The Extent of Climate Warming in Canada (Updated)

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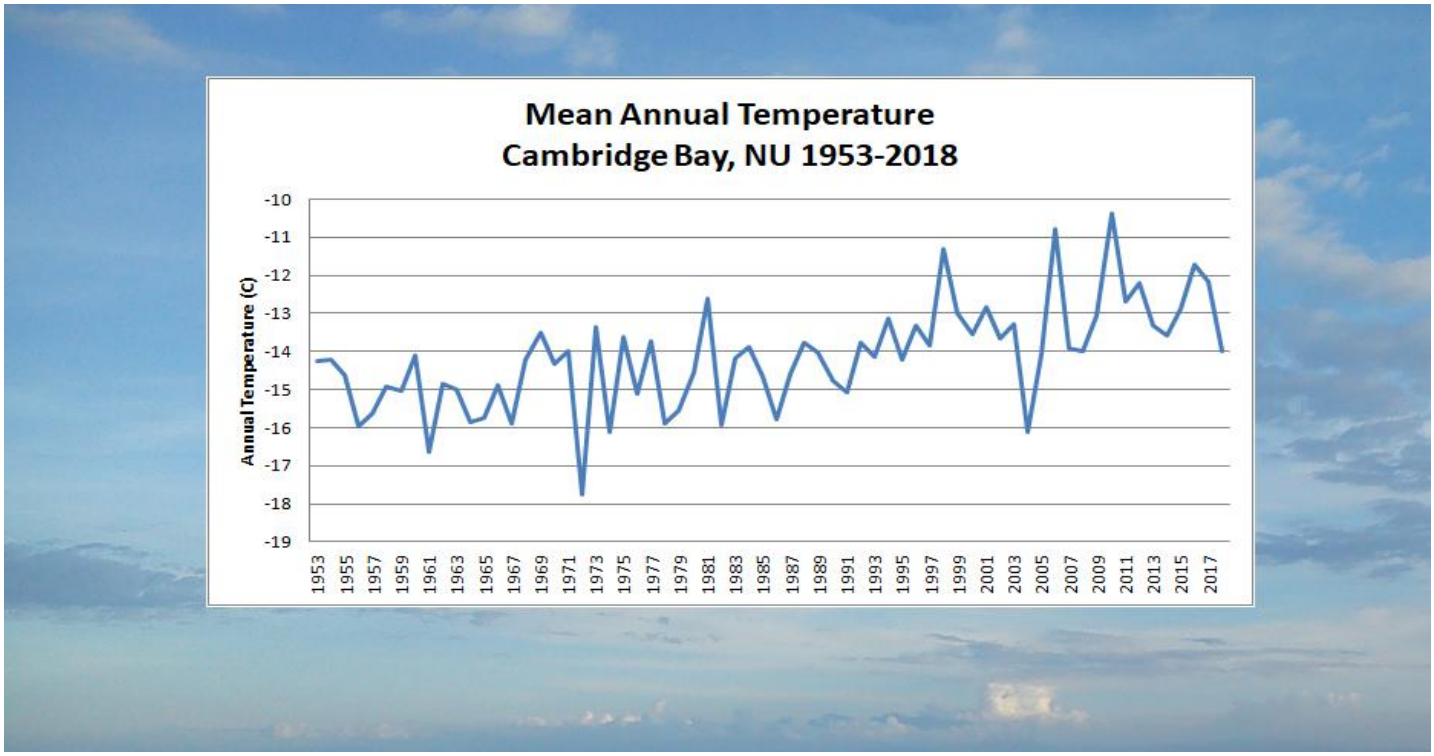

(This study was updated by adding data from an additional nine stations, as well as adding data from 2018. Thirty year analyses dropped 1988 and added 2018.)

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Overview

This paper measures the impact of global warming at nineteen Canadian sites from 1953 to 2018. Daily mean temperatures (the average of maximum and minimum temperatures) were collected and analyzed for each year during the period 1953 to 2018. The data was for nineteen sites across Canada from coast to coast and into the Arctic. The results would be slightly different than official annual mean temperatures, in that official annual mean temperatures are the average of mean temperatures for twelve months, while these results calculate the mean temperature for 365 (or 366) days of the year.

In March, 2019 the Government of Canada published a report entitled "Canada's Changing Climate Report" (CCCR). The report claims that temperatures in Canada rose an average of 1.7 Deg. C since 1948.

Between 1948 and 2016, the best estimate of mean annual temperature increase is 1.7ºC for Canada as a whole and 2.3ºC for northern Canada.[1]

The data and conclusions of this study are in line with the CCCR report. In the analysis of individual stations, there is a considerable variance in the temperature changes across the country. However, the average increasing trend of 2.2 Deg. C per 100 years is close to the CCCR actual estimate of the increase since 1948 (68 years) of 1.7 Deg. C.

The projections into the future in the CCCR report are also stated.

Averaged over the country, warming projected in a low emission scenario is about 2ºC higher than the 1986–2005 reference period, remaining relatively steady after 2050, whereas in a high emission scenario, temperature increases will continue, reaching more than 6ºC by the late 21st century.[2]

This study analyzes projections from a prominent Canadian climate model through to 2100 at the nineteen stations. The results are very similar to the above conclusions in the CCCR report.

The CCCR report states that the increases in temperatures, both actual and projected, in Canada are nearly twice that of the whole globe. This would be expected, since land temperatures warm more quickly than the ocean surface, and since Canada is located in the northern latitudes where temperatures are increasing more rapidly than at lower latitudes. Other countries in the northern hemisphere at northern latitudes are showing similar trends[3].

[1] Canada's Changing Climate Report, Natural Resources Canada, March 2019, p. 116.
[2] Ibid, p. 116
[3] Climate in Svalbard 2100, Norwegian Meteorological Institute. p. 56

The Data

Table 1 lists the nineteen observation points and years of data that were included in the study.

Table 1 Observation Points for Temperature Data

City, Province	Years Analyzed	Missing Data	Notes
St John's NL	1953-2018		St. John's International Airport
Halifax, NS	1961-2018		Halifax International Airport
Bagotville, QC	1953-2018		CFB Bagotville
Montreal, QC	1953-2018		Trudeau International Airport
Ottawa, ON	1953-2018		CDA Station
Toronto, ON	1953-2018		Pearson International Airport
Timmins, ON	1955-2018		Timmins Airport
Winnipeg, MB	1953-2018		Winnipeg International Airport
Churchill, MB	1953-2018		Churchill Airport
Regina, SK	1953-2005 2006-2018		Regina Airport Regina Climate Station
Cold Lake, AB	1954-2018		CFB Cold Lake
Edmonton A, AB	1961-2018		Edmonton International Airport
Lethbridge, AB	1953-2018		Lethbridge Airport
Kamloops, BC	1953-2018		Kamloops Airport
Fort nelson, BC	1953-2018		Fort nelson Airport
Victoria, BC	1953-2018		Victoria International Airport
Sandspit, BC	1953-2018	1993-1995 2007-2010	Sanndspit Airport
Iqaluit, NU	1953-2018		Iqaluit International Airport
Cambridge Bay, NU	1953-2018		Cambridge Bay Airport

Figure 1 shows the nineteen stations on a map of Canada.

Figure 1 - Map of Nineteen Stations

Results:

Table 2 presents the results of the analysis by displaying the annual rate of change that was calculated by finding the linear equation for the best-fit trend line for the data sample. For the period of record since 1953, all annual rates of change were positive, with the range of values being 0.0121 Deg. C at Regina to 0.0432 Deg. C at Cambridge Bay. Since it appears from the graphs that the rate of change may be accelerating, the mean annual temperatures for the last 30 years (1989-2018) were analyzed separately. These results are presented in the last column of the Annual Rate of Change data. The results show that the rate of increase is an average of 10% greater in the last thirty years than for the whole 66 years. Eight stations in Western Canada are exceptions to this trend, with three stations actually showing a negative trend in the last 30 years. For these eight stations, climate warming appeared to peak in the 1980's and 1990's, with colder years since 2010. Climate warming describes an overall trend over decades, although there are natural cycles of warming and cooling embedded in the trend.

