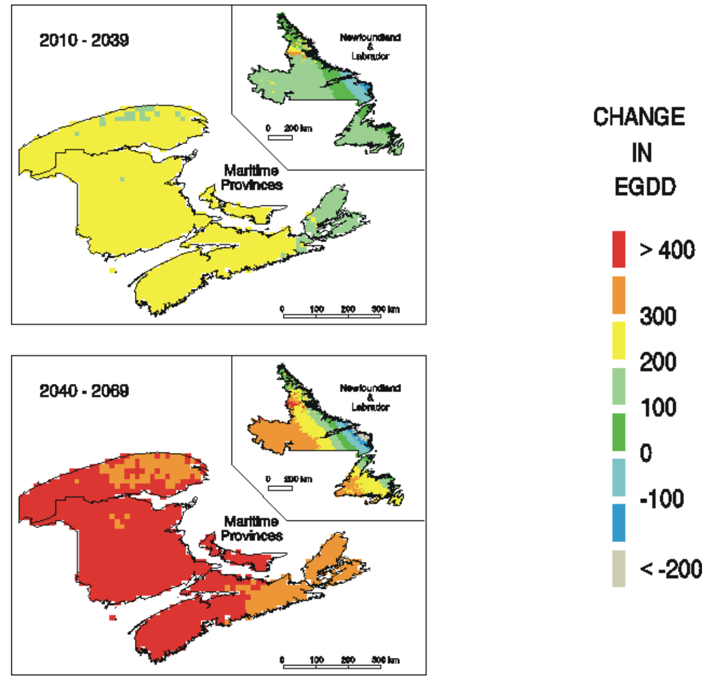


Figure 9. Change in Effective Growing Degree-Days (EGDD) for two future time periods compared to 1961-1990 baseline period.

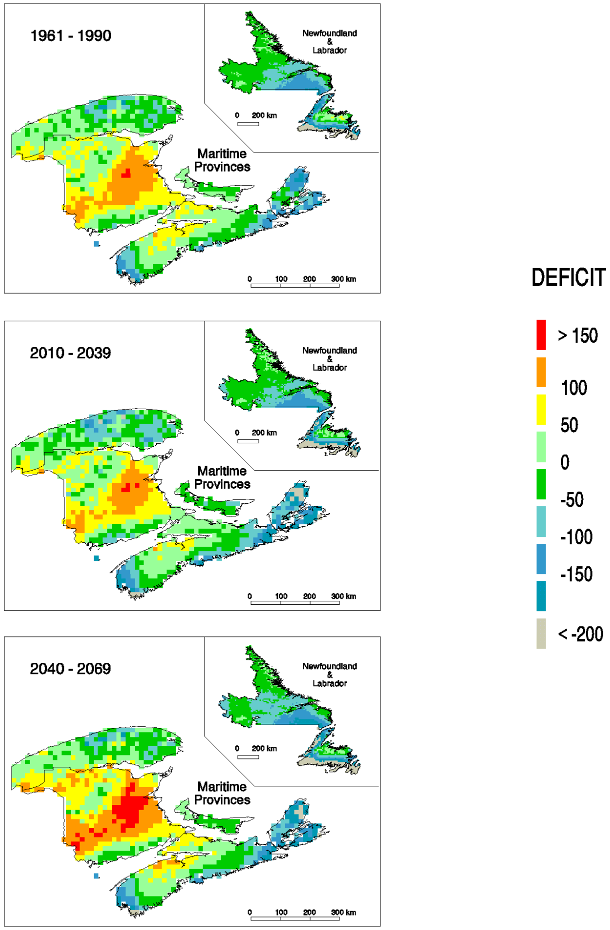


Figure 10. Average water deficits (mm) for baseline period (1961-1990) and two future time periods.

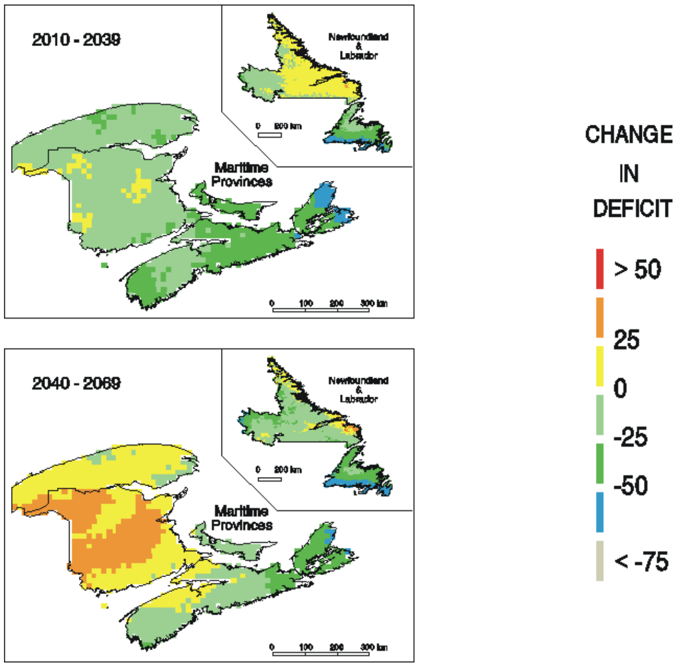


Figure 11. Change in water deficits (mm) for two future time periods compared to 1961-1990 baseline period.

indicating increases in the 25-50 mm class for the 2040-2069 period (Fig. 11). In areas of eastern Nova Scotia and much of Newfoundland water surpluses increased by 25-50 mm for this time period. Slight to moderate increases in surpluses were evident for much of the Maritime Provinces and Newfoundland for the 2010-2039 period. A slight increase in deficits in most of Labrador for 2010-2039 was mostly reversed in the 2040-2069 period (Fig. 11).

Potential impact of change scenarios on crop production

a) Grain corn

The relationship between average grain corn yields from hybrid trials and average CHU is shown in Figure 12. Yields tend to increase linearly with available CHU. A linear regression line fitted to the data had an R^2 of 0.92 (P<0.001) and a slope of 0.0064 t ha^{-1} CHU^{-1}, suggesting that with each increase of 100 CHU, grain corn yields could potentially increase by 0.64 t ha^{-1}. Applying these changes to the scenarios developed in this study indicates that yields could increases by 2.56 t ha^{-1} by the year 2025 and 3.8 t ha^{-1} by 2055, assuming an increase of 400 and 600 CHU, respectively, as indicated in Figure 4. The time frame is based on the assumption that the average increases in yield will be reached mid-way through the 30-year period. Assuming an average yield of about 6.5 t ha^{-1}under present climates, these represent increases of about 37% and 58%, respectively.

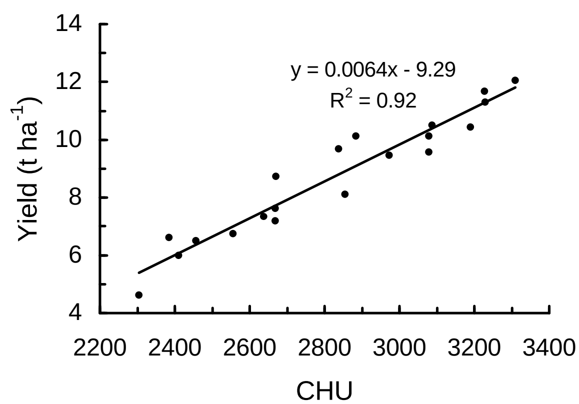


Figure 12. Relationship between grain corn yields from hybrid trials and CHU.

