Crop Heat Units (CHU) for Canada for Land Suitability Rating System (LSRS) and impacts of climate change

Final Report for Agriculture and Agri-Food Canada Contract #3000321992 – ASSESSMENT OF CLIMATE CHANGE IMPACTS ON CANADIAN AGRICULTURAL LAND SUITABILITY: Modeling Corn & Canola Crops.

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Background:

Crop Heat Units (CHU) are widely used in Canada to rate the suitability of the climate in each region for producing specific corn hybrids and soybean varieties (Brown and Bootsma, 1993; Bootsma et al.,1999; Bootsma et al., 2001) and are being used in the LSRS for Canada (Pettapiece and Tychon, 2007). An existing computer program (in C++ language) is available which calculates seasonal average CHU from 30 year monthly climate normals of daily maximum and minimum air temperature. The Brooks sine wave interpolation procedure is used (Brooks, 1943) to generate 365 daily values of average Tmax, Tmin and Tmean from 12 monthly average values (Subroutine DAILY). Daily average CHU are then computed from the 365 daily Tmax and Tmin values using the following formula (Brown and Bootsma, 1993):

$$Ymax = 3.33\ (Tmax - 10.0) - 0.084\ (Tmax - 10.0)^2$$
$$Ymin = 1.8\ (Tmin - 4.44)$$
If $Tmax < 10.0$, $Ymax = 0.0$; if $Tmin < 4.44$, $Ymin = 0.0$

Where Ymax and Ymin are the contributions to CHU from daily maximum (Tmax) and minimum (Tmin) air temperature respectively.

Then, $$\text{Daily CHU} = (Ymax + Ymin) / 2.0$$

To compute seasonal CHU sums (CHUnormal), daily CHU values are accumulated from starting and stopping dates determined by the dates when certain temperature threshold values are reached. Starting dates are based on a threshold for the mean daily temperature (Tmean) and stopping dates are based on mean daily minimum temperature (Tmin). The threshold temperatures are "calibrated" to correspond closely to the average date of planting in spring and the date of 10% probability of occurrence of killing frost (-2ºC) in the fall in each region. The fall cut-off date is appropriate for grain corn production. Cut-off dates for determining CHU available for silage corn are earlier, since killing frosts for silage would have occurred prior to this date

In past studies for Ontario, Quebec and the Maritimes, the threshold values used for Tmean and Tmin to determine starting and ending dates for accumulating CHU were as follows:

	Starting date (Tmean)	Ending date (Tmin)	Reference
Ontario:	12.8ºC	6.5ºC	(Bootsma et al. 2004)
Quebec:	12.8ºC	6.5ºC	(Bootsma et al. 1999)
Maritimes:	11.0ºC	5.8ºC	(Bootsma et al. 2001)

Appropriate thresholds were not yet available for other regions of Canada and thus needed to be determined as part of this contract. Average accumulated CHU values (CHUnormal) determined by this procedure need to be adjusted to correspond with average CHU calculated from daily data for the 30 year period (CHUave) using a regression algorithm where available. Average CHU are used for mapping CHU available for corn and soybean production in most regions of Canada and are also used as a variable in the LSRS. CHU available at the 80% probability level (CHU80%) can also be estimated in a similar manner. CHU80% represents the CHU that are available at least 8 years out of 10. This value represent a lower level of risk for achieving adequate maturity levels in corn or soybeans than the average CHU. In Quebec, the 80% CHU value is used in mapping CHU for corn hybrid/soybean variety recommendations, i.e., corn hybrids of equivalent CHU rating may be expected to achieve adequate maturity at least 80% of the time (CRAAQ, 2002). The algorithms for computing CHUave and CHU80% are known and have been used in previous studies for Ontario, Quebec and the Maritime provinces. However, they also needed to be determined for the rest of Canada as part of this contract. The algorithms used to adjust the CHUnormal values in the past were as follows:

For Atlantic region:
CHUave = 185.2 + 0.93771*CHUnormal
CHU80% = -11.80 + 0.95382*CHUnormal

For Quebec:
CHUave = 157.45 + 0.9194*CHUnormal
CHU80% = 37.55 + 0.9297*CHUnormal

For Ontario:
CHUave = 177.82 + 0.91502*CHUnormal
CHU80% = 68.62 + 0.90195*CHUnormal

Modified program for computing CHU:

The procedures for calculating CHU variables in the C++ program were incorporated into the Java program for computing climate indices for the LSRS (CLIMATE INDICE TOOL for the LAND SUITABILITY RATING SYSTEM (LSRS)Version 1.0.0 Beta), and is available to run on-line at: http://ncrxeis4.agr.gc.ca/LSRS/index.jsp). Maximum flexibility for setting temperature threshold values and coefficients for the regression algorithms were achieved by reading these values from a spreadsheet (.xls) file for set ranges of latitude and longitude (used as the “threshold input” on the web site; see Table 4 for example). If the data are outside the latitude/longitude ranges on this file, the output record will not include any data for the CHU variables, but all the other LSRS variables that are selected will be computed. If the ranges overlap, an error message will result.

