Cold Temperature Frequency Analysis for Alberta

Prepared by

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for the Alberta Electric System Operator

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Introduction

The Alberta Electric System Operator (AESO) requested that hourly extreme temperature data for the province of Alberta be analyzed to determine the frequency of temperatures below industry-defined thresholds. The cold threshold of interest is -40 C although other thresholds could be selected.

There are two types of weather observing stations operated for or by Environment Canada. A network of hourly weather stations provides data for aviation and other uses and is the source of hourly temperature data. Although data exists in paper copy before 1953, only the data observed from 1953 to the present has been archived in a digital format by Environment Canada. There are many more volunteer or cooperative climate stations which observe maximum and minimum temperature on a daily basis. The daily data were not used in this cold temperature analysis.

The hourly stations for Alberta and surrounding regions in Canada are shown in Figure 1. The most useful stations are the long-term stations which have operated 24 hours a day from 1953 to the present. What the figure does not indicate is which stations do not have a full 24-hour observing program. Stations with a minimum of 10 years are useful in providing better spatial coverage for the hourly analysis although they must be used with caution. Many of these shorter records commenced in the mid 1990s with the introduction of automated weather stations.

The hourly temperatures are not hourly averages but are instantaneous temperatures measured on the hour. They are commonly used to represent the temperature for the previous hour but it should be remembered that they represent a sample value on the hour. The values taken on the hour do not necessarily record the minimum temperature for the day which can occur between the hourly observations.

A FORTRAN program was written to undertake the hourly temperature analysis, “hly cold T stats m40.for”. The program computes the average annual frequency (hours) of temperatures less than specified temperatures from -30 to -50 C. The program also lists the actual frequency in hours of temperatures below -40.0 degrees Celsius for each month and year of record (see Table 1).

The output as shown in Table 1 was imported into Microsoft Excel workbooks in which it is possible to select a different threshold temperature for the summation statistics and to select the operating season of interest for up to two seasons for winter and summer seasons (see Table 2). It should be noted that a different threshold and season can be selected within the spreadsheet but the processing of the frequencies of hourly data was done externally.

Figure 1: Hourly weather stations in Alberta and the surrounding region of Canada

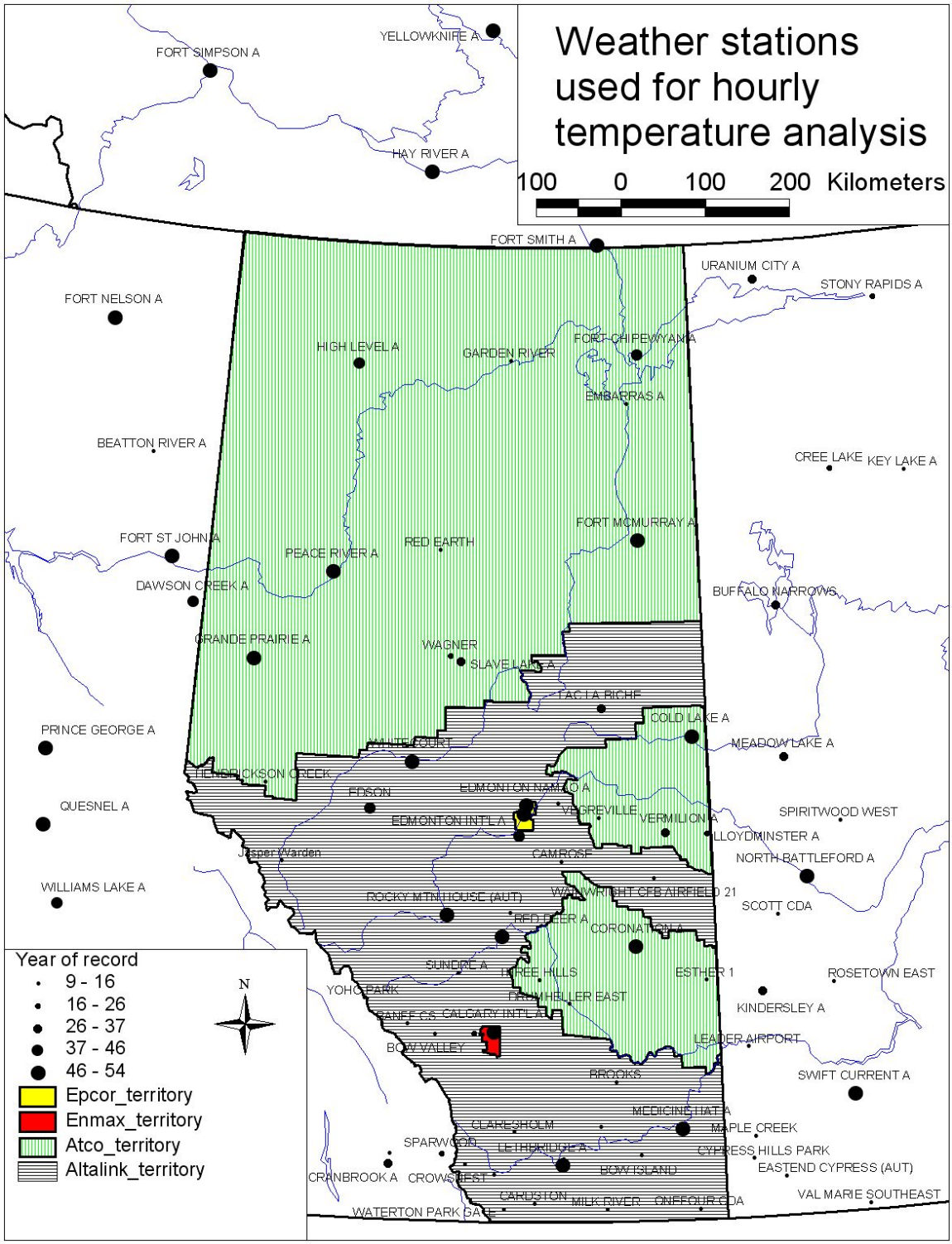


Table 1: Sample output from program "hly cold T stats m40.for" for Edmonton Int'l A