The relationship between corn yield and available CHU is largely due to the fact that longer season hybrids that have higher yields can be grown in the higher CHU areas. These hybrids are able to take full advantage of the longer and warmer growing season in these areas. Not only do longer seasons allow for more time for the corn plant to accumulate dry matter, but accumulations proceed at a faster rate in the higher CHU areas where temperatures are closer to the optimum for growth and development, which is near 30°C (Yan and Hunt, 1999). As the climate of the Atlantic region warms, producers should be readily able to switch to the longer season hybrids that are already being grown in the higher CHU areas of southern Ontario.

The potential increases in yield are due only to increasing temperatures and do not include the direct effect of elevated atmospheric CO_2 concentrations on yield, nor any increases that may be achieved through breeding or improved technology. They also do not include consideration of potential change of the impacts of weeds, insects and diseases on yield under a changed climate. Since corn is a C_4 plant, the direct effect of elevated CO_2 on photosynthesis is not expected to be large (Warrick, 1988). Elevated CO_2 may reduce transpiration in corn and thereby increase water use efficiency. However, this will not likely have a large effect on corn yields in the Atlantic region. This is supported by the fact that when we added DEFICIT as an independent variable in addition to CHU, the explained variance in corn yields was not improved significantly (P>0.10). While there may be occasional years in which water stress affects corn yields significantly in eastern Canada, in our data it does not appear to be a major factor that influences average yields under existing climate. Since average DEFICIT values projected for the future time periods (Fig. 10) are no larger than the range used in the analyses of present-day climate, increased water stress based on our scenarios is not likely to influence average corn yields significantly in the Atlantic region. This conclusion may not hold true, however, if the corn is grown on shallow soil with abnormally low water-holding capacity.

The potential increases in grain corn yield shown in Figure 12 may not necessarily be realized at the farm level. Figure 13 indicates that the correlation and slope of regression line for grain corn yields obtained from Statistics Canada surveys and CHU are considerably lower than for the yield data from hybrid trials. In this case, the R^2 using only CHU as an independent variable is 0.19 (P<0.01) and the slope is 0.0015 t ha^{-1} CHU^{-1}, indicating an increase of 0.15 t ha^{-1} for each increase of 100 CHU. When DEFICIT was included as a second independent variable in regression the R^2 increased to 0.24, although this was not statistically significant (P>0.10). Nevertheless, the increased importance of DEFICIT as a variable in explaining variation in farm yields compared to trial yields may be an indication that farm level yields are more sensitive to moisture stress.

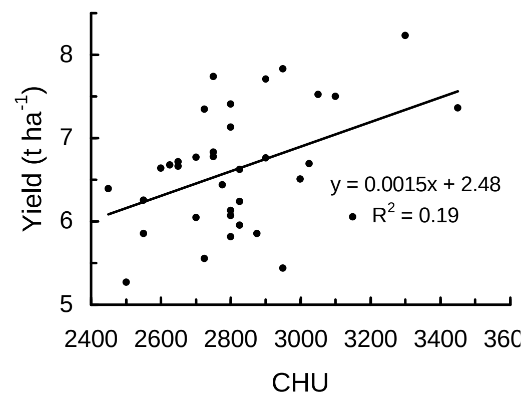


Figure 13. Relationship between grain corn yields from farm statistics and CHU.

Reasons may be speculated for the lower correlation and lesser response of farm yields to CHU. Provincial and county level yield figures are generally derived from probability surveys, and accuracy of the estimates may suffer in areas where there is relatively little farming activity. The estimates of climate variables from maps are also less reliable than the values derived for specific location near field trials. These factors add variability to the data and may be partly responsible for lower R^2 values and greater uncertainty of the slope. Farm data may include corn grown under management and soil conditions that are less than ideal for corn production, thus adding to the variability. Field trials are usually located on the better soils and conducted so that management factors such as planting and harvesting dates and fertility may be less limiting. Producers may also experience harvest losses that are not included in hybrid trial results. Comparison of Figures 12 and 13 suggest that producers in some of the high CHU areas of southern Ontario, such as Essex County, in particular are not able to fully tap the climatic potential for growing corn, possibly due to sub-optimal fertility or soil conditions.

Our results are somewhat different from results obtained when the EPIC model (Williams et al., 1989; Williams, 1995) was used to simulate the yield response of grain corn to a $2xCO_2$ climate scenario (De Jong, personal communications). When nitrogen (N) stress was eliminated from both the baseline and the $2xCO_2$ simulations, simulated corn yields increased by 10, 2 and 37% respectively at Fredericton, Kentville and Charlottetown. The relatively low yield increases at Fredericton and Kentville were most likely due to increased simulated moisture stress (no moisture stress was simulated at Charlottetown). However, it should be noted that EPIC yields *de*creased by up to 10% under the $2xCO_2$ scenario when current recommended fertilizer practices were used. The complex and dynamic interactions between water and N stress as they occur in the field are not necessarily correctly captured within the EPIC model, nor in the simple regression equation relating average yields to average CHU's.

Statistics on grain corn production in the Atlantic region were only available for Nova Scotia. Statistics Canada reports (Field Crop Reporting Series 22-002-XPB) indicate that from 1995-1998, a yearly average of 2,327 hectares of grain corn were harvested in Nova Scotia, with an average yield of 5.6 t ha^{-1}, total production of about 13,000 tonnes per year and farm value of $2.4 million per year. Production in the other provinces was too small to report. We could assume, however, that an additional 500 hectares or more are grown in the other provinces. It seems realistic to assume that average yields of 7 t ha^{-1} could be achieved by the year 2050, when CHU could typically exceed the 3000 value (Fig. 4). In the 1996 census year, Statistics Canada reported well over 100,000 hectares of land seeded to small grain cereals (wheat, oats, barley, mixed grain, etc.) and silage corn. It is not unreasonable to assume that at least 50% of this area would switch to corn and soybeans as these crops become more economically advantageous under a warmer climate. Furthermore, if we assume about a 60/40 split between corn and soybeans, this would project a production of over 210,000 tonnes of grain corn from over 30,000 hectares with a farm value of over $39 million by the year 2050.

b) Soybeans

The relationship between average yields from soybean variety trials in eastern Canada and CHU is shown in Figure 14. Yields from trials on clay soils in southern Ontario were not included in the analyses, since these trials tended to yield lower than those on clay loam soils in the same area (Table 3). Although yields tended to increase linearly with CHU, the yield response to CHU was considerably lower than for corn. A linear regression line fitted to the data had an R^2 of 0.69 (P<0.001) and a slope of 0.0016 t ha^{-1} CHU^{-1}. These results suggest that for each increase of 100 CHU, soybean yields could potentially increase by 0.16 t ha^{-1}. Applying this to our scenario indicates yield increases of about 0.64 and 0.96 t ha^{-1} by the years 2025 and 2055, respectively. These represent increases of about 21 and 32%, respectively, if we assume a present average yield of about 3 t ha^{-1}. The projected yield increases in soybeans are consistent with simulations using the EPIC model (De Jong, personal communications). Using EPIC, average

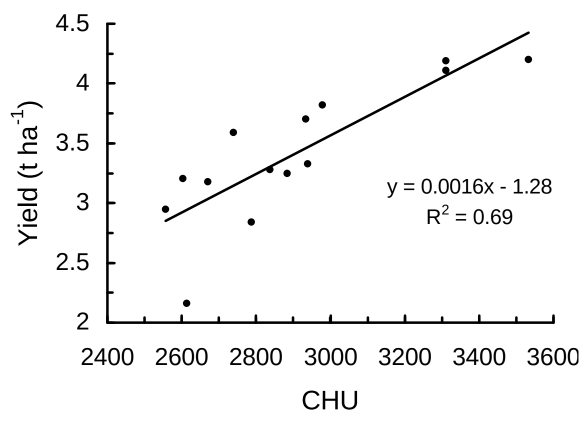


Figure 14. Relationship between soybean yields from variety trials and CHU.

simulated soybean yields for a $2xCO_2$ scenario for Fredericton, Kentville and Charlottetown increased from 2.3 to 3.2 t ha^{-1}, or an increase of about 40%. This included the direct effect of increased CO_2 concentration on yield. When EPIC was run with 1965-1990 baseline data at these same locations with double CO_2 concentration, simulated soybean yields increased an average of 22%.