A "standard input" file of climate data is also required, which must be an ASCII text file containing longitude (negative decimal degrees), latitude, elevation (metres), 12 monthly Tmax values, 12 monthly Tmin values (ºC), and 12 monthly precipitation values (mm). If the input text file is created using Excel spreadsheet, it needs to be saved as a Tab delimited txt file (*.txt). The output file is saved (downloaded) as a .dbf file which can be converted to a spreadsheet file such as .xls, if the file is not too large.

Threshold temperature for starting CHU accumulations:

To determine threshold temperatures for starting CHU accumulations, data on seeding dates of corn from field trials were gathered from as many locations as were readily available in the prairie region, British Columbia and Newfoundland. These dates were assumed to be fairly representative for seeding corn in each region. Average monthly air temperatures for the 1971-2000 normal period from climate stations in the vicinity of each field trial (Environment Canada, 2002a) were then used to generate average mean daily temperature for 365 days of the year (Tmean) using subroutine DAILY. The average temperature on the average seeding date was selected as the threshold temperature for starting CHU accumulations.

Data for seeding date temperature thresholds are presented in Table 1. Based on these results, appropriate threshold temperatures for each region are summarized as follows:

British Columbia: 12.7ºC
Prairie Provinces: 11.2ºC (note: although there were slight differences between provinces, it was thought best to use one threshold for Alberta, Saskatchewan and Manitoba to avoid discontinuity at the borders.)
Newfoundland: 8.8ºC

Threshold temperature for ending CHU accumulations:

Threshold temperatures for establishing ending dates for CHU accumulations were determined for each region/province by calculating the 10% probability date of first fall freeze (-2ºC) for selected climate stations in each region, and comparing this date with the daily mean minimum air temperature (Tmin) generated from monthly climate normals. Average values of Tmin were then determined for each region/province. The results of these analyses are shown in Table 2.

Following the calculation of accumulated CHU using the above threshold temperatures, the ending dates and CHUnormal values were compared with values using the end date for accumulating EGDD (GDD2Stop). The accumulated CHUs using this method are labelled as 'CHU2normal' in the Java program output. GDD2Stop is an estimate of the average date of first fall frost (0ºC) computed by the Java program. The results indicated that the end dates and CHU values were very close to a 1:1 relationship using these two methods (see Figures 1 to 4). Therefore, it was decided to use **CHU2normal** rather than CHUnormal as the CHU value for calculating CHUave and CHU80%. This eliminates the need for determining accurate threshold temperatures for ending the accumulation of CHU in each region, and will provide more seamless coverage of results.

Coefficients for determining CHUave and CHU80%:

CHUs computed from daily temperature data were examined for each region in Canada where coefficients have not yet been determined (BC, Prairie provinces, Nfld). These data were compared to CHU2normal values computed from monthly normals data for similar periods as the daily data. The monthly normals were first interpolated to daily normals using Subroutine DAILY. These comparisons facilitated the calculation of the required coefficients for computing CHUave and CHU80%.

Coefficients for Prairie provinces

Comparisons between CHU2normal and CHUave and CHU80% are presented in Table 3 and Figures 5 and 6. The prairie CHU values computed from daily data (CHUave and CHU80%) were derived from Master's thesis work done by Nadler (2007), using data from the 1971 to 2000 period. The linear regressions fits to the data in Figs. 5 and 6 indicate a high correlation so that these relationships can be used with a good deal of confidence.
Nadler began each season from a modeled seeding date where the following conditions needed to be met: AWHC < 90% within top 5 cm, precipitation < 2.0 mm, and Tavg >10°C for 10 days though not necessarily consecutively. If the modeled start date ended up later than June 6, then June 6 was used (crop insurance deadlines). End of season was triggered by first heavy frost where Tmin <=-2.2ºC. CHU80% was calculated from the mean CHU and Standard deviation (Sd), assuming a normal distribution, since Nadler only published 75% and 90% risk values.