Hours with temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
< .0 C	681.53	587.89	519.28	189.70	26.33	.57	.00	.30	28.67	199.22	540.04	668.57	3442.10
< -30.0 C	49.51	12.36	4.38	.00	.00	.00	.00	.00	.00	1.93	24.04	92.23	
< -31.0 C	41.94	9.96	3.64	.00	.00	.00	.00	.00	.00	1.17	19.39	76.10	
< -32.0 C	32.04	7.28	2.47	.00	.00	.00	.00	.00	.00	.41	13.61	55.81	
< -33.0 C	24.72	5.23	1.81	.00	.00	.00	.00	.00	.00	.26	9.26	41.29	
< -34.0 C	18.81	3.98	1.38	.00	.00	.00	.00	.00	.00	.09	5.85	30.10	
< -35.0 C	14.13	2.91	1.00	.00	.00	.00	.00	.00	.00	.04	3.43	21.52	
< -36.0 C	11.49	2.13	.68	.00	.00	.00	.00	.00	.00	.02	2.13	16.45	
< -37.0 C	8.43	1.40	.45	.00	.00	.00	.00	.00	.00	.00	.96	11.23	
< -38.0 C	5.94	.87	.34	.00	.00	.00	.00	.00	.00	.00	.57	7.71	
< -39.0 C	4.04	.57	.15	.00	.00	.00	.00	.00	.00	.00	.39	5.16	
< -40.0 C	2.64	.34	.02	.00	.00	.00	.00	.00	.00	.00	.33	3.33	
< -42.0 C	1.11	.04	.00	.00	.00	.00	.00	.00	.00	.00	.20	1.34	
< -44.0 C	.34	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02	.36	
< -46.0 C	.19	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.19	
< -48.0 C	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
< -50.0 C	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
Number of years	47	47	47	47	46	46	46	46	46	46	46	47	
# hours met criterion	32032	27631	24406	8916	1211	26	0	14	1319	9164	24842	30754	160315
# hours of valid data	34968	31848	34968	33528	34224	33120	34224	34224	33120	34224	33120	34224	405792
# of missing values	18	5	10	6	0	19	14	7	4	11	14	12	120

BEGIN YEAR = 1961
END YEAR = 2007

Climate ID = 3012205

# hours < -40C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1961	0	0	0	0	0	0	0	0	0	0	0	0	0
1962	0	5	0	0	0	0	0	0	0	0	0	0	5
1963	0	0	0	0	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0	0
1966	4	0	0	0	0	0	0	0	0	0	0	0	4
1967	0	0	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	38	0	0	0	0	0	0	0	0	0	0	0	38
1970	8	0	0	0	0	0	0	0	0	0	0	0	8
1971	0	0	0	0	0	0	0	0	0	0	0	1	1
1972	36	0	1	0	0	0	0	0	0	0	0	0	37
1973	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	4	0	0	0	0	0	0	0	0	0	0	0	4
1975	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	10	0	0	0	0	0	0	0	0	0	0	0	10
1977	0	0	0	0	0	0	0	0	0	0	0	14	14
1978	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0

1982	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	8	0	0	0	0	0	0	0	0	0	0	8
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	12	3	0	0	0	0	0	0	0	0	0	0	15
1997	2	0	0	0	0	0	0	0	0	0	0	0	2
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	5	0	0	0	0	0	0	0	0	0	0	0	5
2004	4	0	0	0	0	0	0	0	0	0	0	0	4
2005	1	0	0	0	0	0	0	0	0	0	0	0	1

	2006	0	0	0	0	0	0	0	0	0	0	0	0	0
	2007	0	0	0	0	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
Maximum		38	8	1	0	0	0	0	0	0	0	14	38	

Tables 1 and 2 show that for Edmonton International Airport, many years do not experience a temperature colder than -40 C while a particularly cold January in 1969 recorded 38 hours of temperatures less than -40C. Calgary Int'l A (not shown) has no hours with temperatures colder than -40 C for the entire period 1953 to 2007.