The direct effects of elevated CO_2 on soybean yields are likely to be greater than for corn. Soybeans are plants with the C_3 photosynthetic pathway, and higher CO_2 concentrations directly increase the rate in which carbon is fixed and reduce the rate of photorespiration. According to Warrick (1988), doubling of atmospheric CO_2 concentrations could increase yield of major C_3 crops by 10-50%. Heagle et al. (1998) reported an increase in soybean yield of 16% for $2xCO_2$ concentration at slightly elevated ozone levels. While transpiration per unit leaf area may be reduced at higher CO_2 (Dugas et al. 1997), other evidence suggests that, when the effect of increased biomass at elevated CO_2 concentrations is taken into consideration, there is likely to be little change in crop transpiration (Carlson and Bunce, 1996). In our analyses, adding DEFICIT as a second independent variable in regression in addition to CHU did not improve the explained variance of trial yields significantly (P>0.10), suggesting no trend of lower yields at higher DEFICIT values. We conclude that changes in water status due to either direct or indirect effect of CO_2 are not likely to impact average soybean yields significantly under our climate change scenarios. It is probably reasonable to assume that the direct effect of double CO_2 concentrations on photosynthesis and respiration could increase yields by 15-20%.

As in the case for corn, the potential increase in soybean yields based on variety trial data may not be fully realized at the farm level. Both the correlation and regression coefficients for soybean yields at county/province level regressed on CHU were much lower than for the analyses based on yields from variety trials (Figure 15). In this case, the R^2 was only 0.08 (significant at P=0.09) and the regression coefficient was 0.00033, indicating an increase of only 0.033 t ha^{-1} for each increase of 100 CHU. Some of the reasons for the low response to CHU using farm yield statistics are similar to those given for corn. Lower yield response of soybeans to higher CHU values compared to corn may be due to the fact that optimum temperatures for growth and development of soybeans are significantly lower than for corn. The optimum temperature for growth and development of corn is near 30°C (Yan and Hunt, 1999). There are indications that the optimum temperature for soybeans is somewhat lower (Raper and Kramer, 1987). Flowers and pods may be reduced in soybeans grown at temperatures approaching 30°C (Thomas and Raper, 1977). Consequently, corn yields will likely respond more favourably to climate warming in eastern Canada. As in the case for corn, producers should be readily able to switch to longer season varieties already available in higher CHU areas as the climate warms.

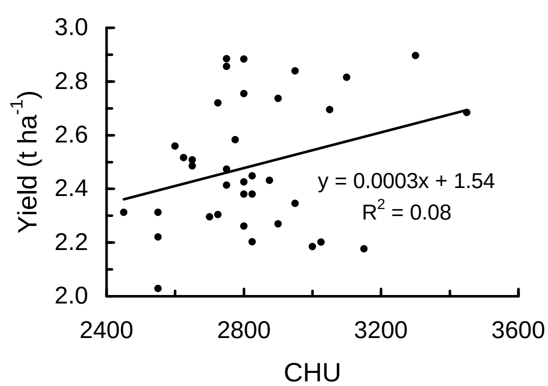


Figure 15. Relationship between soybean yields from farm statistics and CHU.

Statistics on soybean production in the Atlantic region were only available from Prince Edward Island. In the 1990's, soybean acreage averaged around 3500 ha, and yielded about 2.3 t ha^{-1} for a total farm value of about $2 million. It is probably realistic to assume about 0.7 t ha^{-1} yield increase in soybeans by the year 2050, due to both direct and indirect effects of increased GHG's. This is about 50% of the yield increase we projected for corn. Nevertheless, with warmer climate, substantial increase in area seeded to soybeans may still be expected, as it will likely gain competitive advantage over small grain cereals and forage crops. Soybeans would likely remain competitive with corn due to lower production costs, high level of protein content and considerably higher return in $ per tonne. The 1995-1998 average prices for corn and soybeans in Ontario were about $149 and $327 per tonne, respectively. Average price for soybeans for Prince Edward Island for that period was about $325 per tonne. If we assume 20,000 hectares under soybean production by the year 2055 with an average yield of 3.0 t ha^{-1}, total production would be around 60,000 tonnes for a farm value of around $20 million.

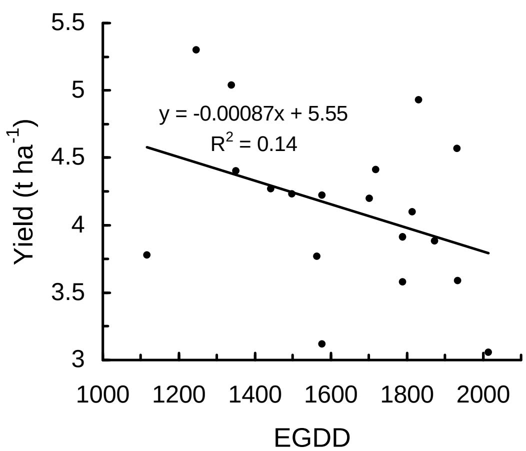


Figure 16. Relationship between 2-row barley yields from variety trials and EGDD.

c) Barley

Relationships between yields and climate variables were relatively weak for both 2-row and 6-row barley (Fig. 16 and 17). Correlations between yield and EGDD were negative, i.e. there was a tendency for lower yields at higher EGDD values. This may be due in part to the fact that warmer climates tend to hasten development, thus reducing the time available for assimilation of dry matter. Results of regression analyses of yield versus climate variables are summarized in Table 7. Only the 6-row barley relationship with EGDD was statistically significant (R^2=0.24, P=0.02). However, this R^2 was considerably lower than the values determined for corn and soybeans. Relationships with DEFICIT and REGDD were not statistically significant (P>0.05). Also, adding REGDD as a second independent variable in addition to EGDD did not improve the R^2 significantly (P>0.10). We conclude that, because of the weak relationship between yield and climate, climate change (warming) will have considerably less impact on average yields of barley than of corn and soybeans. Overall, the 6-row barley yields exceeded those of 2-row barley by about 0.7 t ha^{-1}. There was a significant tendency (P=0.05) for yield differences to be less in the warmer (higher EGDD) areas (Fig. 18, Table 5). This may be partly due to the fact that 6-row barley is more susceptible to powdery mildew, fusarium head blight and drought than 2-row barley (T.M. Choo, personal communication).