For the Prairie provinces, the regression equations used to estimate CHUave and CHU80% from the CHUnormal values were as follows:

CHUave = 212.93 + 0.9071*CHU2normal
CHU80% = 143.75 + 0.8436*CHU2normal

Coefficients for British Columbia

Comparisons between CHU2normal and CHUave and CHU80% are shown in Table 3. Since relatively few locations were available for BC, the values were combined with prairie data to obtain the required regression constants and coefficients (Figures 7 and 8). Because of the small amount of data available for BC, less confidence can be put in these results compared to the prairie data. However, it is noted that the available BC data fitted well with the prairie results, but resulted in slightly lower estimates of CHUave and slightly higher values for CHU80%. It should be noted that the BC data is based on using an ending date that is appropriate for silage corn since grain trial data was not available for the province. The relationships for BC can be further validated or modified in future as more data becomes available.

For British Columbia, the regression equations used to estimate CHUave and CHU80% from the CHUnormal values were as follows:

CHUave = 343.24 + 0.8427*CHU2normal
CHU80% = 121.28 + 0.8545*CHU2normal

Coefficients for Newfoundland

Comparisons between CHU2normal and CHUave and CHU80% are shown in Table 3. Since relatively few locations were available for Newfoundland, the values were combined with data from the three Maritime provinces to obtain the required regression constants and coefficients (Figures 9 and 10). Because of the small amount of data available for Newfoundland, less confidence can be put in these results compared to the Maritime data. However, it is noted that the available Newfoundland data fitted well with the Maritime results. In fact, the regression fit for CHUave resulted in almost identical values. For CHU80%, estimates were similar at CHU2normal values of about 2400, but at higher and lower CHU values, the Newfoundland estimates were somewhat higher and lower, respectively, than estimates based on the equation for the Maritimes. The relationships for Newfoundland can be further validated or modified in future as more data becomes available.

For the Newfoundland, the regression equations used to estimate CHUave and CHU80% from the CHUnormal values were as follows:

CHUave = 164.96 + 0.9465*CHU2normal

CHU80% = -207.54 + 1.0342*CHU2normal

Input threshold file to program:

Table 4 shows an example of an input file to the Java program containing the threshold temperatures and regression coefficients described in this report. This file can be readily modified to accommodate more area distinctions if necessary (latitudes and longitudes) or improved coefficients when these become available in future. The values shown in this table were used as input in the trial runs described below.

Output from Java program:

The following variables (in addition to the variables described in previous reports) related to CHU are output from the Java program:

CHUnormal
Start_CHU
Stop_CHU
CHU2normal
CHUave
CHU80
GDD2Stop

CHUnormal are calculated based on ending dates computed from the threshold temperature for Tmin; Start_CHU is the starting date for accumulating CHU based on the threshold temperature for Tmean: Stop_CHU is the ending date for accumulating CHUnormal; CHU2normal is based on accumulating CHU to the ending date determined by the program (GDD2Stop); CHUave are the average CHU determined by adjusting CHU2normal using the regression equations; CHU80 is the CHU value equalled or exceeded 80% of the time, calculated from CHU2normal using the regression equations. GDD2Stop is the ending date for accumulating CHU2normal, based on the estimated average date of first fall frost (0°C) (also the ending date for accumulating GDD2 and EGDD values).

Analyses of CHU on gridded national data:

The revised Java program was used to compute CHU for selected grids across Canada using climate normals for the baseline (1961 to 1990) and 2040 to 2069 period. The climate change scenario was based on the output of the Canadian GCM (CGCMI ga1). The threshold file shown in Table 4 was used as input for the temperature thresholds and regression coefficients. Results are presented in Tables 5, 6 and 7.

There are several points of interest to note from the results. Average values for the 21 locations for CHUnormal and CHU2normal were nearly identical (Tables 5 and 6). Average values for Stop_CHU and GDD2Stop were identical for the 1961 to 1990 period (Table 5) and only different by one day for the 2040 to 2069 period (Table 6). This further confirms the validity of using GDD2Stop as the ending date for accumulating CHU.

Starting and ending dates averaged 17 days earlier and 14 days later, respectively, for the 2040 to 2069 period (Table 7). Average increases in CHUave and CHU80 were 743 and 726 CHU, respectively for the 2040 to 2069 period.

Conclusions:

The CHU calculations using the modified Java program and the threshold input file from Table 4 will provide improved estimates of average CHU and CHU available at 80% probability level than are currently available for the Prairie provinces, British Columbia and Newfoundland. Further improvements may be made in future as more data becomes available for British Columbia and Newfoundland for calibrating the regression variables. CHU estimates for other regions of Canada (Ontario, Quebec and the Maritime provinces) use the same threshold temperatures and regression coefficients as in the earlier C++ program, and hence the values are not changed if the same climatic input data are used.

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Table 1. Relationship between average seeding date of corn and average mean daily air Temperature (Tmean).