Table 2: Sample spreadsheet table of hourly temperature exceedances for Edmonton Int'l A

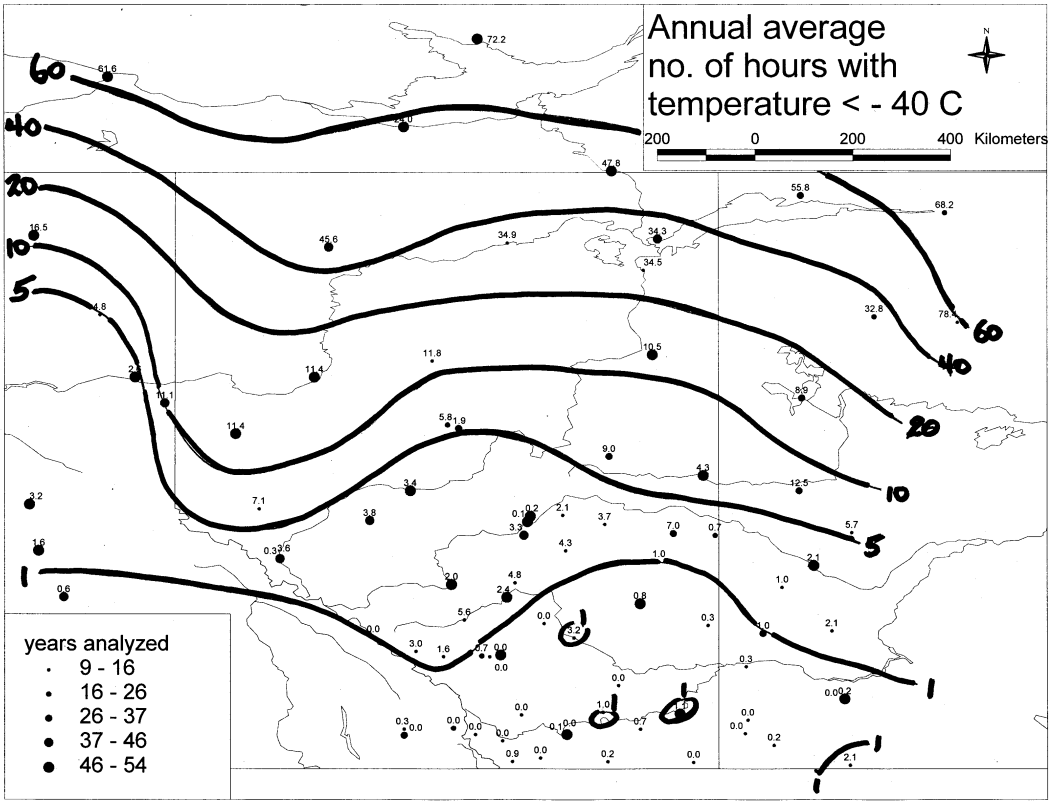
Hours with temperature		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
<	0 C	681.53	587.89	519.28	189.7	26.33	0.57	0	0.3	28.67	199.22	540.04	668.57	3442.1
<	-30 C	49.51	12.36	4.38	0	0	0	0	0	0	0	1.93	24.04	92.23
<	-31 C	41.94	9.96	3.64	0	0	0	0	0	0	0	1.17	19.39	76.1
<	-32 C	32.04	7.28	2.47	0	0	0	0	0	0	0	0.41	13.61	55.81
<	-33 C	24.72	5.23	1.81	0	0	0	0	0	0	0	0.26	9.26	41.29
<	-34 C	18.81	3.98	1.38	0	0	0	0	0	0	0	0.09	5.85	30.1
<	-35 C	14.13	2.91	1	0	0	0	0	0	0	0	0.04	3.43	21.52
<	-36 C	11.49	2.13	0.68	0	0	0	0	0	0	0	0.02	2.13	16.45
<	-37 C	8.43	1.4	0.45	0	0	0	0	0	0	0	0	0.96	11.23
<	-38 C	5.94	0.87	0.34	0	0	0	0	0	0	0	0	0.57	7.71
<	-39 C	4.04	0.57	0.15	0	0	0	0	0	0	0	0	0.39	5.16
<	-40 C	2.64	0.34	0.02	0	0	0	0	0	0	0	0	0.33	3.33
<	-42 C	1.11	0.04	0	0	0	0	0	0	0	0	0	0.2	1.34
<	-44 C	0.34	0	0	0	0	0	0	0	0	0	0	0.02	0.36
<	-46 C	0.19	0	0	0	0	0	0	0	0	0	0	0	0.19
<	-48 C	0	0	0	0	0	0	0	0	0	0	0	0	0
<	-50 C	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of years		47	47	47	47	46	46	46	46	46	46	46	46	47
# hours met criterion		32032	27631	24406	8916	1211	26	0	14	1319	9164	24842	30754	160315
# hours of valid data		34968	31848	34968	33528	34224	33120	34224	34224	33120	34224	33120	34224	405792
# of missing values		18	5	10	6	0	19	14	7	4	11	14	12	120
BEGIN YEAR = 1961														
END YEAR = 2007														
Climate ID = 3012205														