Table 2 - Annual Change Per Year 1953-2018

City, Province	Days in Sample	Annual Rate of Change 1953-2018	Annual Rate of Change 1989-2018
St John's NL	24,019	0.0153 Deg. C	0.0546 Deg. C
Halifax, NS	21,604	0.0290 Deg. C	0.0463 Deg. C
Bagotville, QC	24,104	0.0210 Deg. C	0.0499 Deg. C
Montreal, QC	23,991	0.0214 Deg. C	0.0475 Deg. C
Ottawa, ON	24,107	0.0269 Deg. C	0.0386 Deg. C
Toronto, ON	24,032	0.0315 Deg. C	0.0505 Deg. C
Timmins, ON	23,287	0.0175 Deg. C	0.0103 Deg. C
Winnipeg, MB	23,795	0.0179 Deg. C	0.0215 Deg. C
Churchill, MB	23,986	0.0292 Deg. C	0.0268 Deg. C
Regina, SK	24,031	0.0121 Deg. C	-0.0015 Deg. C
Cold Lake, AB	23,900	0.0303 Deg. C	0.0317 Deg. C
Edmonton A, AB	21,131	0.0173 Deg. C	-0.014 Deg. C
Lethbridge, AB	22,349	0.0091 Deg. C	0.0094 Deg. C
Kamloops, BC	23,736	0.0236 Deg. C	0.0108 Deg. C
Fort Nelson, BC	23,990	0.0327 Deg. C	0.0311 Deg. C
Victoria, BC	24,055	0.0159 Deg. C	0.0115 Deg. C
Sandspit, BC	22,960	0.0037 Deg. C	-0.049 Deg. C
Iqaluit, NU	24,055	0.0188 Deg. C	0.0251 Deg. C
Cambridge Bay, NWT	24,069	0.0432 Deg. C	0.0554 Deg. C
Averages		**0.0218 Deg. C**	**0.0239 Deg. C**

Figures 2 to 4 display the results for all nineteen locations on a graph for the period 1953 - 2018. It is apparent from the graphs that certain subsets of the period in question have different trends. The first twenty years, for example, show a downward trend in temperatures. The general upward trend is apparent from about 1975 onwards. After 2000, the rising temperature trend plateaus, and from 2009 onwards for 11 of the 19 stations, the temperature trend is negative. Even in the Arctic where the temperatures are rising the most, the trend is towards colder temperatures since 2009. A few cold years can easily mask a general trend. It is important to look at long term trends for 30 years or more since year to year fluctuations make it difficult to identify an overall trend. Natural cycles occur where a decade of warming is often followed by a decade of cooling.