Location	Prov.	Average seeding date	# of years of field trial data	Average daily mean temperature (°C)*
Abbotsford	BC	15-May	8	12.5
Agassiz	BC	08-May	8	12.6
Armstrong	BC	11-May	5	11.7
Chilliwack	BC	18-May	5	13.5
Saanich	BC	17-May	4	12.2
Coldstream	BC	20-May	3	13.6
			BC Average:	12.7
Lethbridge	AB	08-May	6	10.2
Vauxhall	AB	08-May	6	11.0
Brooks	AB	13-May	6	11.3
Bow Island	AB	13-May	6	11.8
Lacombe	AB	16-May	4	10.4
			AB Average:	10.9
Outlook	SK	18-May	4	12.5
Carman	MB	06-May	3	10.4
Reinland	MB	10-May	4	11.9
St Pierre	MB	12-May	3	11.3
			MB Average:	11.2
			Prairie average:	11.2
St John's	NFLD	02-Jun	n/a	8.5
Deer Lake	NFLD	25-May	n/a	8.8
Stephenville	NFLD	26-May	n/a	9.2
			Nfld Average:	8.8

* Based on 1971-2000 average, interpolated from monthly averages using subroutine DAILY
Source of field trial data:
i) BC = Pacific Field Corn Association Hybrid Evaluation Program. Available at: www.farmwest.com
ii) AB and SK = Alberta Corn Committee Hybrid Corn Performance Trials. Available at: http://www.albertacorn.com
iii) MB = Manitoba Corn Committee Corn Hybrid Performance Trials. Available at: http://www.gov.mb.ca/agriculture/crops/specialcrops
iv) Nfld seeding dates are taken from Kwabiah et al., 2003.

Table 2. Relationship between date of 10% probability of occurrence of -2ºC and the average mean daily minimum air temperature (Tmin).

MSC Station #	Station name	Prov	10% probability of -2ºC	Average Tmin (ºC)
1021830	Comox A	BC	29-Oct	4.0
1016940	Saanichton CDA	BC	5-Nov	4.5
1100030	Abbotsford A	BC	30-Oct	3.7
1100120	Agassiz CDA	BC	31-Oct	4.7
1108447	Vancouver Int A	BC	31-Oct	4.5
1123970	Kelowna A	BC	18-Sep	5.1
1125760	Oliver	BC	27-Sep	5.3
1126510	Princeton A	BC	15-Sep	4.5
1163780	Kamloops A	BC	4-Oct	5.1
1183000	Fort St John A	BC	12-Sep	5.1
1192940	Fort Nelson A	BC	6-Sep	4.9
1096450	Prince George A	BC	8-Sep	4.8
1127800	Summerland CDA	BC	18-Oct	3.7
			AVERAGE:	4.6
3033890	Lethbridge CDA	AB	16-Sep	5.0
3023720	Lacombe CDA	AB	6-Sep	4.6
3012205	Edmonton A	AB	6-Sep	5.0
3072920	Grande Prairie A	AB	8-Sep	4.9
3032800	Gleichen	AB	6-Sep	5.2
			AVERAGE:	4.9
4016560	Regina A	SK	13-Sep	5.1
4057120	Saskatoon A	SK	15-Sep	4.4
4020160	Aneroid	SK	9-Sep	5.4
4047240	Scott CDA	SK	7-Sep	5.2
4055085	Melfort CDA	SK	8-Sep	5.8
4019080	Yorkton	SK	10-Sep	5.4
4012400	Estevan A	SK	14-Sep	5.6
			AVERAGE:	5.3
5010760	Deloraine	MB	12-Sep	6.4
5010480	Brandon A	MB	12-Sep	5.0
5022780	Steinbach	MB	13-Sep	6.3
5021848	Morden CDA	MB	22-Sep	6.1
5052880	The Pas A	MB	14-Sep	5.2
5040680	Dauphin A	MB	12-Sep	5.6
			AVERAGE:	5.8
8401300	Corner Brook	NFLD	13-Oct	4.1
8401501	Deer Lake A	NFLD	13-Sep	5.5
8401700	Gander Int'l A	NFLD	8-Oct	3.1
8402050	Grand Falls	NFLD	5-Oct	3.5
8403600	ST John's West CDA	NFLD	12-Oct	4.2
8403506	ST John's A	NFLD	14-Oct	3.4
8402975	Port Aux Basques	NFLD	26-Oct	2.3
8403800	Stephenville A	NFLD	21-Oct	2.5
8400650	Botwood	NFLD	3-Oct	4.5
			AVERAGE:	3.7

Table 3. Comparisons between CHU2normal, CHUave and CHU80% for various locations in Canada.