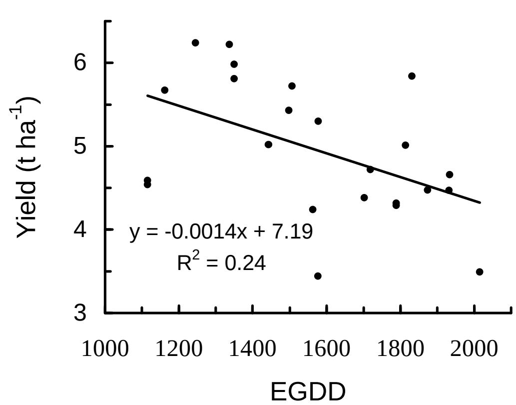


Figure 17. Relationship between 6-row barley from variety trials and EGDD.

Table 7. Results of regression analyses of barley yields with climate variables.

Dependent variable	Independent variable(s)	Regression constant	Regression coefficient(s)	Standard error(s) of coefficient	R2	S.E.E.	N	P-level
2-row barley yield	EGDD	5.55	-0.00087	0.00052	0.14	0.57	19	0.12
	DEFICIT	4.22	-0.00096	0.00245	0.01	0.61	19	0.70
	REGDD	6.63	-0.23343	0.19018	0.08	0.59	19	0.24
6-row barley yield	EGDD	7.19	-0.00142	0.00056	0.24	0.72	23	0.02
	DEFICIT	4.96	-0.00007	0.00318	0.00	0.83	23	0.98
	REGDD	9.29	-0.41063	0.21137	0.15	0.76	23	0.07
	EGDD +	4.87	-0.00232	0.00139	0.26	0.73	23	0.05
	REGDD		0.35304	0.50062				
DEFICIT	EGDD	60.55	0.02804	0.04337	0.02	56.15	23	0.52

If we assume an average increase of about 400 EGDD by the year 2055 (Fig. 9), and use the regression coefficients from Table 7, we conclude that yields of 6-row and 2-row barley grown in the Atlantic region could potentially decrease by about 570 and 348 kg ha^{-1}, respectively as of the result of a warmer climate. These yield reductions are about 12 and 8% of present yields of around 4.9 and 4.1 t ha^{-1}, respectively. At present, average yields of 6-row barley at the three locations from the Maritime Provinces exceed 2-row barley by about 0.8 t ha^{-1} (Table 5). This difference may be expected to reduce to 0.5 t ha^{-1} by the year 2055. Yield decreases will likely be due to increase in diseases, reduced net carbon dioxide exchange (Ormrod, 1967) and a more rapid development rate (shorter growing period) at higher temperatures, and not because of higher water deficits. At present, barley grown in northern areas of Ontario and Quebec produces higher yields than in more southern areas (Table 5). Diseases such as powdery mildew, leaf rusts, barley yellow dwarf virus and fusarium head blight are more common in southern Ontario than elsewhere in eastern Canada (T.M. Choo, personal communication). Yield decreases due to warming will most likely be partly offset by the direct effect of CO_2 fertilization on yield. Barley is a C_3 crop and therefore elevated CO_2 concentrations are likely to increase yields by increasing photosynthesis and suppressing photorespiration (Warrick, 1998). The additional direct effect of reducing evapotranspiration will not likely impact average yields significantly, as no significant relationship between yields and DEFICIT could be established in our data.

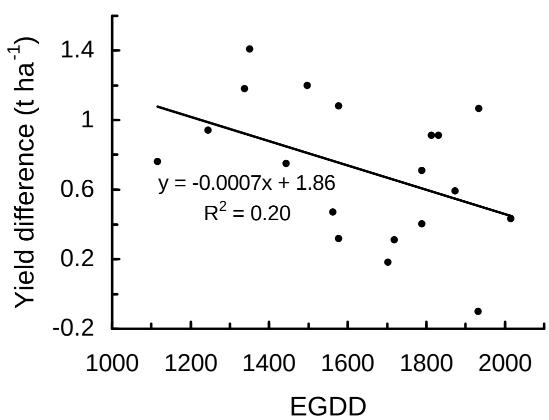


Figure 18. Relationship between EGDD and yield differences (6-row minus 2-row barley)

The relationship between barley yields obtained from county/province statistics is shown

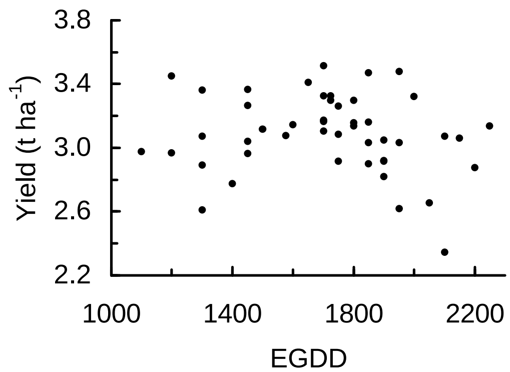


Figure 19. Relationship between barley yields from farm statistics and EGDD

in Figure 19. Average yields from farm statistics are around 3 t ha^{-1}, somewhat lower than the 4 to 5 t ha^{-1} that are typically observed in variety trials in the region. There was no significant linear trend when yields were regressed against either EGDD or DEFICIT (P>0.10). However, Figure 19 suggests that highest farm yields are around the mid-range of EGDD (i.e. 1500-1700 EGDD), with a tendency to decreasing yields in areas with either cooler or warmer climates. Our scenario indicates that by the year 2055, EGDD may be in the 1800 to 2000 range for most of the agricultural areas in the Atlantic region (Figure 8). This again suggests a slight decrease in barley yields due to warmer temperatures. However, as noted earlier, this decrease will likely be more than offset by the direct effect of elevated atmospheric CO_2 concentrations on yield.

Statistics Canada data indicate that the area seeded to barley in New Brunswick, Nova Scotia and Prince Edward Island for the 1993-1997 period averaged about 55,000 ha per year. An average yield of 3 t ha^{-1} and average price of $140 per tonne resulted in total farm production of about 165,000 tonnes for a farm value of about $23 million. It seems reasonable to assume about a 10-15% increase in barley yield by the year 2055 due to direct effects of doubling CO_2. However, the area that is seeded to barley and other small grain cereals is likely to be reduced very significantly as producers switch more to corn and soybeans, which will have a competitive advantage under a double CO_2 climate. Assuming 25,000 hectares grown (50% reduction) with an average yield of 3.15 t ha^{-1}, would result in about 79,000 tonnes of barley at a farm value of about $11 million.

Our assumptions about the increase in barley yields were consistent with simulations from the EPIC model. De Jong and Li (2001) reported almost no change in simulated barley yield at Charlottetown when the direct effect of CO_2 was not included, and an increase in yield of about 10% when the CO_2 fertilization effect was included. More recent calculations indicated an average increase in yield of 22% at Fredericton, Kentville and Charlottetown under a $2xCO_2$ scenario climate if N stress was eliminated (De Jong, personal communications).