number of hours < -40C		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	1953													
	1954													
	1955													
	1956													
	1957													
	1958													
	1959													
	1960													
	1961	0	0	0	0	0	0	0	0	0	0	0	0	0
	1962	0	5	0	0	0	0	0	0	0	0	0	0	5
	1963	0	0	0	0	0	0	0	0	0	0	0	0	0
	1964	0	0	0	0	0	0	0	0	0	0	0	0	0
	1965	0	0	0	0	0	0	0	0	0	0	0	0	0
	1966	4	0	0	0	0	0	0	0	0	0	0	0	4
	1967	0	0	0	0	0	0	0	0	0	0	0	0	0
	1968	0	0	0	0	0	0	0	0	0	0	0	0	0
	1969	38	0	0	0	0	0	0	0	0	0	0	0	38
	1970	8	0	0	0	0	0	0	0	0	0	0	0	8
	1971	0	0	0	0	0	0	0	0	0	0	0	1	1
	1972	36	0	1	0	0	0	0	0	0	0	0	0	37
	1973	0	0	0	0	0	0	0	0	0	0	0	0	0
	1974	4	0	0	0	0	0	0	0	0	0	0	0	4
	1975	0	0	0	0	0	0	0	0	0	0	0	0	0
	1976	10	0	0	0	0	0	0	0	0	0	0	0	10
	1977	0	0	0	0	0	0	0	0	0	0	0	14	14
	1978	0	0	0	0	0	0	0	0	0	0	0	0	0
	1979	0	0	0	0	0	0	0	0	0	0	0	0	0
	1980	0	0	0	0	0	0	0	0	0	0	0	0	0
	1981	0	0	0	0	0	0	0	0	0	0	0	0	0
	1982	0	0	0	0	0	0	0	0	0	0	0	0	0
	1983	0	0	0	0	0	0	0	0	0	0	0	0	0
	1984	0	0	0	0	0	0	0	0	0	0	0	0	0
	1985	0	0	0	0	0	0	0	0	0	0	0	0	0
	1986	0	0	0	0	0	0	0	0	0	0	0	0	0
	1987	0	0	0	0	0	0	0	0	0	0	0	0	0
	1988	0	0	0	0	0	0	0	0	0	0	0	0	0
	1989	0	0	0	0	0	0	0	0	0	0	0	0	0
	1990	0	0	0	0	0	0	0	0	0	0	0	0	0
	1991	0	0	0	0	0	0	0	0	0	0	0	0	0
	1992	0	0	0	0	0	0	0	0	0	0	0	0	0
	1993	0	0	0	0	0	0	0	0	0	0	0	0	0
	1994	0	8	0	0	0	0	0	0	0	0	0	0	8
	1995	0	0	0	0	0	0	0	0	0	0	0	0	0
	1996	12	3	0	0	0	0	0	0	0	0	0	0	15
	1997	2	0	0	0	0	0	0	0	0	0	0	0	2
	1998	0	0	0	0	0	0	0	0	0	0	0	0	0
	1999	0	0	0	0	0	0	0	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0	0	0	0	0	0
	2001	0	0	0	0	0	0	0	0	0	0	0	0	0
	2002	0	0	0	0	0	0	0	0	0	0	0	0	0
	2003	5	0	0	0	0	0	0	0	0	0	0	0	5
	2004	4	0	0	0	0	0	0	0	0	0	0	0	4
	2005	1	0	0	0	0	0	0	0	0	0	0	0	1
	2006	0	0	0	0	0	0	0	0	0	0	0	0	0
	2007	0	0	0	0									
Maximum no. of hours <-40C		38	8	1	0	0	0	0	0	0	0	0	14	38
Annual median no. of hours <-40C														0
Years of Record														46
User enter winter season	Nov	Apr												
User enter summer season	May	Oct												
Hourly violations														
User enter winter threshold	-40	2.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.3
User enter summer threshold	0	0.0	0.0	0.0	0.0	26.3	0.6	0.0	0.3	28.7	199.2	0.0	0.0	255.1

Spatial Frequency of Cold Temperatures

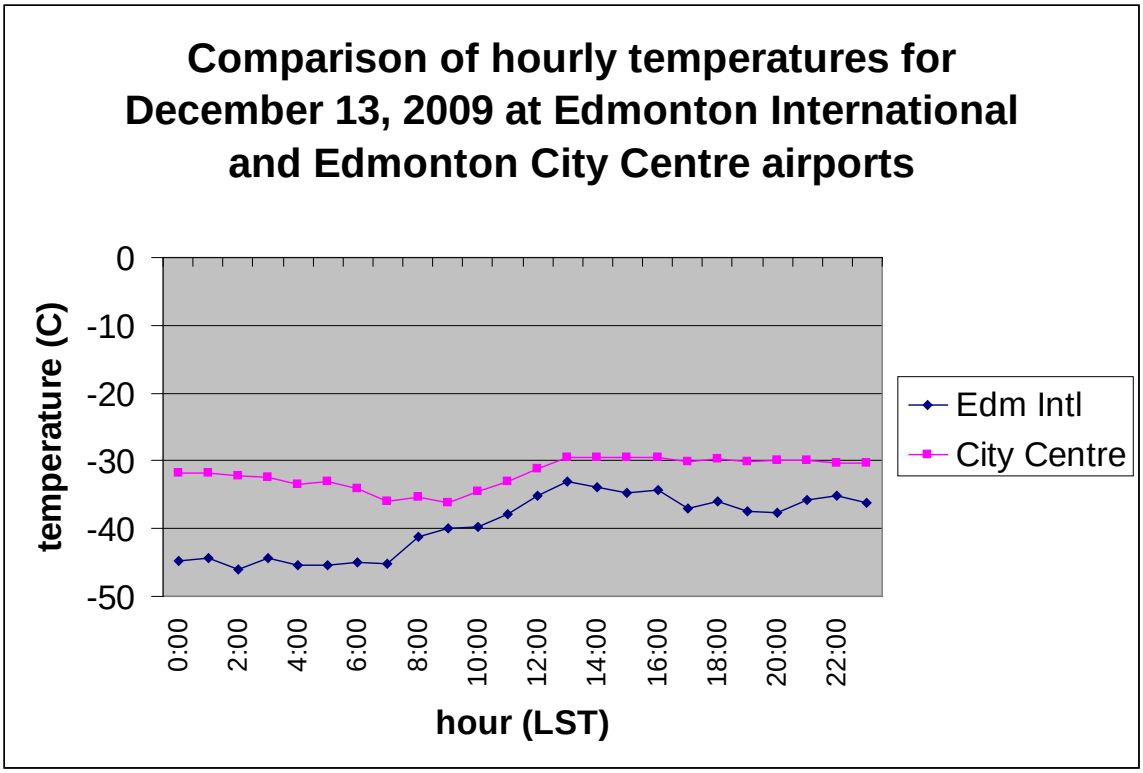
There are several ways to represent the frequency of cold temperatures. For example the annual average number of hours less than -40 C illustrates that on average -40 C rarely occurs over southern Alberta (Figure 2) whereas over the northern portion of the province the frequency ranges from 5 hours per year at the latitude of Cold Lake to about 50 hours per year near the NWT border.