STATION NAME	PROV	STN #	CHU2normal	CHUave	Sd	CHU80%	Period
Lethbridge CDA	AB	3033890	2366	2363	259.0	2145	1971-2000
Lacombe CDA	AB	3023720	1755	1778	201.0	1609	1971-2000
Edmonton A	AB	3012205	1837	1874	232.4	1678	1971-2000
Grande Prairie A	AB	3072920	1836	1850	249.6	1640	1971-2000
Gleichen	AB	3032800	1994	2025	261.4	1805	1971-2000
Regina A	SK	4016560	2344	2364	266.4	2140	1971-2000
Saskatoon A	SK	4057120	2244	2309	250.5	2098	1971-2000
Aneroid	SK	4020160	2309	2335	257.4	2118	1971-2000
Scott CDA	SK	4047240	2048	2052	212.6	1873	1971-2000
Melfort CDA	SK	4055085	2119	2117	243.4	1912	1971-2000
Yorkton A	SK	4019080	2143	2170	239.7	1968	1971-2000
Outlook PFRA	SK	4055736	2429	2424	230.0	2230	1971-2000
Deloraine	MB	5010760	2582	2512	325.1	2238	1971-2000
Brandon A	MB	5010480	2198	2270	248.3	2061	1971-2000
Steinbach	MB	5022780	2432	2443	246.0	2236	1971-2000
Morden CDA	MB	5021848	2833	2732	296.4	2483	1971-2000
The Pas A	MB	5052880	2017	2017	211.9	1839	1971-2000
Dauphin A	MB	5040680	2215	2211	246.1	2004	1971-2000
Chilliwack	BC	1101530	2614	2451	N/A	N/A	1999-2003
Saanichton CDA	BC	1016940	2452	2359	N/A	N/A	1999-2002
Abbotsford A	BC	1100030	2664	2536	N/A	2410	1999-2006
Agassiz CDA	BC	1100120	2774	2668	N/A	2506	1999-2006
Deer Lake	NFLD	8401500	1920	2010	N/A	1770	1945-2001
Stephenville A	NFLD	8403800	1978	2084	N/A	1874	1945-2001
St John's West CDA	NFLD	8403600	1803	1780	N/A	1515	1945-2001
Deer Lake	NFLD	8401500	2059	2125	N/A	1885	1990-2001
Stephenville A	NFLD	8403800	2051	2109	N/A	1860	1990-2001
St John's West CDA	NFLD	8403600	2055	2135	N/A	2000	1990-2001

Sources:

CHU2normal is computed using the Java program and climate normals for periods indicated, except for BC where they were computed manually from average seeding to harvest dates in silage trials using spreadsheets.

For Prairies, CHUave, and Standard deviation (Sd) and CHU80% values are from Nadler, 2007; CHU80% was computed assuming a normal distribution.

For BC, CHUave were computed from silage trial data available at http://farmwest.com ; CHU80% were estimated from short term data and are therefore only approximate.

For Newfoundland, CHUave and CHU80% were taken from Kwabiah et al., 2003

Table 4: Example of input threshold file for calculating Crop Heat Units (CHU)

Latitude range		Longitude range		Start temp.	Stop temp	CHU ave		CHU 80%	
Minimum	Maximum	Minimum	Maximum			Constant	Coeff.	Constant	Coeff.
46.000	66.00	-59.5	-51.00	8.8	3.7	164.96	0.9465	-207.54	1.0342
42.000	47.95	-68.0	-59.50	11.0	5.8	185.20	0.9377	-11.80	0.9538
44.000	47.95	-74.0	-68.05	12.8	6.5	157.45	0.9194	37.55	0.9297
47.951	66.00	-79.0	-59.55	12.8	6.5	157.45	0.9194	37.55	0.9297
40.000	47.95	-95.0	-74.01	12.8	6.5	177.82	0.9150	68.62	0.9020
47.951	66.00	-95.0	-79.01	12.8	6.5	177.82	0.9150	68.62	0.9020
48.000	66.00	-101.5	-95.01	11.2	5.8	212.93	0.9071	143.75	0.8436
48.000	66.00	-110.0	-101.51	11.2	5.3	212.93	0.9071	143.75	0.8436
48.000	52.00	-115.0	-110.01	11.2	4.9	212.93	0.9071	143.75	0.8436
52.001	66.00	-120.0	-110.01	11.2	4.9	212.93	0.9071	143.75	0.8436
48.000	52.00	-136.0	-115.01	12.7	4.6	343.24	0.8427	121.28	0.8545
52.001	66.00	-140.0	-120.01	12.7	4.6	343.24	0.8427	121.28	0.8545

Table 5. Results of CHU calculations by revised Java program for 21 selected grid locations across Canada, using 1961 to 1990 climate normals.