Figure 2 - Annual Mean temperatures - Eastern Canada 1953-2018

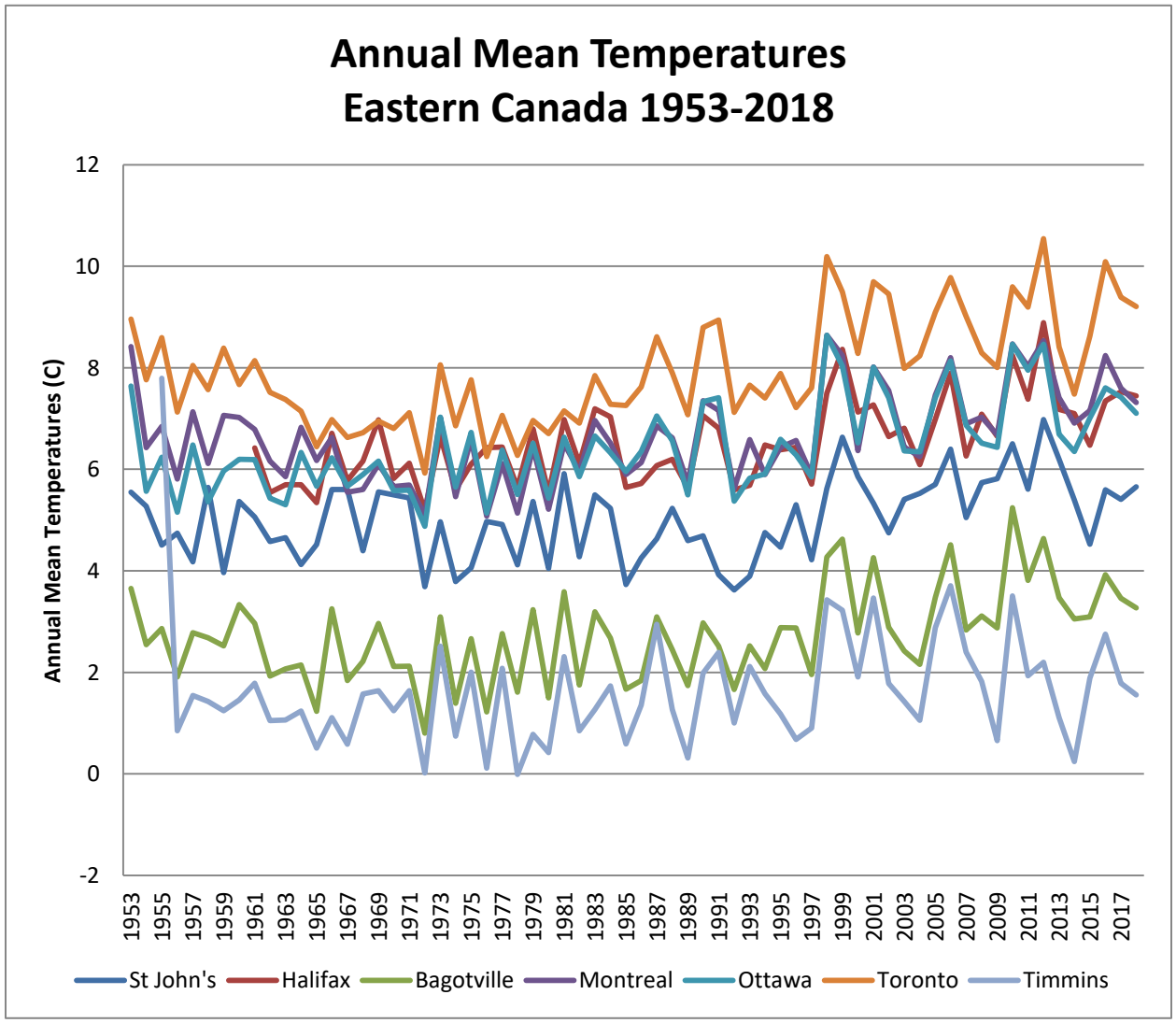


Figure 3 - Annual Mean Temperatures - Western Canada 1953-2018

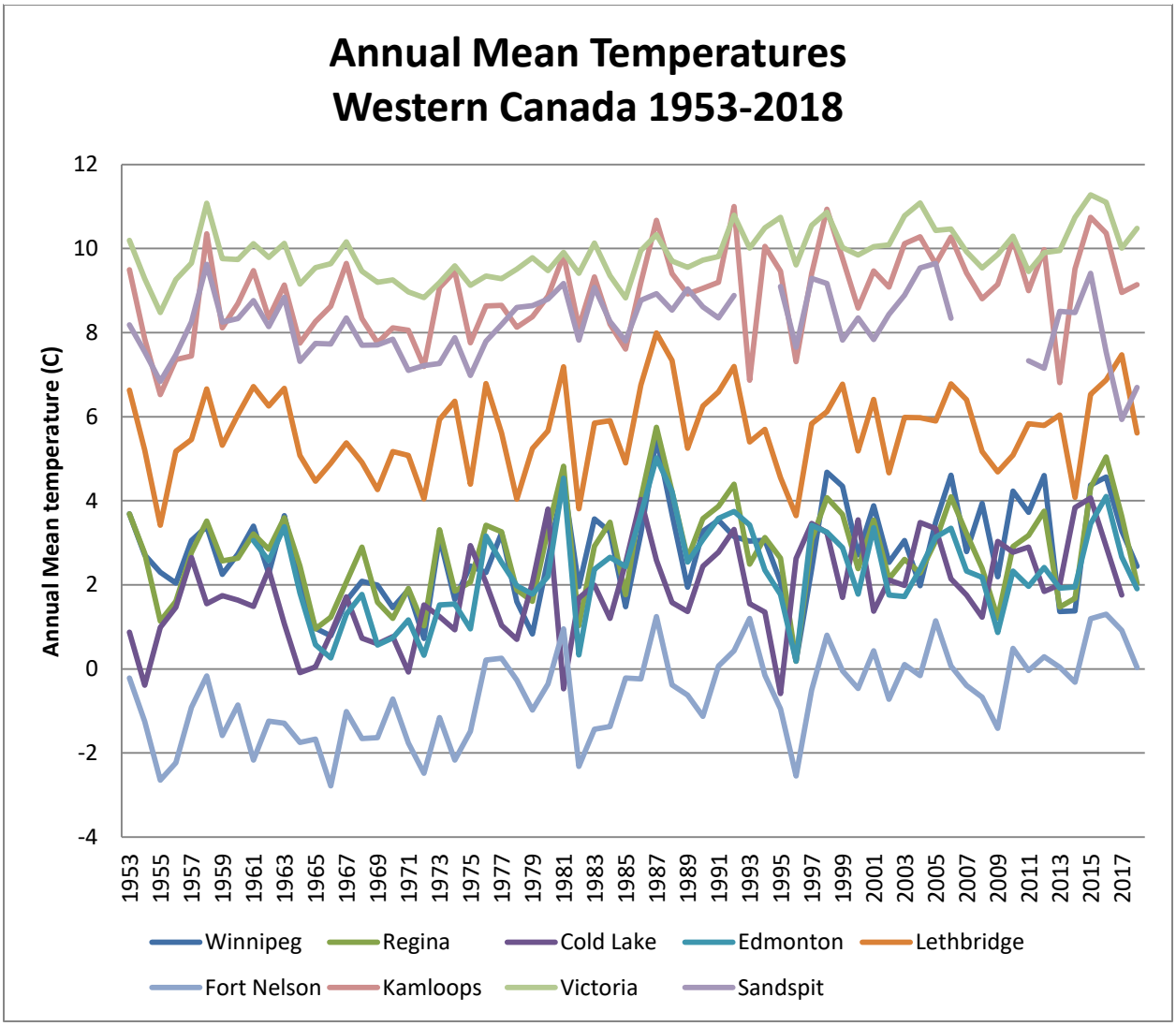
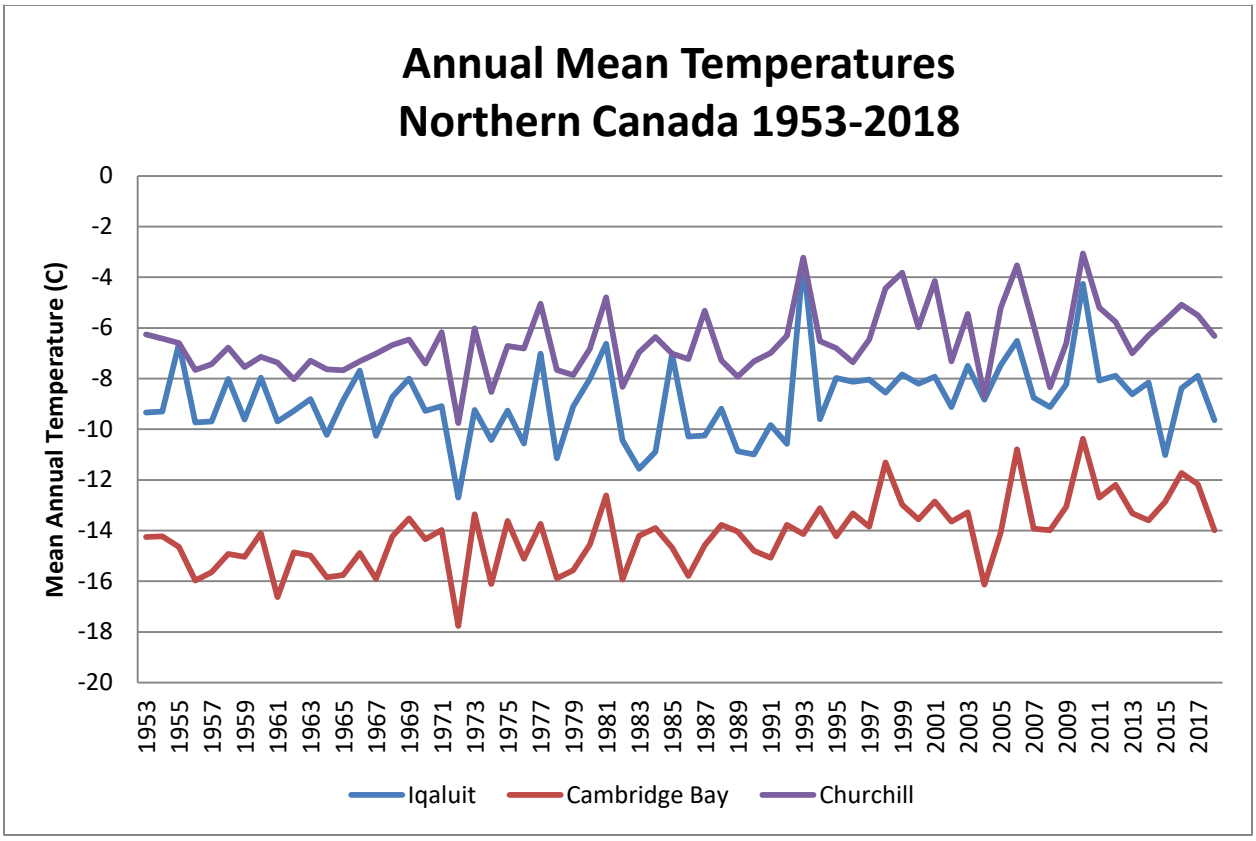


Figure 4 - Annual Mean Temperatures - Northern Canada 1953-2018



The greatest degree of warming is at Cambridge Bay in the Arctic, approximately 4.3 Deg. C per 100 years for the entire record and 5.5 Deg. C per 100 years for the last 30 years. The least changes have occurred at Sandspit where the rate of warming is less than 0.37 Deg. C per 100 years, likely impacted by the moderating effect of the Pacific Ocean. Overall, the ten stations average a rate of warming over the entire 66 years at a rate of 2.18 Deg. C per 100 years, increasing to 2.39 Deg. C per 100 years since 1989.

Climate Model Projections

Climate models are mathematical and physical models of atmospheric conditions from the current period well into the future, up to the year 2100 or so. Some models are really ensembles of a number of models of the atmosphere, ocean, ice cover and land-sea interaction. There are about 32 climate models that have been developed by climate modellers and researchers around the world. Climate model projections vary depending upon the modelling characteristics, resolution, and parameters considered.

Another variance in model projections is related to the Representative Concentration Pathway (RCP) value that is assumed as input into the model. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. The RCP is presented as total radiative forcing in watts per square meter, i.e. the difference between solar energy received in the atmosphere and the earth's surface, and the energy radiated back into space from the earth or its atmosphere. Essentially, a number of socioeconomic factors is considered in estimating RCP values as this century progresses. The lower RCP values assume GHG emissions are controlled and reduced by mid-century, while the highest RCP values assume GHG emissions continue to grow through 2100. The most current calculation of the earth's atmospheric RCP value is 1.94 w/m^2. RCP values for modelling purposes have more less been standardized at 2.6 w/m^2, 4.5 w/m^2, and 8.5 w/m^2.