Figure 2: Average annual number of hours with temperature less than -40 C



The values plotted for number of hours in Figure 2 come directly from the seasonal information at the bottom of Table 2 for each of the respective stations (for example 3.3 hours for Edmonton Int'l A). The influence of the heat island created by the city of Edmonton is evident in comparing the figure of 0.1 hours per year at Edmonton City Centre with the frequency at Edmonton International Airport. Large urban centers like Edmonton are well known to be warmer than the surrounding rural area because of residential and industrial heating and other combustion sources. This was very evident on several days from December 12 to 14, 2009 when Edmonton International airport record minimum temperatures below -40 while Edmonton City Centre had minimum temperatures about 10 C warmer (Figure 3).

Figure 3: Hourly temperatures at Edmonton International and Edmonton City Centre airports on December 13, 2009



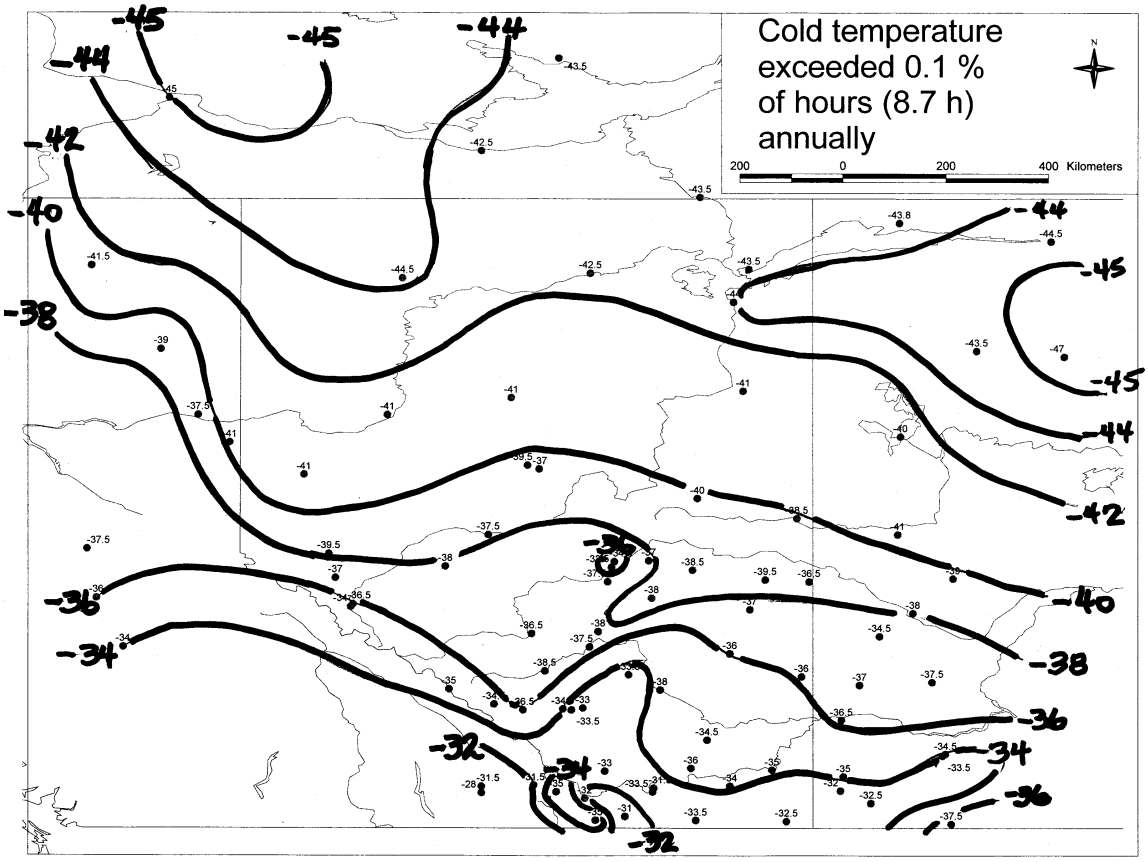
Calgary's airport is located near the edge of the city and is probably experiencing increased urban influence over the past decade or so with the northward development of the city. However, Calgary Int'l A has never recorded a temperature of -40C. Most other airports are located sufficiently far from significant urban influences as to be more truly representative of the rural climate. Some low lying areas are subject to cold air pooling as shown by some non-zero average frequencies of temperatures below -40C over southern Alberta in Figure 2.