Our estimates of areas that will switch from barley to corn and soybean production by the year 2055 are less than would be projected from comparison with areas in Ontario with heat unit ratings similar to those anticipated for the Atlantic region by 2055. The projected area of production of grain corn, soybeans and barley we assume are in a ratio of 40:27:33. In the 1996 census year, average ratios of land area under corn, soybean and barley production for counties in Ontario which have CHU ratings that are similar to what the Atlantic region may experience by 2055 (2800 to 3200 CHU) were approximately 49:45:6. However, the proportion of land area under barley production will likely remain higher in the Atlantic region as long as potatoes continue to be a major commodity in the region, since barley is an excellent crop in rotation with potatoes. It is also likely that there will be considerable production of other cereals, particularly winter wheat if winter survival conditions become more favourable, and of fodder corn. In the 1996 census year, the average ratios of grain corn, soybeans and all other cereals (winter wheat, barley, oats and mixed grain) in Ontario counties with 2800 to 3200 CHU was approximately 39:35:26. Large increases in corn and soybean production in the Maritime Provinces may have detrimental effects on soil by increasing erosion, and this will need to be taken into consideration as changes in production systems are introduced.

CONCLUSIONS AND RECOMMENDATIONS

The climatic changes expected to occur in the Atlantic region within the next 50 years or so, based on the Canadian GCM model and a ‘business as usual’ emission scenario for GHG’s, are likely to have significant impacts on crop production in the region. Heat units are expected to increase significantly, while only slight to moderate changes in water deficits may be expected. This will likely result in substantial increases in yields and production of corn and soybeans. Yields of barley are likely to change only slightly, but the competitive advantage in relation to corn and soybeans will be significantly reduced and likely lead to major shifts in areas seeded to these crops. Overall, the crop productivity will be increased by increased yields and by the switch to high energy and high protein content crops that are better adapted to the warmer climate. However, there will still likely be large acreages of small grain cereal crops as these are very desirable in rotation with potatoes and produce straw used as bedding in animal production. The potential impact of these shifts on soil erosion needs to be evaluated.

This study was based on the results from a single GCM scenario. There is a need to evaluate potential impacts of climate change using results from more GCM’s and for a range of GHG emission scenarios. An expanded analysis would provide better indication of the variations and uncertainties that may be associated with regional climate change scenarios and their impacts. A methodology has been established in this study that will readily facilitate such further investigation. It would also allow for more rapid assessment of impacts of new scenarios generated by GCM’s in the future. Our investigations have assumed that there will be little or no change in variability of the climate in the future. Further analyses is needed to determine if changes in variability projected by different GCM’s are consistent and whether or not such changes would affect our conclusions. There is also a need to expand the analysis to other agricultural regions in Canada, and the methodologies developed would provide an efficient way of implementing broader geographic assessments.

The procedures used to apply climate data and climate change scenarios to the fine grid were based on relatively simple interpolation procedures of mean monthly data. There is need to determine if more sophisticated downscaling methodologies would significantly impact the conclusions derived from this study. There is presently interest in developing climate change scenario data at about 0.5 degree grid interval for agricultural regions using other downscaling methodologies such as regression methods, stochastic weather generators and/or high resolution regional climate models (Wilby and Wigley, 1997), and funding is needed to stimulate such development.

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Appendix 1: Extracts of climate change scenarios from the Canadian GCM for grid points in the Atlantic region of Canada.

IPCC Data Distribution Centre CGCM1 Results 25-Aug-98
Mean change values for 2010-2039 with respect to 1961-1990
GSA CCGSA1
Maximum screen air temperature (celsius)

Lat. (Deg. N	Long. (Deg. W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
42.6776	56.25	1.17	0.79	0.82	0.83	0.94	1.11	1.04	0.97	1.09	1.01	0.87	0.99
42.6776	60.00	1.14	0.84	0.81	0.83	0.72	0.89	0.87	0.96	1.08	1.03	0.79	0.99
42.6776	63.75	1.10	0.98	1.01	0.98	0.79	0.82	0.73	0.75	0.89	0.95	0.73	0.99
42.6776	67.50	1.11	1.14	1.18	1.12	0.90	0.82	0.70	0.75	0.87	1.02	0.78	1.01
42.6776	71.25	1.86	1.55	1.68	2.95	0.62	1.08	1.56	1.86	1.81	1.37	0.37	2.44
46.3886	52.50	1.21	0.97	1.10	1.09	0.98	1.01	0.79	0.64	0.80	0.77	0.83	0.95
46.3886	56.25	1.17	0.95	1.08	0.98	0.81	0.81	0.62	0.55	0.81	0.90	0.85	0.96
46.3886	60.00	1.12	0.99	1.08	0.92	0.66	0.70	0.65	0.71	0.89	0.97	0.82	0.91
46.3886	63.75	1.44	0.89	0.85	2.70	0.87	1.34	1.22	1.30	1.38	1.34	0.48	1.68
46.3886	67.50	1.13	1.16	0.37	1.81	0.95	1.26	1.28	1.34	1.51	1.25	0.29	1.07
46.3886	71.25	1.48	1.44	0.38	1.34	0.92	1.16	1.32	1.41	1.69	1.20	0.38	0.48
50.0995	52.50	0.59	0.34	0.07	-0.23	-0.57	-0.27	-0.10	-0.05	0.23	0.31	0.36	0.45
50.0995	56.25	0.90	0.52	0.36	1.29	0.44	1.30	1.14	0.74	1.21	1.10	0.68	0.93
50.0995	60.00	1.26	1.24	1.13	1.19	1.13	1.17	1.25	1.16	1.21	1.20	0.98	1.12
50.0995	63.75	1.44	1.56	0.93	0.91	1.40	1.33	1.41	1.32	1.36	1.27	0.96	1.17
50.0995	67.50	2.18	1.82	0.92	0.19	1.51	1.43	1.14	0.89	1.21	1.12	0.37	1.09
50.0995	71.25	2.23	1.81	0.70	0.09	0.88	1.31	1.19	0.99	1.28	0.97	0.28	1.05
53.8103	52.50	-0.56	-1.70	-2.21	-2.99	-3.49	-2.96	-2.39	-1.95	-1.27	-0.75	-0.41	-0.34
53.8103	56.25	0.03	-0.69	-1.58	-2.03	-2.11	-2.03	-1.83	-1.67	-1.27	-0.82	-0.43	-0.07
53.8103	60.00	2.36	1.32	1.41	0.55	1.26	1.35	1.26	0.81	1.23	0.98	0.23	1.36
53.8103	63.75	2.62	1.85	1.48	0.47	0.54	1.80	1.30	0.81	1.24	1.11	0.18	2.17
53.8103	67.50	2.73	2.31	1.67	0.54	0.29	2.14	1.36	0.92	1.15	1.20	0.01	2.69
57.521	56.25	-0.62	-1.02	-1.00	-1.37	-1.51	-1.36	-1.34	-1.13	-0.73	-0.38	-0.13	-0.28
57.521	60.00	-0.06	-1.16	-0.88	-0.91	-0.77	-0.62	-0.62	-0.51	-0.24	-0.04	0.09	0.30
57.521	63.75	2.53	0.81	2.06	0.65	0.39	2.86	1.43	0.93	1.15	1.06	0.13	2.57
57.521	67.50	2.51	2.54	3.43	1.42	0.60	3.38	1.60	1.03	1.22	1.21	0.31	3.06
61.2316	60.00	0.03	-0.44	0.63	0.59	0.53	0.47	0.34	0.30	0.49	0.47	0.58	0.49
61.2316	63.75	0.61	0.09	-0.08	-0.17	0.07	0.35	0.40	0.36	0.57	0.59	0.62	0.75
61.2316	67.50	1.14	1.64	3.14	1.51	0.59	0.89	0.92	0.85	0.97	0.83	0.82	1.03

IPCC Data Distribution Centre CGCM1 Results 25-Aug-98
Mean change values for 2010-2039 with respect to 1961-1990
GSA CCGSA1
Minimum screen air temperature (celsius)