Model projections for each location are presented below as Figures 5 to 23. The historical trend lines are also included based on the data from Table 2. The Climate Model chosen in this paper was the CanESM2 model developed by Environment Canada's Canadian Centre for Climate Modelling and Analysis located at the University of Victoria. The model data was obtained using the software ClimateNA_v560 developed by Tongli Wang, Centre for Forest Conservation Genetics, Department of Forest Sciences, University of British Columbia; Andreas Hamann, Department of Renewable Resources, University of Albert; and Dave Spittlehouse, Research Branch, BC Ministry of Forests (Contact: tongli.wang@ubc.ca)

Figure 5 - St. John's Model Projections

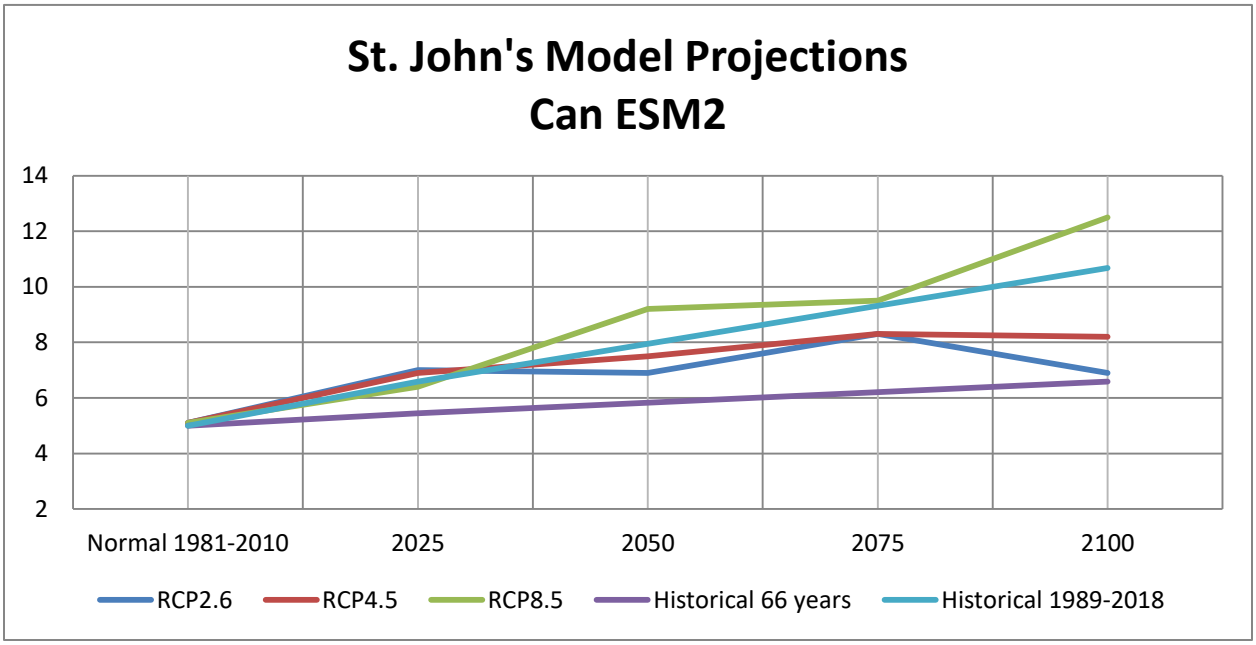