Another way to represent cold temperature frequencies is to express them as a cold temperature which will be negatively exceeded 0.1 percent of the time or 8.76 hours per year on average (24 h times 365 days = 8760 hours. Note: leap years ignored as no significant difference). The upper portion of Table 2 was used to determine the 0.1 % cold temperature for each station by finding the location in the last column (annual) of Table 2 that was closest to 8.76 hours and determining the corresponding temperature to the nearest half degree Celsius. For Edmonton International, the temperature corresponding most closely to 8.76 hours was -37.5 C (see Table 3). The highlighted rows show the values that bracket 8.76 hours. A similar procedure was used for all of the hourly stations and the values plotted in Arcview © for spatial analysis and contoured manually (Figure 4)

Table 3: Calculating the 0.1 % cold temperature for three stations

	Edmonton	0.1 % T		Grande Prairie	0.1 % T		Fort Smith	0.1 % T
0.0	3442.1		0.0	3384.7		0.0	4354.9	
-30.0	92.2		-30.0	148.3		-30.0	498.7	
-31.0	76.1		-31.0	130.3		-31.0	441.8	
-32.0	55.8		-32.0	103.8		-32.0	370.4	
-33.0	41.3		-33.0	82.1		-33.0	307.2	
-34.0	30.1		-34.0	64.4		-34.0	248.8	
-35.0	21.5		-35.0	49.6		-35.0	197.2	
-36.0	16.5		-36.0	40.4		-36.0	166.3	
-37.0	11.2	-37.5	-37.0	31.1		-37.0	131.2	
-38.0	7.7		-38.0	22.6		-38.0	97.3	
-39.0	5.2		-39.0	16.7		-39.0	70.1	
-40.0	3.3		-40.0	11.4	-41.0	-40.0	47.8	
-42.0	1.3		-42.0	5.5		-42.0	23.3	-43.5
-44.0	0.4		-44.0	1.4		-44.0	7.8	
-46.0	0.2		-46.0	0.3		-46.0	2.6	
-48.0	0.0		-48.0	0.1		-48.0	0.2	
-50.0	0.0		-50.0	0.0		-50.0	0.0	

Figure 4: Cold temperature exceeded 0.1 % of the time (8.76 hours) on an annual basis.



From approximately the latitude of Cold Lake northward, a temperature of -40 C on average will be negatively exceeded 0.1 % of the time annually or 8.76 hours. For points further south, this

does not mean that -40 C cannot occur but rather that it is rarer than 8.76 hours per year. For example, Edmonton Int'l has 3.3 hours annually with a temperature less than -40 C but that is less frequent than 0.1 % of the hours (only 3.33 hours on average versus the 8.76 hours).

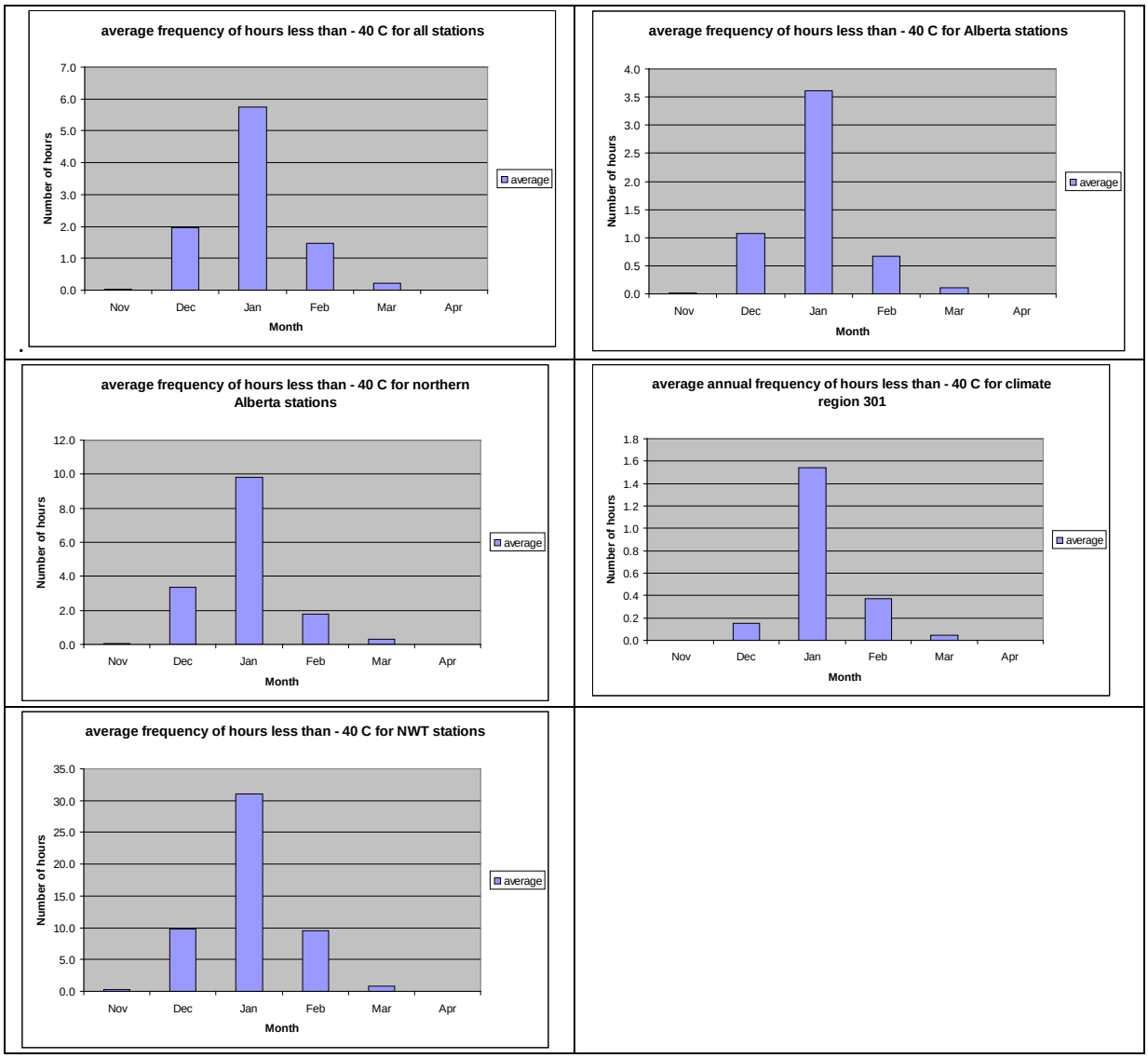
The interpolation error from the station tables is +/- 0.3 C down to -40 C and +/- 0.5 C below -40 C. Variation in record length is another possible source of error and the lack of nighttime observations at some stations is yet another. Both factors could tend to give such records a warm bias relative to stations with full 24-hour observing programs and/or complete records from 1953 to 2007. These biases are difficult to quantify but could be up to +1.5 C at a given station. Another source of error is the frost hollow phenomenon which will result in greater frequencies of cold temperatures at those locations. The urban heat island is yet another source of error and it can be very significant. For example, Edmonton City Centre statistics do not represent the nearby rural area! The movement of stations, particularly those at airports, can result in a non homogeneous record which could affect the extreme statistics. Other changes at airports such as major construction of buildings near the instrument compound may impact the frequency of cold temperatures.