Lat. (Deg. N	Long. (Deg. W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
42.6776	56.25	1.24	0.99	0.92	0.91	0.94	1.07	1.02	0.93	1.11	1.01	0.91	1.09
42.6776	60.00	1.21	1.08	0.86	0.83	0.73	0.86	0.85	0.92	1.06	1.01	0.84	1.07
42.6776	63.75	1.19	1.26	1.02	0.94	0.83	0.79	0.72	0.74	0.85	0.95	0.81	1.03
42.6776	67.50	1.19	1.44	1.19	1.07	0.89	0.82	0.73	0.77	0.87	1.03	0.83	1.04
42.6776	71.25	1.90	4.05	1.61	1.36	0.63	1.28	1.48	1.58	1.84	1.42	-0.03	0.97
46.3886	52.50	1.18	1.23	1.10	1.04	0.95	0.91	0.83	0.74	0.77	0.83	0.88	1.06
46.3886	56.25	1.16	1.21	1.08	0.95	0.83	0.74	0.65	0.63	0.76	0.93	0.92	1.06
46.3886	60.00	1.14	1.26	1.10	0.93	0.73	0.68	0.68	0.76	0.89	0.98	0.91	0.96
46.3886	63.75	2.77	4.69	1.82	0.98	1.02	1.64	1.09	1.01	1.36	1.50	0.24	0.58
46.3886	67.50	3.80	4.73	1.93	0.68	1.03	1.54	1.14	1.22	1.43	1.15	0.06	0.36
46.3886	71.25	4.88	3.93	2.22	0.57	0.97	1.45	1.17	1.23	1.48	1.06	0.10	0.41
50.0995	52.50	0.62	0.55	0.04	-0.30	-0.57	-0.31	-0.07	0.05	0.20	0.32	0.37	0.45
50.0995	56.25	3.40	2.66	1.66	0.62	0.37	1.40	1.15	0.66	1.31	1.22	0.45	0.26
50.0995	60.00	1.30	2.02	2.06	1.30	1.12	1.18	1.23	1.21	1.19	1.20	1.03	1.16
50.0995	63.75	1.65	3.71	3.92	2.45	1.38	1.37	1.38	1.34	1.29	1.25	1.00	1.24
50.0995	67.50	3.73	2.09	2.21	2.68	0.99	1.69	1.23	1.04	1.11	0.85	0.12	3.01
50.0995	71.25	3.43	1.97	1.73	1.63	0.64	1.47	1.30	1.09	0.98	0.83	0.10	3.21
53.8103	52.50	-0.52	-1.60	-2.77	-3.28	-3.45	-2.96	-2.30	-1.81	-1.25	-0.78	-0.45	-0.33
53.8103	56.25	0.08	-0.53	-1.56	-2.01	-2.05	-1.98	-1.73	-1.55	-1.23	-0.83	-0.45	-0.03
53.8103	60.00	3.27	1.32	1.86	2.87	1.17	1.38	1.40	0.84	1.35	0.84	0.02	2.92
53.8103	63.75	3.46	2.07	2.43	1.90	0.69	1.73	1.54	0.87	1.33	0.83	0.06	4.20
53.8103	67.50	3.30	2.45	2.79	1.27	0.92	1.98	1.73	0.87	1.04	0.66	0.39	4.67
57.521	56.25	-0.54	-0.90	-0.99	-1.36	-1.50	-1.36	-1.24	-1.04	-0.73	-0.36	-0.16	-0.24
57.521	60.00	0.05	-0.98	-0.83	-0.85	-0.73	-0.61	-0.55	-0.46	-0.27	-0.03	0.09	0.38
57.521	63.75	3.00	1.04	2.47	0.87	1.08	2.62	1.74	1.19	1.24	0.64	0.36	3.84
57.521	67.50	2.71	1.99	3.97	1.94	1.56	3.10	1.97	1.19	1.11	0.69	1.11	4.20
61.2316	60.00	0.11	-0.26	0.69	0.66	0.55	0.48	0.39	0.36	0.44	0.48	0.59	0.56
61.2316	63.75	0.70	0.32	0.02	-0.08	0.13	0.37	0.44	0.43	0.54	0.61	0.65	0.82
61.2316	67.50	1.37	3.06	6.15	5.49	1.49	0.89	0.92	0.89	0.92	0.85	0.83	1.10

Appendix 1 (cont'd): Extracts of climate change scenarios

IPCC Data Distribution Centre CGCM1 Results 25-Aug-98
Mean change values for 2040-2069 with respect to 1961-1990
GSA CCGSA1
Maximum screen air temperature (celsius)

Lat. (Deg. N	Long. (Deg. W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
42.6776	56.25	1.78	1.48	1.65	1.66	1.86	1.94	1.87	1.83	1.92	1.84	1.66	1.55
42.6776	60.00	1.71	1.61	1.55	1.42	1.44	1.64	1.75	1.83	1.97	1.88	1.61	1.54
42.6776	63.75	1.68	1.77	1.86	1.70	1.64	1.54	1.44	1.38	1.60	1.64	1.47	1.50
42.6776	67.50	1.73	1.96	2.19	2.02	1.78	1.52	1.39	1.34	1.49	1.61	1.54	1.48
42.6776	71.25	3.40	3.31	5.49	5.51	1.78	2.33	2.53	2.73	2.64	2.08	2.14	2.48
46.3886	52.50	1.95	1.89	2.06	2.02	1.85	1.69	1.47	1.24	1.43	1.46	1.53	1.66
46.3886	56.25	1.96	1.89	2.00	1.87	1.59	1.39	1.18	1.14	1.52	1.69	1.70	1.81
46.3886	60.00	1.85	1.82	1.87	1.61	1.27	1.15	1.18	1.28	1.62	1.85	1.74	1.76
46.3886	63.75	2.43	1.73	3.22	5.03	1.98	2.24	2.20	2.07	2.49	2.04	1.87	2.33
46.3886	67.50	1.65	1.68	0.61	4.50	2.12	2.29	2.32	2.10	2.49	2.01	2.06	1.13
46.3886	71.25	1.96	2.38	0.71	2.94	2.13	2.27	2.31	2.15	2.52	2.10	2.34	0.44
50.0995	52.50	0.71	0.53	-0.04	-0.66	-1.19	-1.03	-0.83	-0.69	-0.30	0.03	0.24	0.46
50.0995	56.25	1.21	0.96	0.64	3.10	1.86	2.05	2.22	1.33	2.27	1.81	1.74	1.34
50.0995	60.00	2.01	2.12	2.03	2.15	2.11	2.03	2.02	1.93	2.07	2.14	1.88	1.81
50.0995	63.75	2.26	2.52	1.78	1.85	2.34	2.16	2.22	2.12	2.21	2.21	1.89	1.85
50.0995	67.50	3.04	2.97	1.49	0.71	3.70	2.41	2.23	1.56	2.31	2.15	1.69	1.35
50.0995	71.25	3.09	2.99	1.20	0.44	3.19	2.42	2.27	1.70	2.26	2.02	1.64	1.50
53.8103	52.50	-1.14	-2.40	-2.99	-4.62	-6.29	-5.72	-4.79	-4.14	-3.26	-2.17	-1.37	-1.00
53.8103	56.25	-0.39	-1.01	-2.10	-2.66	-2.95	-3.26	-3.23	-3.22	-2.85	-2.05	-1.35	-0.70
53.8103	60.00	3.27	2.44	2.08	1.21	3.29	2.34	2.37	1.47	2.32	1.97	0.98	1.72
53.8103	63.75	3.39	2.96	2.28	0.91	2.38	2.90	2.43	1.62	2.37	2.26	1.10	2.93
53.8103	67.50	3.68	3.64	2.78	1.03	2.04	3.72	2.57	1.72	2.38	2.51	0.97	3.83
57.521	56.25	-1.02	-1.60	-2.00	-1.50	-1.91	-4.09	-3.84	-3.30	-2.67	-1.73	-0.93	-0.80
57.521	60.00	-0.39	-1.98	-2.32	-2.30	-2.18	-2.17	-2.25	-2.12	-1.83	-1.21	-0.69	-0.19
57.521	63.75	3.88	1.35	2.61	1.95	1.12	5.07	2.59	1.75	2.29	2.02	0.76	4.36
57.521	67.50	3.95	4.59	5.66	2.93	2.05	5.65	2.84	1.96	2.50	2.43	0.98	4.72
61.2316	60.00	-0.26	-1.46	-1.02	-0.89	-1.13	-1.09	-1.01	-0.84	-0.55	-0.06	0.42	0.44
61.2316	63.75	0.92	0.20	-0.32	-0.44	-0.24	0.02	0.10	0.16	0.41	0.74	0.95	1.15
61.2316	67.50	1.93	2.58	4.07	2.39	1.35	1.67	1.71	1.65	1.71	1.67	1.67	1.89