Figure 6 - Halifax Model Projections

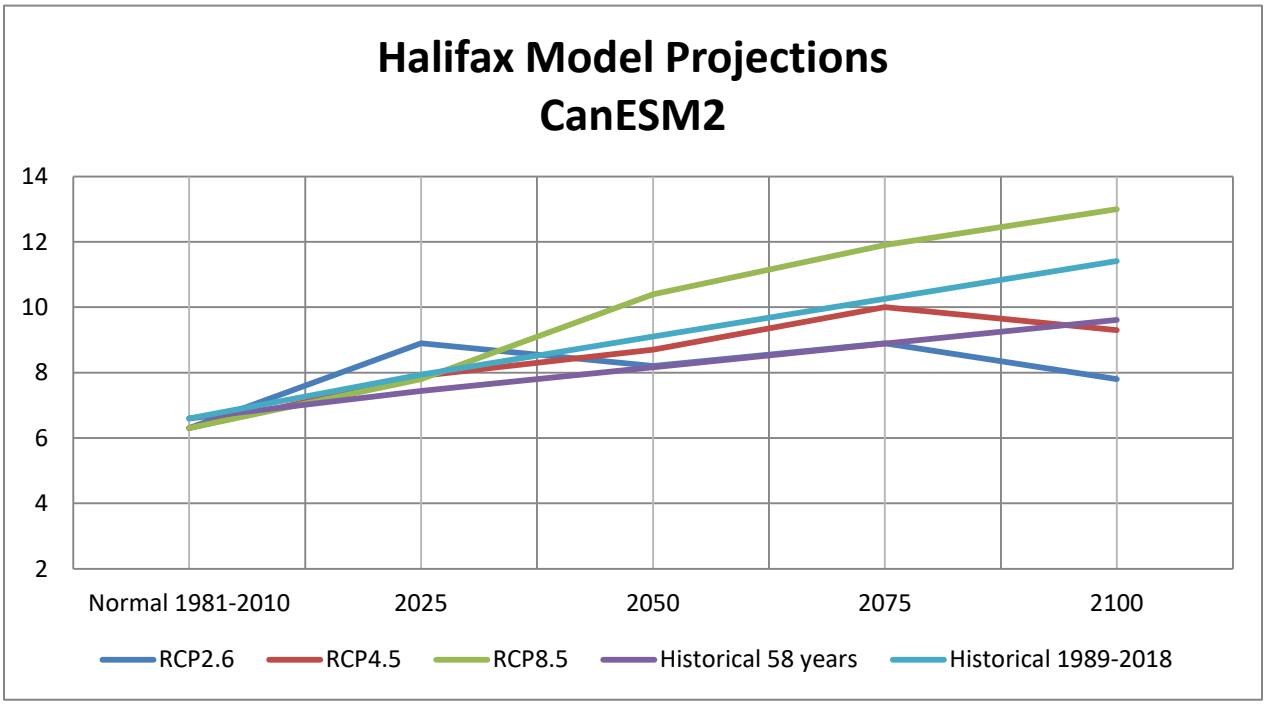


Figure 7 - Bagotville Model Projections

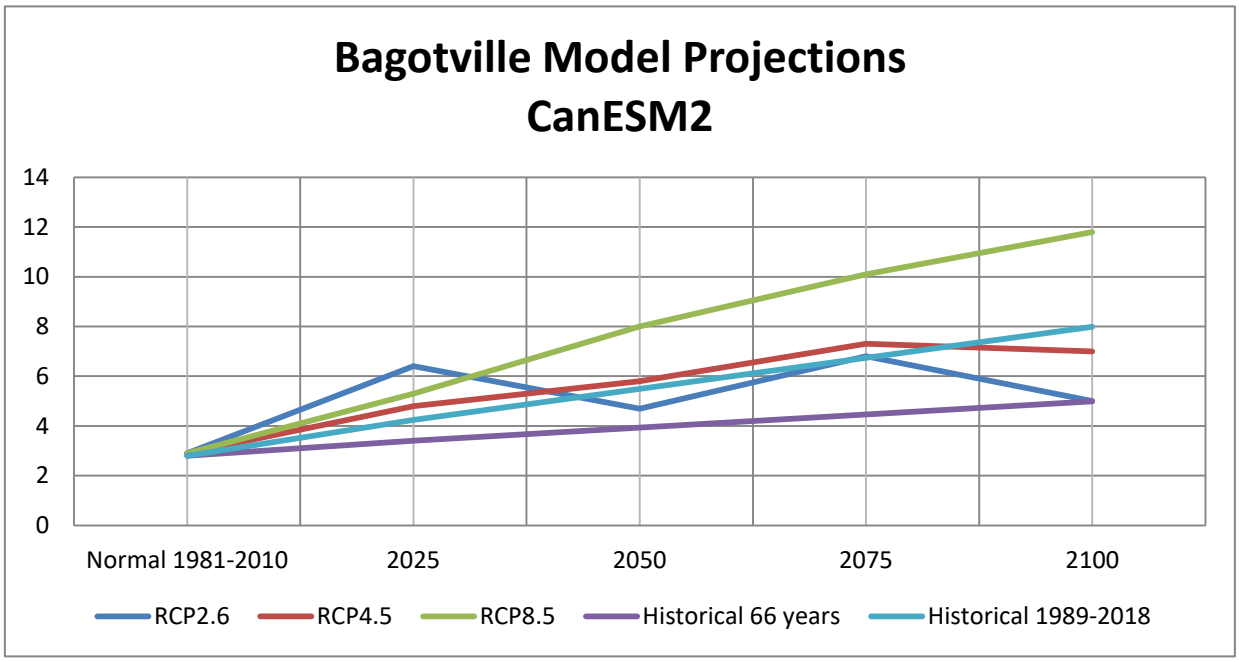


Figure 8 - Montreal Model Projections

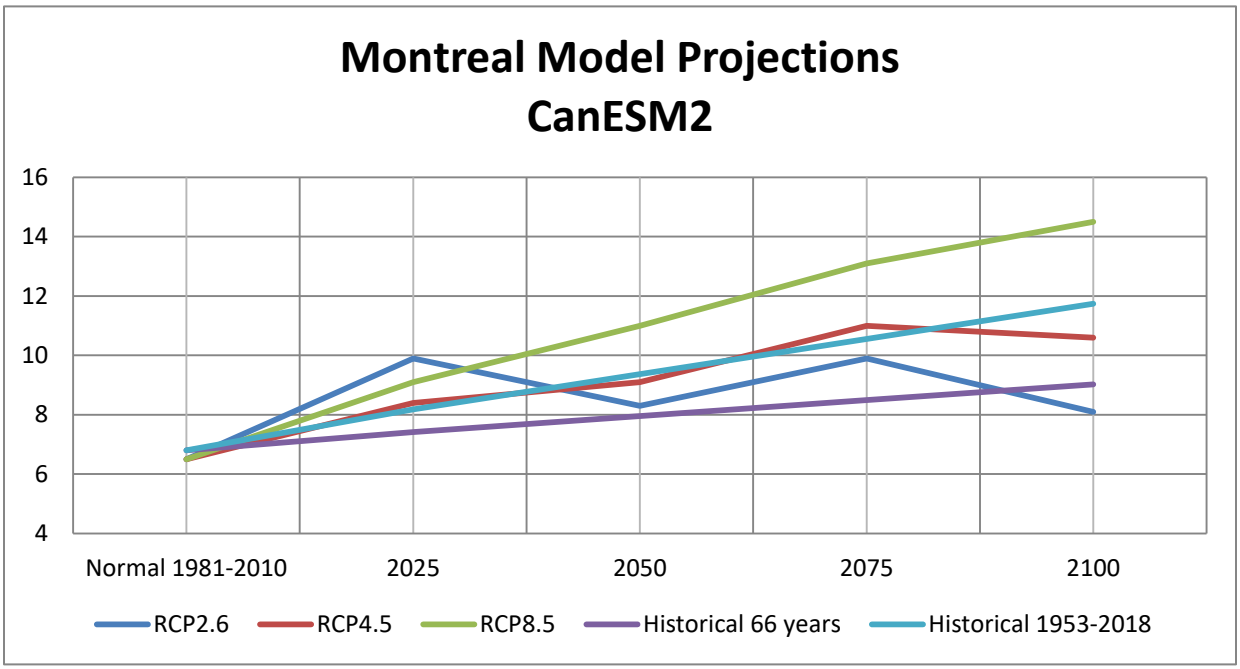


Figure 9 - Ottawa Model Projections

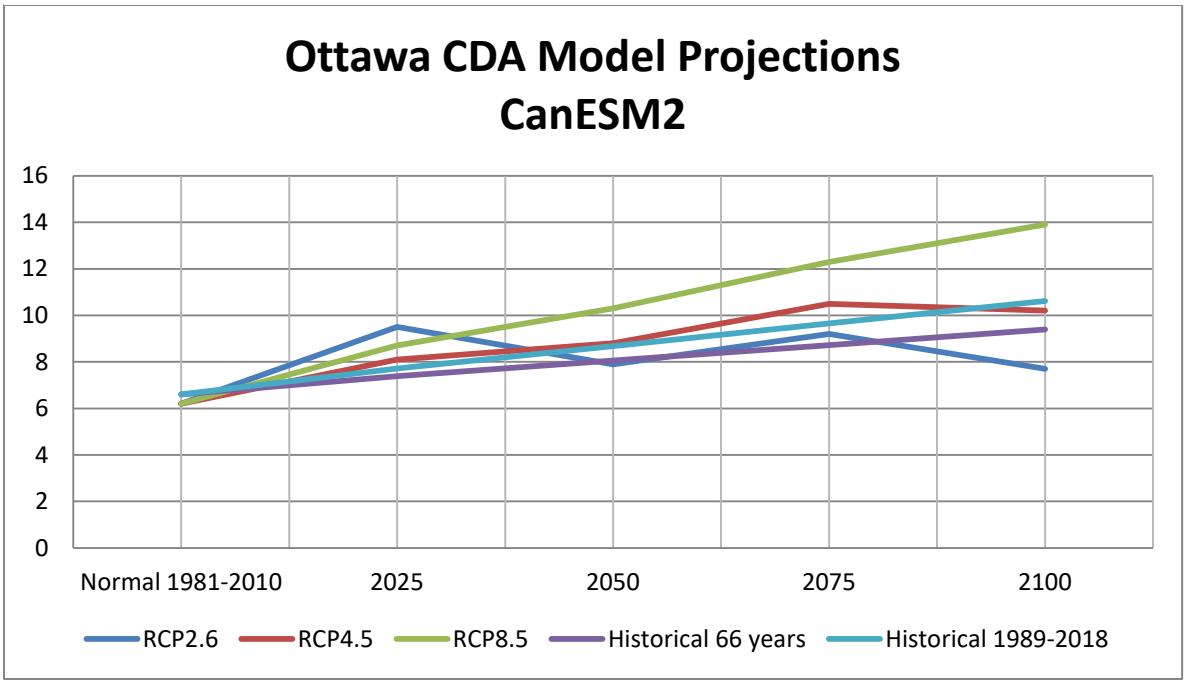


Figure 10 - Toronto Model Projections

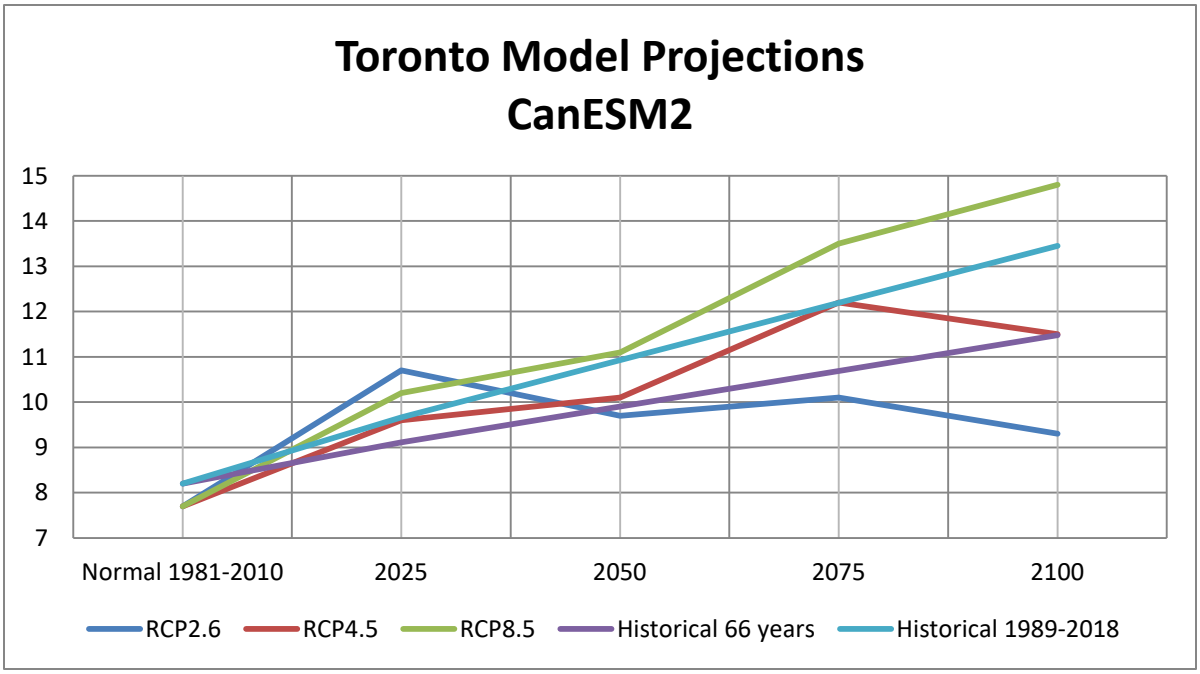