The contour mapping of the 0.1 % temperature is a better guide than relying solely on the nearest station data because greater weight has been given to long record stations with full 24-hour observing programs.

Temporal Distribution of cold temperatures

The mostly likely month of occurrence for temperatures colder than -40 C is January (see Figure 5). There are also significant non-zero frequencies in December and February although the frequencies in these months are about a third or less of the January frequency. Temperatures less than -40 C can occur in November and March, but such occurrences are quite rare even in the NWT stations. It should be noted that the graphs in Figure 5 have different ordinate scales and there was no plot for extreme southern Alberta where occurrences are virtually zero!

Figure 5: Monthly frequency distribution of temperatures less than -40 C for all stations in study, for Alberta stations, for northern Alberta only, for climate region 301 (includes Edmonton, Lloydminster and Rocky Mountain House) and for the NWT stations bordering northern Alberta.

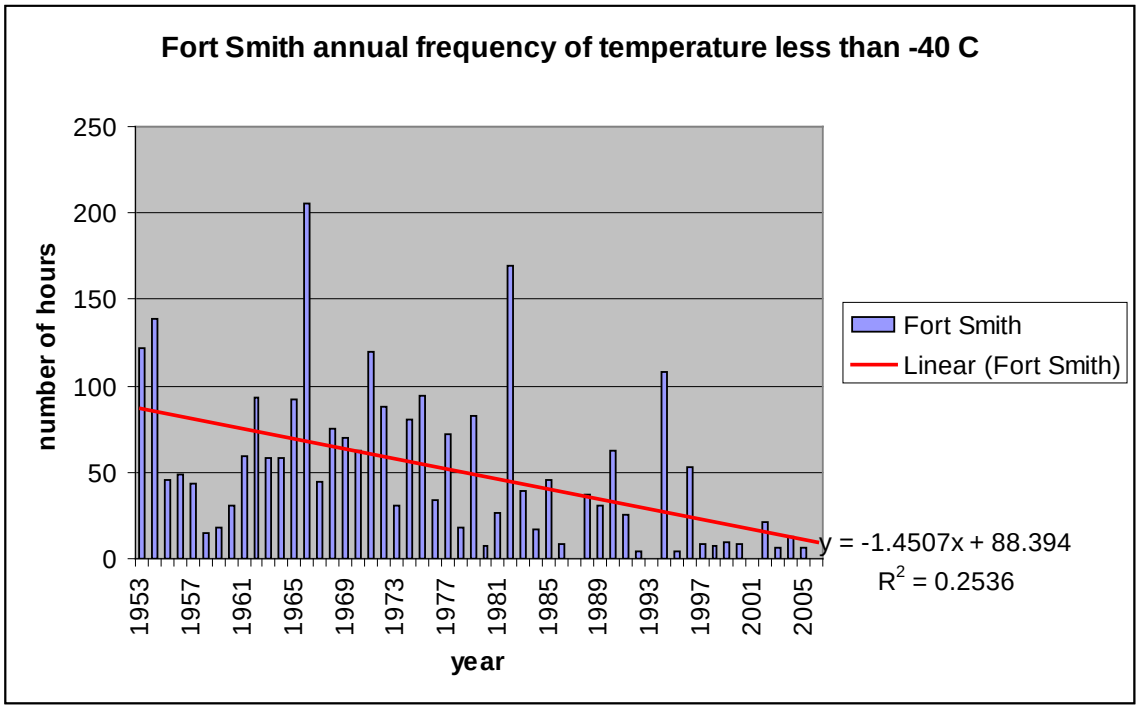


Trend analysis of cold temperatures

The statistics derived in this study are based on the period 1953 to 2007 during which time there has been a significant warming of surface temperatures on a global scale as documented in the most recent IPCC report and elsewhere. There was no significant trend in extreme high temperatures over Alberta during the summer months during this period. However, winter and spring temperatures over much of Canada have become less cold on average.