IPCC Data Distribution Centre CGCM1 Results 25-Aug-98
Mean change values for 2040-2069 with respect to 1961-1990
GSA CCGSA1
Minimum screen air temperature (celsius)

Lat. (Deg. N	Long. (Deg. W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
42.6776	56.25	1.88	1.72	1.74	1.78	1.91	2.01	1.88	1.78	1.94	1.87	1.77	1.68
42.6776	60.00	1.79	1.86	1.60	1.51	1.52	1.73	1.76	1.80	1.97	1.90	1.70	1.63
42.6776	63.75	1.76	2.02	1.87	1.78	1.72	1.63	1.49	1.45	1.60	1.67	1.56	1.55
42.6776	67.50	1.78	2.25	2.18	2.04	1.82	1.67	1.50	1.43	1.52	1.65	1.57	1.52
42.6776	71.25	2.49	5.34	2.97	2.73	2.02	2.77	2.76	2.45	2.64	2.13	1.22	0.87
46.3886	52.50	1.91	2.03	2.04	1.97	1.82	1.73	1.58	1.38	1.45	1.51	1.62	1.73
46.3886	56.25	1.94	2.09	2.01	1.88	1.63	1.46	1.29	1.27	1.52	1.74	1.80	1.87
46.3886	60.00	1.86	2.07	1.90	1.65	1.35	1.24	1.29	1.41	1.66	1.85	1.82	1.76
46.3886	63.75	3.14	6.33	3.21	2.13	2.07	2.75	2.41	1.87	2.65	2.02	1.31	0.71
46.3886	67.50	4.61	8.10	3.96	1.80	2.16	2.79	2.51	2.11	2.58	1.91	1.08	0.34
46.3886	71.25	6.73	7.54	4.64	1.49	2.06	2.73	2.48	2.25	2.54	2.09	1.17	0.42
50.0995	52.50	0.71	0.68	0.01	-0.74	-1.23	-0.96	-0.64	-0.49	-0.28	0.01	0.25	0.46
50.0995	56.25	4.69	5.26	3.50	1.55	1.70	2.15	2.37	1.46	2.60	1.82	1.02	0.50
50.0995	60.00	2.06	2.90	3.03	2.24	2.05	2.06	2.10	2.01	2.07	2.08	1.90	1.90
50.0995	63.75	2.48	4.78	5.05	3.40	2.29	2.24	2.26	2.17	2.17	2.16	1.90	1.98
50.0995	67.50	5.71	4.03	4.36	4.09	2.23	2.87	2.77	1.80	2.42	1.95	0.76	3.92
50.0995	71.25	4.88	4.26	3.20	2.87	1.91	2.87	2.83	1.96	2.30	1.89	0.74	4.70
53.8103	52.50	-1.12	-2.31	-4.40	-5.97	-6.41	-5.57	-4.59	-3.93	-3.16	-2.21	-1.45	-0.99
53.8103	56.25	-0.33	-0.85	-2.03	-2.73	-2.91	-3.13	-3.05	-3.04	-2.73	-2.08	-1.39	-0.65
53.8103	60.00	4.68	3.00	3.33	4.54	2.75	2.40	2.69	1.60	2.52	1.76	0.42	3.96
53.8103	63.75	4.47	3.69	3.80	4.12	1.93	2.97	2.88	1.72	2.58	1.82	0.44	6.16
53.8103	67.50	4.48	4.45	4.48	3.54	2.79	3.63	3.18	1.82	2.50	1.69	0.83	7.55
57.521	56.25	-0.95	-1.46	-2.56	-3.79	-3.56	-4.21	-3.65	-3.18	-2.56	-1.72	-0.98	-0.70
57.521	60.00	-0.29	-2.10	-2.35	-2.26	-2.12	-2.06	-2.08	-2.02	-1.74	-1.17	-0.69	-0.06
57.521	63.75	4.51	1.40	3.16	3.18	2.33	4.59	2.96	2.21	2.56	1.48	0.72	7.08
57.521	67.50	4.33	3.93	6.00	4.46	4.21	5.00	3.30	2.33	2.65	1.64	1.64	7.49
61.2316	60.00	-0.14	-1.23	-0.87	-0.80	-1.07	-1.01	-0.88	-0.77	-0.46	-0.05	0.43	0.55
61.2316	63.75	1.05	0.50	-0.15	-0.26	-0.14	0.05	0.19	0.22	0.47	0.75	0.99	1.26
61.2316	67.50	2.19	4.37	8.01	7.30	2.34	1.67	1.75	1.70	1.73	1.66	1.70	1.99

Appendix 1 (cont'd): Extracts of climate change scenarios

IPCC Data Distribution Centre CGCM1 Results 25-Aug-98
Mean change values for 2010-2039 with respect to 1961-1990
GSA CCGSA1
Total precipitation rate (mm/day)