Figure 11 - Timmins Model Projections

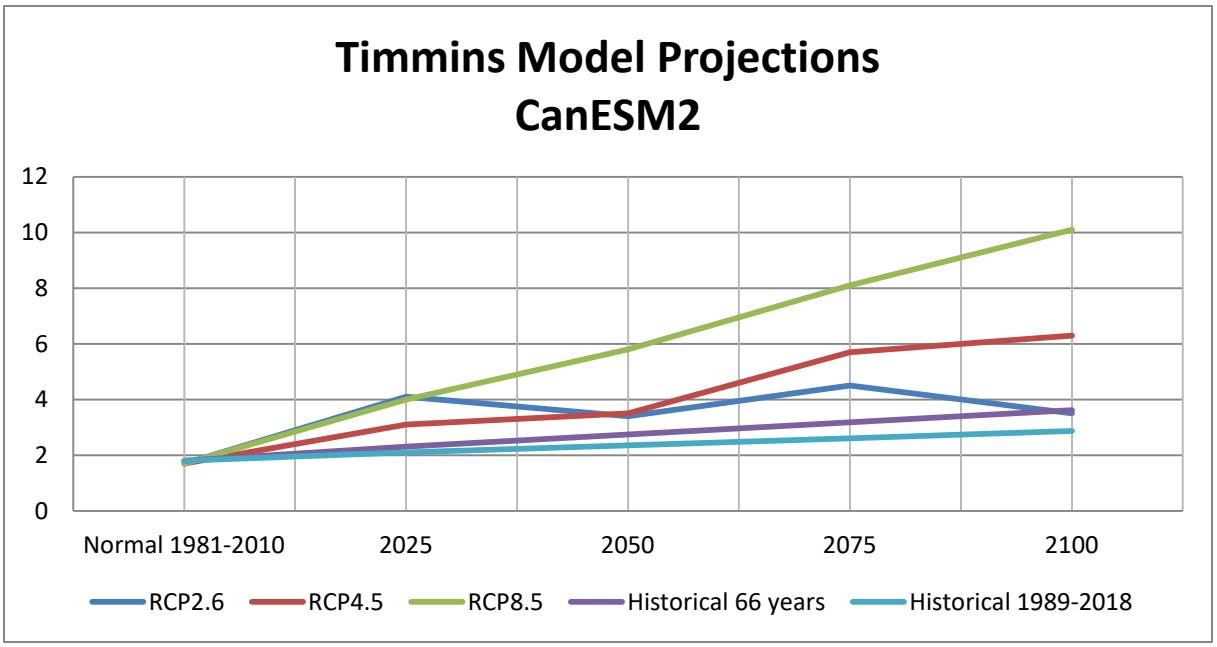


Figure 12 - Winnipeg Model Projections

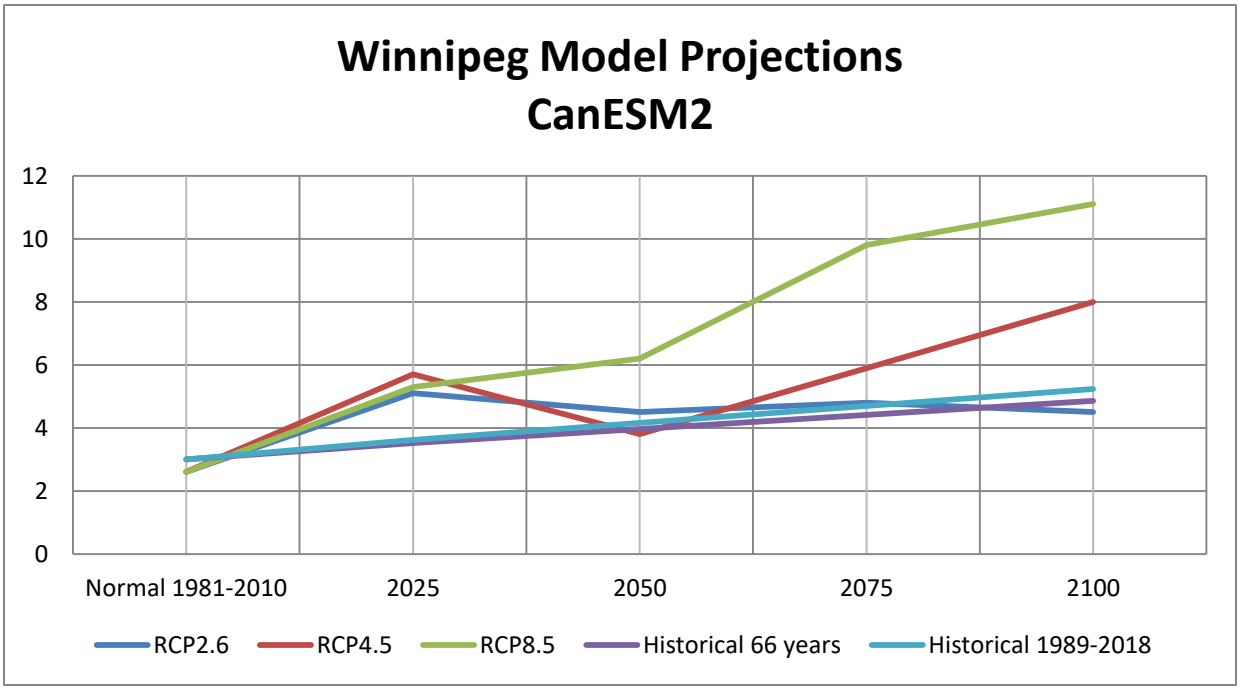


Figure 14 - Churchill Model Projections

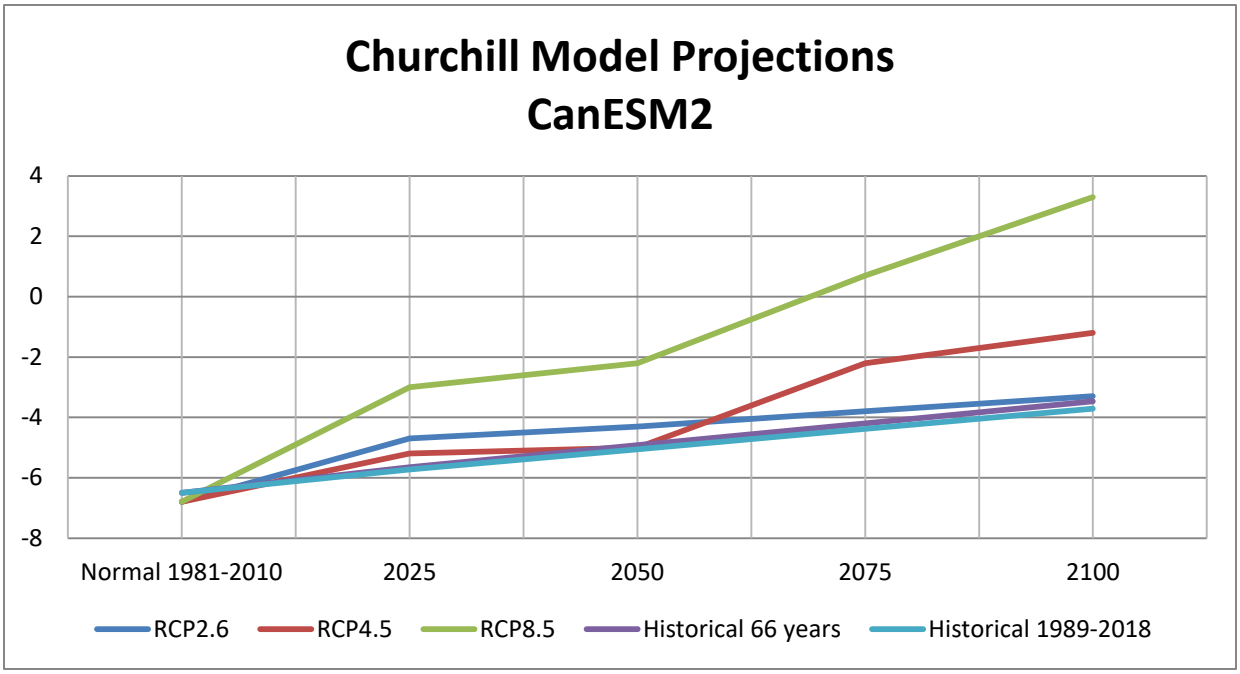


Figure 13 - Regina Model Projections

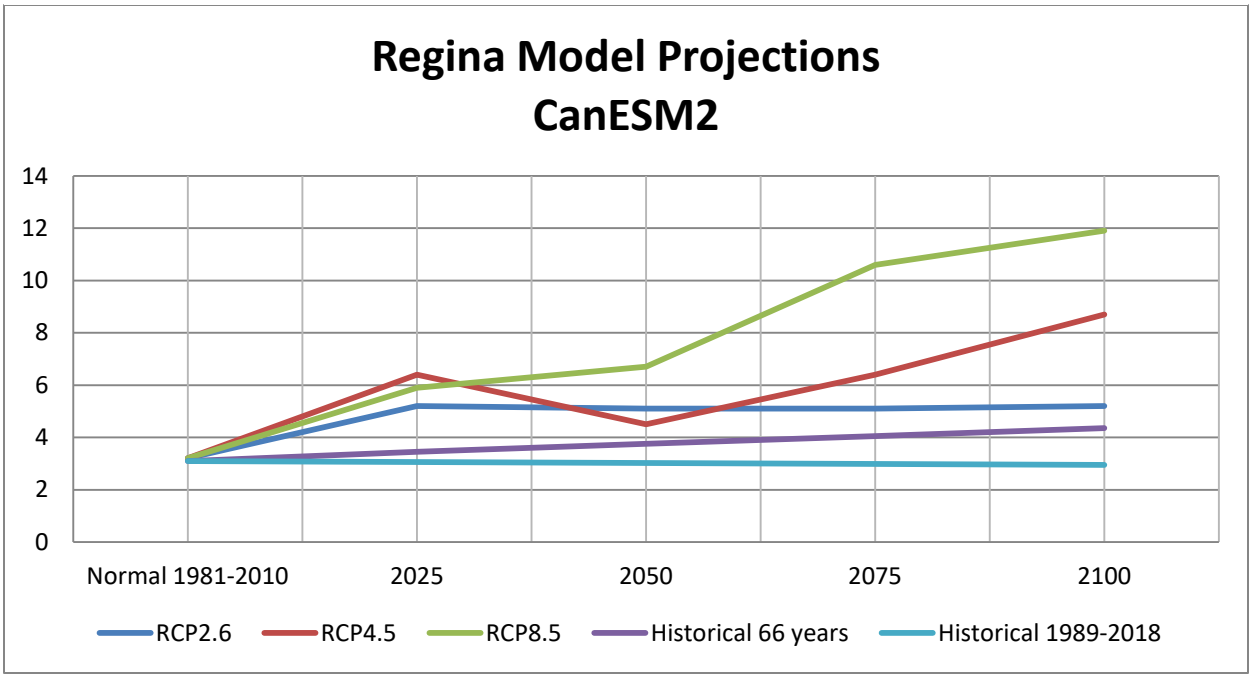


Figure 16 - Cold Lake Model Projections

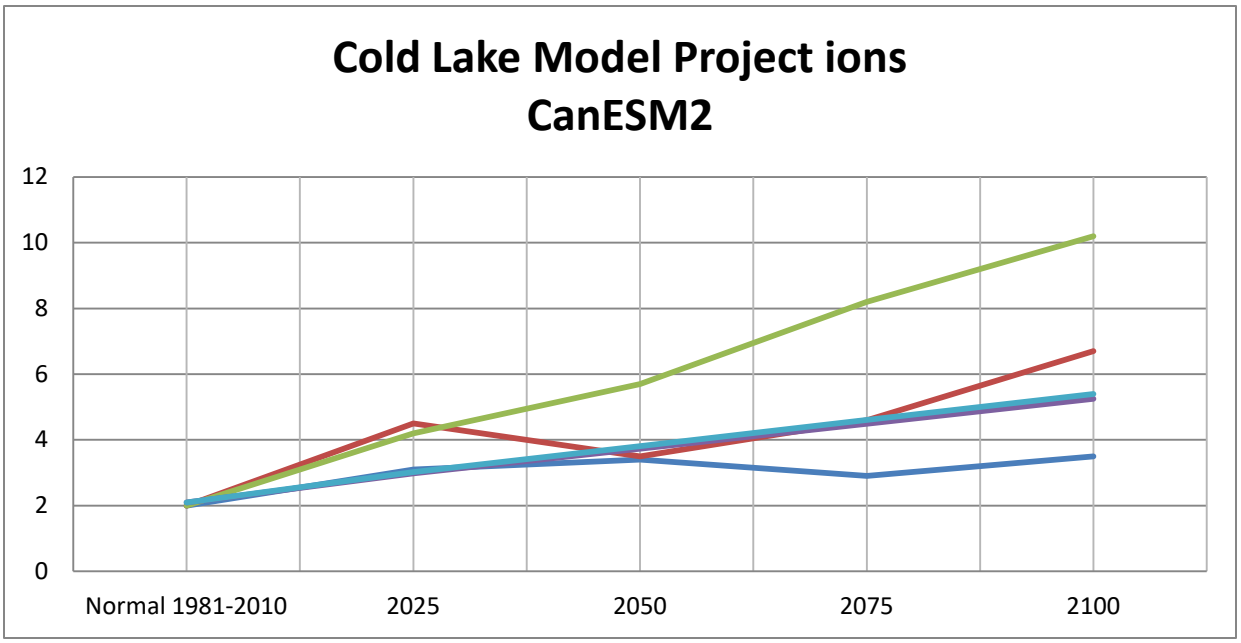