Approx. location	Prov	Grid point co-ordinates			1961 to 1990 data						
		Lat.	Long.	Elev.	CHUnormal	Start_CHU	Stop_CHU	GDD2Stop	CHU2normal	CHUave	CHU80
Vancouver	BC	49.264	-123.042	58	2855	138	307	306	2853	2748	2560
Oliver	BC	49.125	-119.569	294	2875	132	275	267	2779	2685	2496
Fort Nelson	BC	58.847	-122.625	339	1653	154	250	246	1613	1703	1500
Lethbridge	AB	49.681	-112.764	909	2233	136	257	261	2278	2279	2066
Edmonton	AB	53.292	-113.597	713	1989	137	254	258	2028	2052	1854
Fort Vermillion	AB	58.431	-116.097	271	1874	140	249	244	1819	1863	1678
Mankota	SK	49.125	-107.069	855	2000	139	246	245	1985	2013	1818
Prince Albert	SK	53.153	-105.681	433	2064	136	250	245	2000	2027	1831
Brandon	MB	49.819	-99.986	396	2393	135	256	253	2353	2348	2129
Flin Flon	MB	54.681	-101.653	302	1968	146	256	255	1960	1991	1798
Churchill	MB	58.708	-94.014	4	377	204	234	240	423	565	450
Harrow	ON	42.042	-82.903	185	3781	128	292	300	3831	3683	3524
Ottawa	ON	45.514	-75.681	104	2623	139	266	266	2623	2578	2435
Kapuskasing	ON	49.403	-82.486	214	1630	159	249	250	1642	1680	1550
Huntingdon	QC	45.097	-74.153	47	3011	134	274	275	3021	2942	2794
Normandin	QC	48.847	-72.486	120	1890	153	253	254	1901	1906	1805
Fredericton	NB	45.931	-66.653	98	2513	137	267	263	2467	2498	2341
Halifax	NS	44.681	-63.458	12	2517	145	282	283	2524	2552	2396
Sydney	NS	46.208	-60.125	20	2141	157	279	284	2172	2222	2060
Charlottetown	PEI	46.208	-63.181	2	2528	144	279	281	2542	2569	2413
St. John's	NFLD	47.458	-52.764	81	1831	153	290	284	1820	1888	1675
			AVERAGE:		2226	145	265	265	2221	2228	2056

Table 6. Results of CHU calculations by revised Java program for 21 selected grid locations across Canada for the 2040-2069 period scenario (CGCMI ga1).

Approx. location		2040 to 2069 data						
	Prov	CHUnormal	Start_CHU	Stop_CHU	GDD2Stop	CHU2normal	CHUave	CHU80
Vancouver	BC	3929	112	324	324	3929	3655	3479
Oliver	BC	3814	109	289	280	3719	3477	3299
Fort Nelson	BC	2533	131	261	258	2505	2454	2262
Lethbridge	AB	3413	106	280	276	3363	3263	2981
Edmonton	AB	2997	113	268	272	3034	2965	2703
Fort Vermillion	AB	2644	127	263	258	2595	2567	2333
Mankota	SK	3001	109	259	258	2986	2922	2663
Prince Albert	SK	2885	124	265	259	2808	2760	2513
Brandon	MB	3442	107	270	264	3357	3258	2976
Flin Flon	MB	2698	138	269	267	2682	2646	2406
Churchill	MB	1390	165	253	258	1414	1471	1344
Harrow	ON	4671	115	302	310	4740	4515	4344
Ottawa	ON	3406	128	280	282	3426	3313	3159
Kapuskasing	ON	2413	144	265	268	2442	2413	2272
Huntingdon	QC	3794	124	287	289	3812	3666	3507
Normandin	QC	2620	141	267	271	2659	2603	2510
Fredericton	NB	3206	127	280	276	3162	3150	3004
Halifax	NS	3142	136	293	295	3156	3145	2998
Sydney	NS	2733	146	292	296	2756	2770	2617
Charlottetown	PEI	3190	135	291	292	3196	3183	3037
St. John's	NFLD	2152	146	299	292	2142	2193	2008
AVERAGE:		3051	128	279	278	3042	2971	2782

Table 7. Difference in CHU variables between 2040 to 2069 and 1961 to 1990 periods.