Lat. (Deg. N	Long. (Deg. W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
42.6776	56.25	0.92	1.00	0.97	1.07	0.95	1.14	0.96	0.88	0.88	0.86	1.20	1.05
42.6776	60.00	0.98	0.89	0.93	1.00	0.92	1.10	1.03	0.85	0.91	0.99	1.08	1.04
42.6776	63.75	0.98	0.81	1.02	0.96	0.94	1.11	0.98	0.75	1.07	1.01	1.05	0.94
42.6776	67.50	0.97	0.81	1.07	0.97	1.00	1.05	0.91	0.71	1.18	1.06	1.00	0.89
42.6776	71.25	1.04	0.76	0.96	1.00	1.03	0.97	0.92	0.67	1.12	1.18	0.91	1.04
46.3886	52.50	1.08	0.95	1.03	1.00	1.12	1.15	1.07	1.01	0.96	0.99	1.07	0.98
46.3886	56.25	1.06	0.90	0.94	1.02	1.13	1.17	0.96	1.05	1.08	0.98	1.01	0.99
46.3886	60.00	1.07	0.86	0.94	1.14	1.09	1.25	0.92	0.99	1.12	1.05	0.93	0.91
46.3886	63.75	1.06	0.84	1.05	1.13	1.09	1.27	0.90	0.97	1.16	1.02	0.87	0.90
46.3886	67.50	1.03	0.87	1.06	1.13	1.07	1.14	0.95	0.90	1.12	1.06	0.89	0.95
46.3886	71.25	1.13	0.88	0.90	1.12	1.03	1.01	0.94	0.96	1.02	0.90	0.95	1.04
50.0995	52.50	0.92	0.88	0.99	0.97	1.05	1.13	1.15	1.04	0.98	0.93	1.01	0.89
50.0995	56.25	0.98	0.82	0.94	1.00	0.96	1.07	1.04	1.05	1.00	0.97	0.93	0.90
50.0995	60.00	1.13	0.81	0.89	1.03	0.98	1.04	0.95	1.00	1.14	0.98	0.89	0.88
50.0995	63.75	1.04	0.81	0.92	1.04	1.02	1.04	0.96	1.05	1.14	1.00	0.89	0.91
50.0995	67.50	0.92	0.85	1.03	1.12	0.96	1.03	1.00	1.16	1.11	0.92	0.93	0.88
50.0995	71.25	1.09	0.88	1.05	1.07	0.99	1.04	1.09	1.15	1.06	0.92	0.95	0.83
53.8103	52.50	1.00	0.83	1.12	1.05	1.00	1.03	0.98	0.96	1.13	0.98	0.93	0.86
53.8103	56.25	0.99	0.87	1.06	1.03	0.99	0.98	0.90	0.89	1.16	1.07	0.93	0.85
53.8103	60.00	1.08	0.90	1.01	1.00	1.01	0.95	0.82	0.94	1.16	1.14	0.85	0.95
53.8103	63.75	1.18	0.87	1.09	1.07	1.07	1.01	0.90	1.01	1.16	1.13	0.85	1.01
53.8103	67.50	1.18	0.91	1.10	1.09	0.97	1.08	1.15	1.03	1.12	1.08	0.96	0.98
57.521	56.25	0.95	0.98	1.16	1.04	0.99	1.04	1.01	1.04	1.26	0.99	0.94	1.00
57.521	60.00	0.90	0.93	1.11	0.89	1.11	1.03	0.99	0.93	1.27	1.02	0.94	1.06
57.521	63.75	0.91	0.91	1.15	0.87	1.12	1.01	1.00	0.96	1.36	1.04	0.96	1.05
57.521	67.50	0.93	0.92	1.10	1.01	1.09	1.00	1.04	1.04	1.36	1.04	1.03	0.98
61.2316	60.00	0.83	0.87	0.93	0.80	0.84	1.01	1.04	1.18	1.25	1.16	1.24	1.00
61.2316	63.75	0.91	0.85	0.93	0.85	0.91	0.93	1.10	1.23	1.37	1.16	1.16	0.98
61.2316	67.50	0.95	0.78	0.99	0.97	0.95	1.00	1.06	1.31	1.37	1.07	1.04	1.04

IPCC Data Distribution Centre CGCM1 Results 25-Aug-98
Mean change values for 2040-2069 with respect to 1961-1990
GSA CCGSA1
Total precipitation rate (mm/day)

Lat. (Deg. N	Long. (Deg. W)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
42.6776	56.25	0.89	1.01	1.01	1.16	0.91	1.14	1.06	0.90	0.95	0.89	1.01	0.99
42.6776	60.00	0.97	1.05	0.96	1.09	0.94	1.08	1.06	0.94	0.94	0.91	0.91	1.03
42.6776	63.75	1.04	1.06	1.01	1.00	0.96	1.12	0.92	0.89	0.98	0.87	0.82	1.02
42.6776	67.50	1.08	1.10	1.08	1.06	0.95	1.07	0.90	0.86	1.19	0.85	0.77	0.98
42.6776	71.25	1.09	0.97	1.06	1.06	1.05	0.99	0.97	0.81	1.10	0.80	0.83	1.10
46.3886	52.50	1.15	1.13	1.10	1.26	1.04	1.14	1.02	0.93	1.04	1.01	1.17	0.95
46.3886	56.25	1.06	1.10	1.08	1.23	1.12	1.15	0.95	0.96	0.97	0.97	1.05	1.01
46.3886	60.00	1.05	1.12	1.10	1.13	1.14	1.23	0.89	0.93	0.99	0.94	0.90	1.01
46.3886	63.75	1.12	1.11	1.14	1.01	1.11	1.21	0.85	0.90	1.02	0.95	0.80	1.04
46.3886	67.50	1.16	1.05	1.11	1.02	1.08	1.01	0.82	0.85	0.99	0.92	0.85	1.00
46.3886	71.25	1.17	0.95	1.01	1.11	1.13	0.93	0.81	0.96	0.99	0.85	1.03	0.94
50.0995	52.50	1.07	0.95	1.09	1.09	1.06	0.99	1.14	1.09	1.10	0.98	1.07	1.05
50.0995	56.25	1.14	0.99	1.05	1.12	1.07	0.92	1.02	1.15	1.10	0.97	1.00	1.02
50.0995	60.00	1.20	1.00	0.96	1.11	1.23	0.99	0.85	1.02	1.08	1.03	0.90	1.01
50.0995	63.75	1.06	0.92	1.00	1.16	1.19	1.10	0.86	0.94	1.02	1.09	0.92	0.98
50.0995	67.50	0.93	0.89	1.05	1.18	1.15	1.04	0.96	1.01	1.02	1.09	1.01	0.86
50.0995	71.25	1.00	1.00	1.10	1.16	1.12	0.97	1.02	0.97	1.01	1.13	1.03	0.82
53.8103	52.50	1.19	0.90	1.09	1.06	1.26	1.07	1.08	1.10	1.07	1.09	0.87	0.92
53.8103	56.25	1.17	0.98	1.03	1.04	1.25	0.98	0.99	1.09	1.07	1.12	0.88	0.87
53.8103	60.00	1.16	0.97	1.00	1.16	1.25	0.91	0.96	1.03	1.01	1.17	0.90	0.93
53.8103	63.75	1.13	1.02	1.16	1.38	1.27	1.08	1.07	1.00	1.07	1.25	0.99	0.97
53.8103	67.50	1.10	1.03	1.12	1.35	1.14	1.26	1.16	0.94	1.16	1.31	1.02	0.94
57.521	56.25	1.16	0.95	1.02	1.12	1.19	1.04	1.01	1.01	1.39	1.01	0.92	1.11
57.521	60.00	1.16	0.82	1.08	1.02	1.21	1.02	0.95	0.97	1.30	0.92	0.97	1.14
57.521	63.75	1.06	0.77	1.22	1.16	1.18	1.10	0.92	1.11	1.32	0.94	1.05	1.06
57.521	67.50	0.98	0.82	1.07	1.12	1.16	1.22	0.88	1.16	1.39	1.00	1.04	1.06
61.2316	60.00	0.97	0.76	0.82	0.97	1.03	1.38	1.19	1.18	1.29	1.12	1.11	1.13
61.2316	63.75	1.03	0.74	0.82	0.96	0.89	1.28	1.16	1.30	1.32	1.07	1.01	1.08
61.2316	67.50	1.03	0.78	0.93	0.89	0.94	1.21	1.06	1.37	1.34	0.95	0.91	1.00