The number of hours with temperatures below -40 C appears to be decreasing at most stations over northern Alberta. This is demonstrated most graphically by Fort Smith (Figure 6) where the annual frequency has decreased to almost zero. The linear trend line as shown is statistically significant at the 99% confidence level.

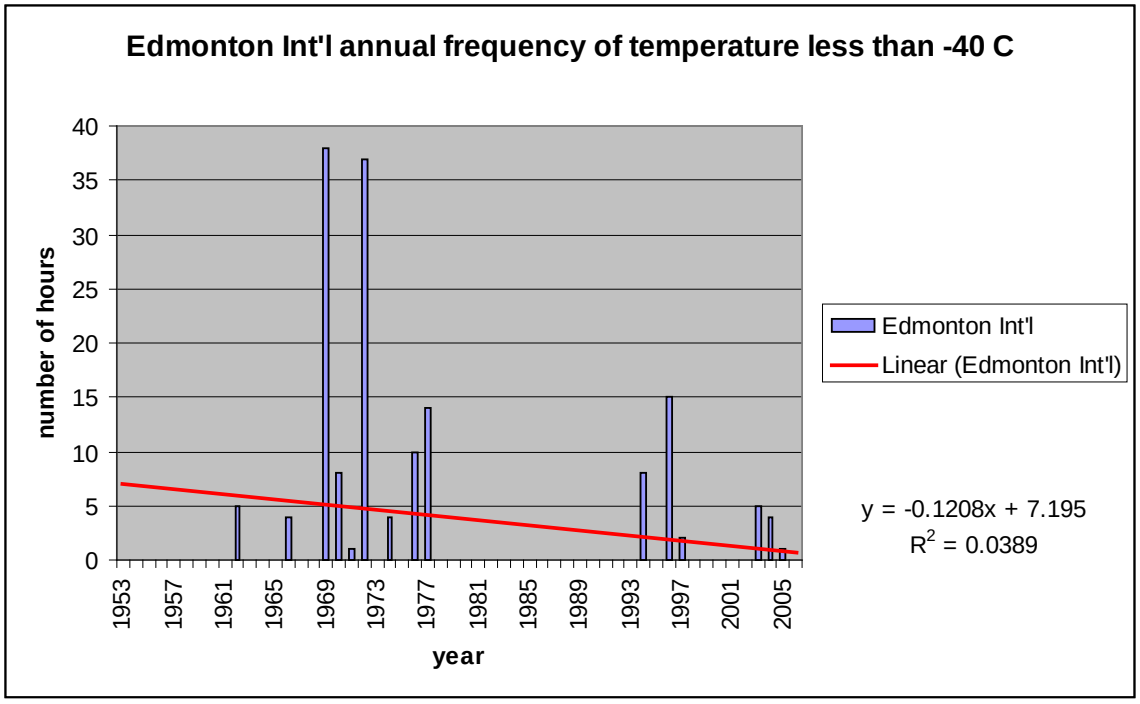
Figure 6: Trend analysis of extreme cold temperatures at Fort Smith.



Yellowknife also has a negative trend which is statistically significant at the 95% confidence level but not at the 99.5% confidence level.

For stations further south, there is a mixture of results with most stations showing a weak negative trend with time but some such as Cold Lake showing no trend. Edmonton Int'l airport as shown in Figure 7 has a weak negative trend but the trend is not statistically significant even at the 95 % confidence level. Even with negative trends, there can still be cold spells such as December 12 to 14, 2009 at Edmonton Int'l. In total there were 25 hours in 2009 with temperatures below -40 C which is comparable with the high frequencies in 1969 and 1972.

Figure 7: Trend analysis of extreme cold temperatures at Edmonton Int'l airport.


Edmonton Int'l annual frequency of temperature less than -40 C
number of hours
40
35
30
25
20
15
10
5
0
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001
2005
year
Edmonton Int'l
Linear (Edmonton Int'l)
y = -0.1208x + 7.195
R2 = 0.0389

Summary

All hourly weather stations in Alberta and neighbouring regions of Canada were analyzed with respect to the average frequency of cold temperatures. The same program also identified the monthly and annual frequency of hourly temperatures below -40 C. This information was imported into individual Excel workbooks for subsequent analysis. The cold temperature analysis focused on temperatures colder than -40 C. The average frequencies were copied to a summary spreadsheet and imported into Microsoft Access and displayed spatially in Arcview. Two maps were included in this report – the annual average number of hours below -40 C and the temperature which on average is negatively exceeded at each station 0.1 % of the time annually (8.76 hours). Values range from -32 C in southern Alberta to -44 C in the northwest corner of the province. The mostly like month for hourly temperatures below -40 C is January followed by December and February.

The trend analysis in the annual number of hours with temperatures colder than -40 C was inconclusive. The number of hours of temperatures below -40C is highly variable from year to year but there does appear to be a weak downward trend in the number of hours with time at most stations in northern Alberta.

Excel worksheets exist for all stations used in this analysis.