Approx. location	Prov	Difference (2040 to 2069 minus 1961 to 1990)			
		Start_CHU	GDD2Stop	CHUave	CHU80
Vancouver	BC	-26	18	907	919
Oliver	BC	-23	13	792	803
Fort Nelson	BC	-23	12	752	762
Lethbridge	AB	-30	15	984	915
Edmonton	AB	-24	14	913	849
Fort Vermillion	AB	-13	14	705	655
Mankota	SK	-30	13	908	845
Prince Albert	SK	-12	14	733	681
Brandon	MB	-28	11	911	847
Flin Flon	MB	-8	12	655	609
Churchill	MB	-39	18	907	894
Harrow	ON	-13	10	832	820
Ottawa	ON	-11	16	735	724
Kapuskasing	ON	-15	18	732	722
Huntingdon	QC	-10	14	723	713
Normandin	QC	-12	17	697	705
Fredericton	NB	-10	13	652	663
Halifax	NS	-9	12	592	602
Sydney	NS	-11	12	548	558
Charlottetown	PEI	-9	11	614	624
St. John's	NFLD	-7	8	305	333
		-17	14	743	726

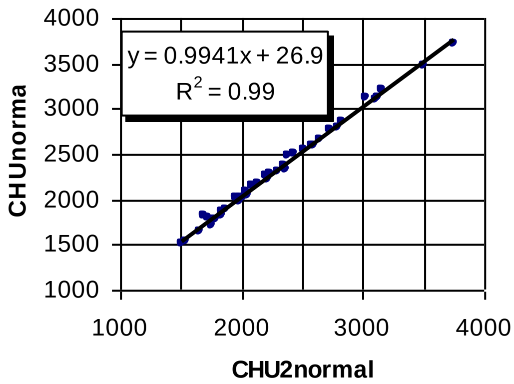

Figure 1. Comparison of CHU2normal with CHUnormal using data from 44 climate stations across Canada (1971-2000 normals).

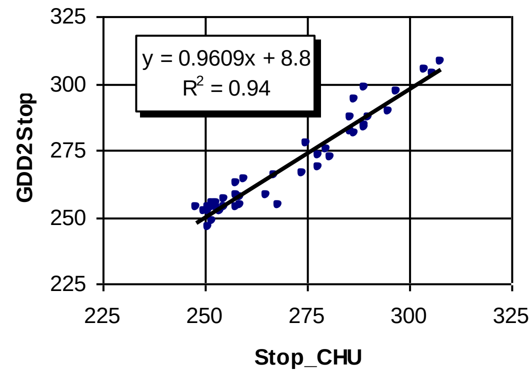

Figure 2. Comparison of two ending dates using data from 44 climate stations across Canada (1971-2000 normals).

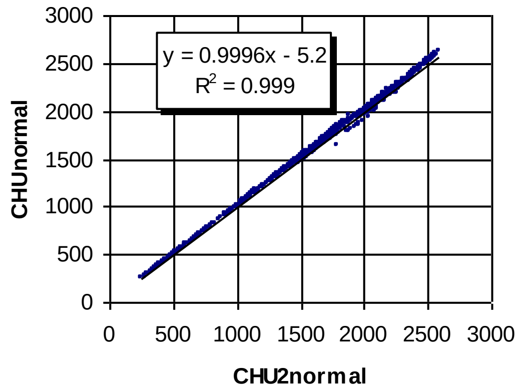

Figure 3. Comparison of CHU2normal with CHUnormal using gridded prairie strip data (1263 grid points from 49 to 65^{o}N, 109 to 11^{o}W) for 1961 to 1990 period.

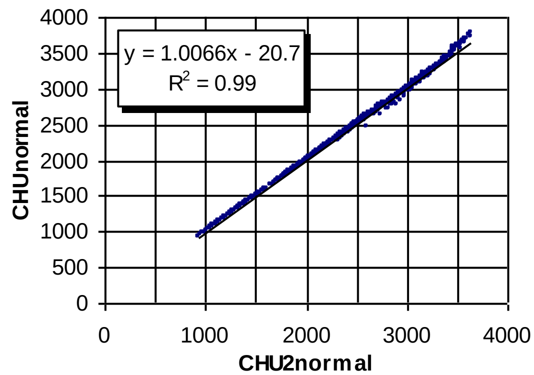

Figure 4. Comparison of CHU2normal with CHUnormal using gridded prairie strip data (1320 grid points from 49 to 65^{o}N, 109 to 11^{o}W) for 2040 to 2069 period (CGCMI ga1 scenario).

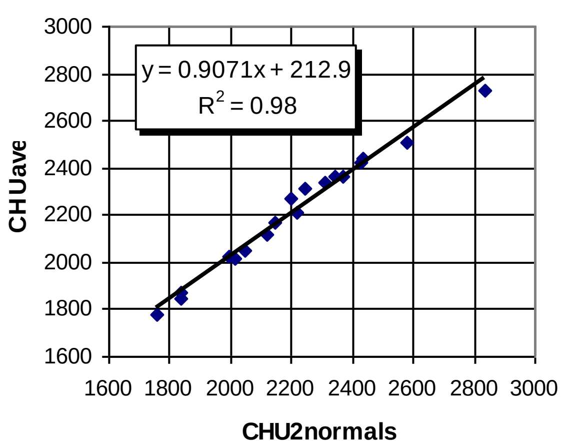

Figure 5. CHUave versus CHU2normals for Prairie provinces, 1971 to 2000 station data.

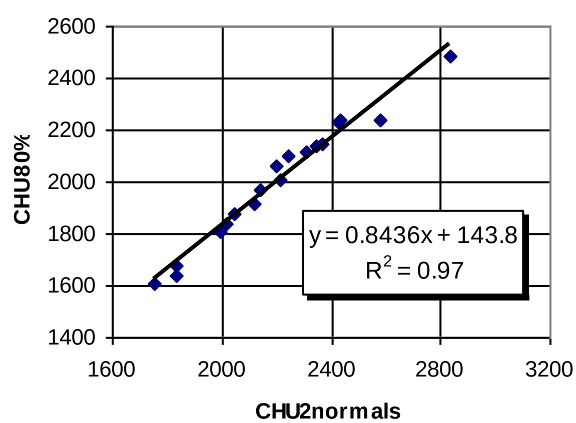

Figure 6. CHU80% versus CHU2normals for Prairie provinces, 1971 to 2000 station data.

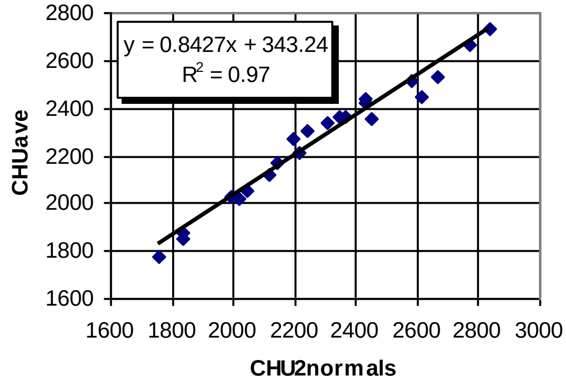

Figure 7. CHUave versus CHU2normals for British Columbia (including Prairie data).

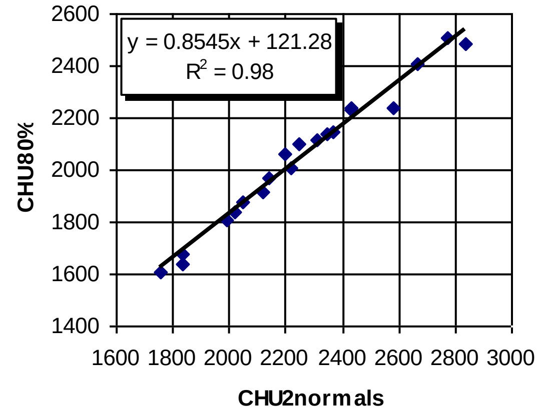

Figure 8. CHU80% versus CHU2normals for British Columbia (including Prairie data).

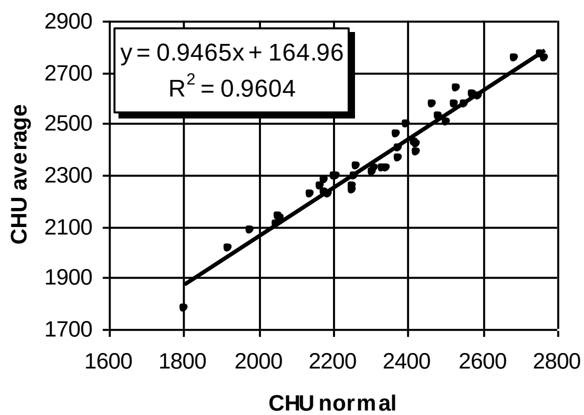

Figure 9. CHUave versus CHU2normals for Newfoundland (including Maritime provinces data).

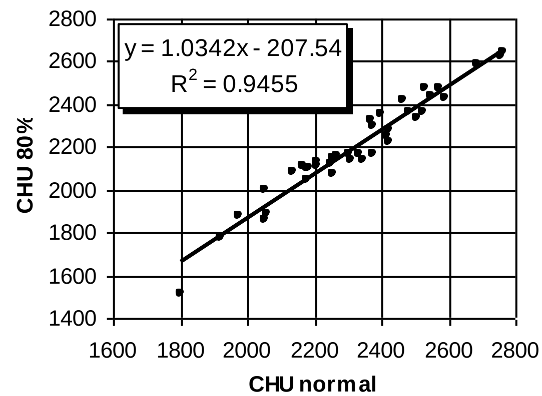

Figure 10. CHU80% versus CHU2normals for Newfoundland (including Maritime provinces data).