Figure 15 - Edmonton A Model Projections

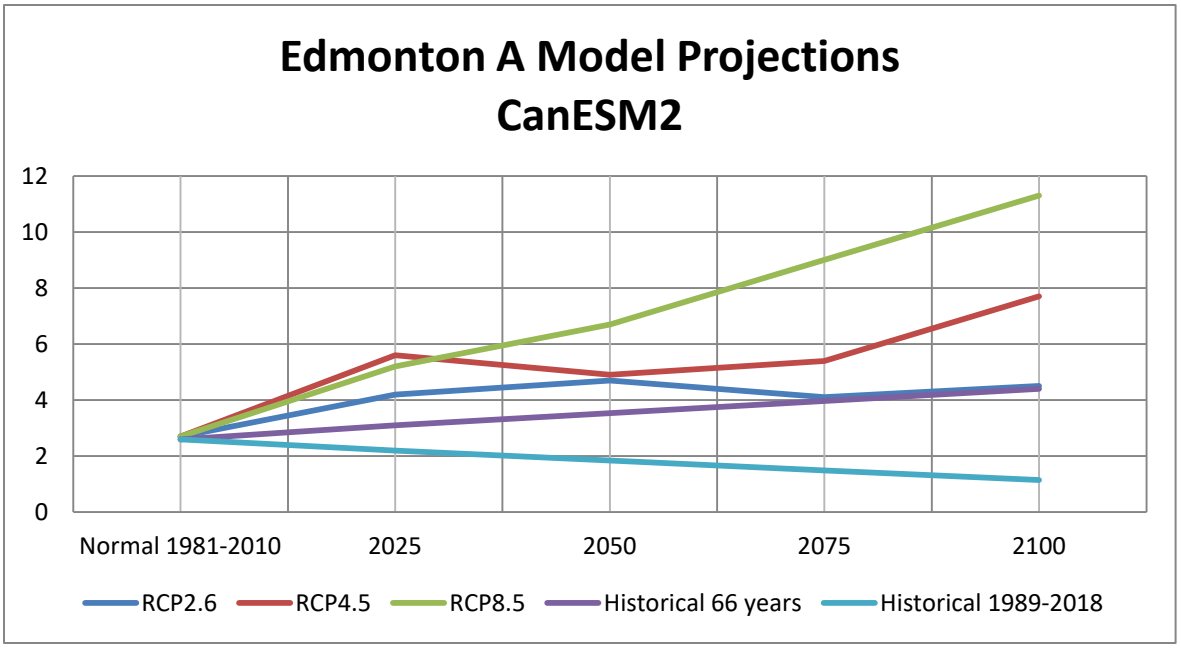


Figure 18 - Lethbridge Model Projections

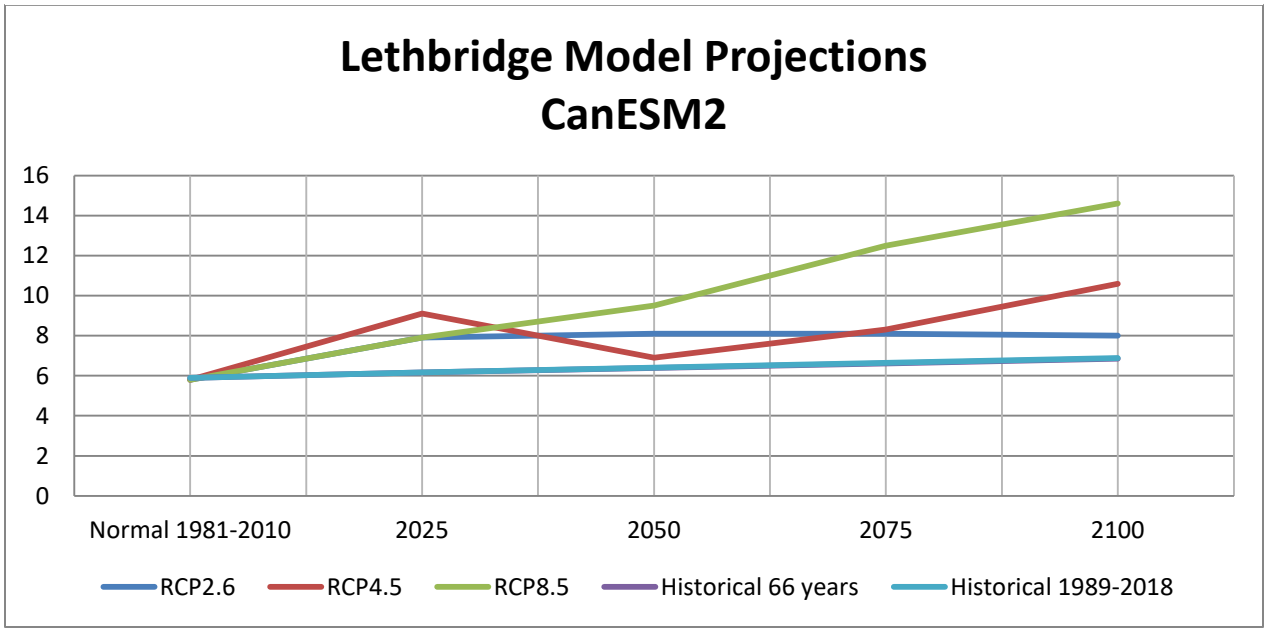


Figure 17 - Fort Nelson Model Projections

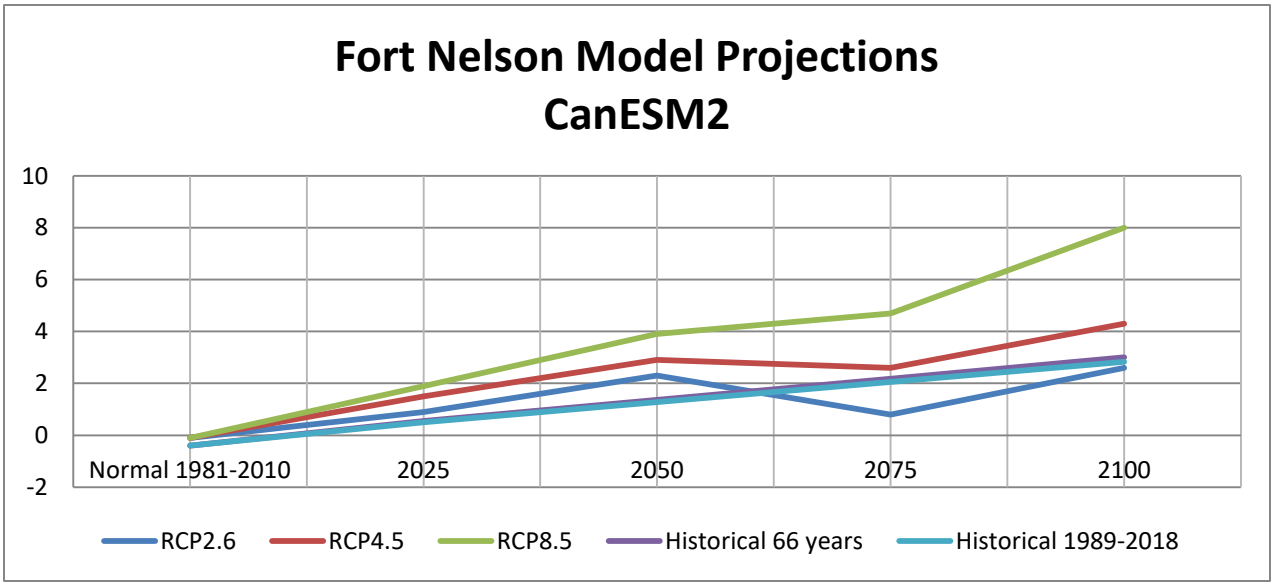


Figure 19 - Kamloops Model Projections

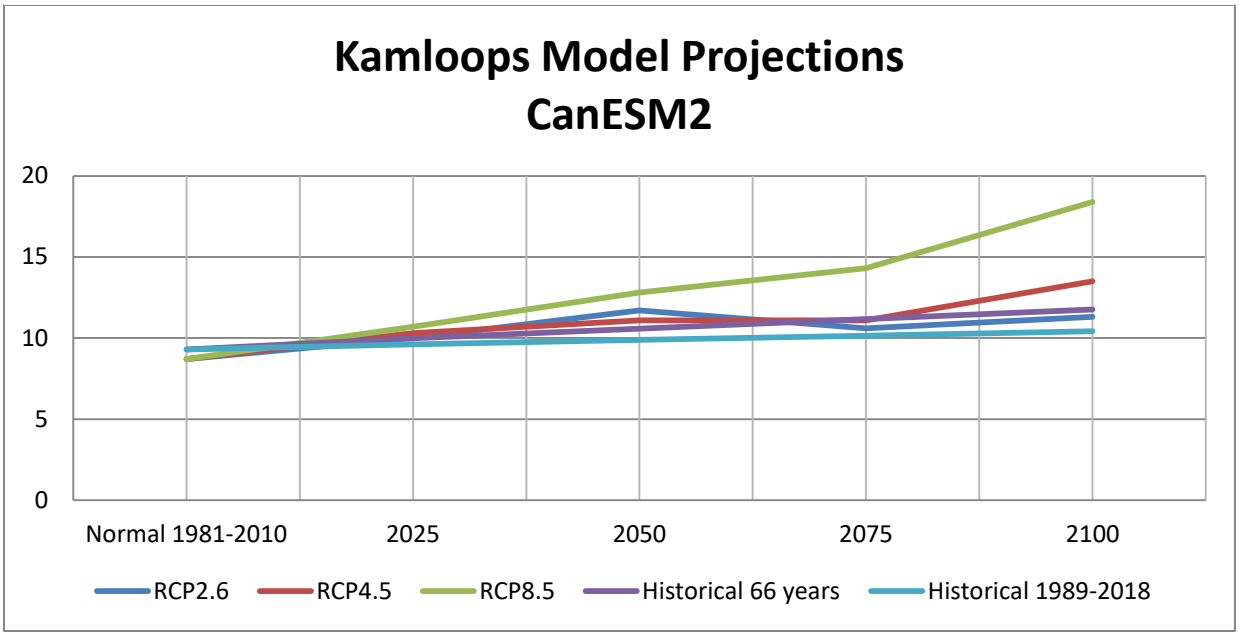


Figure 20 - Victoria Model Projections

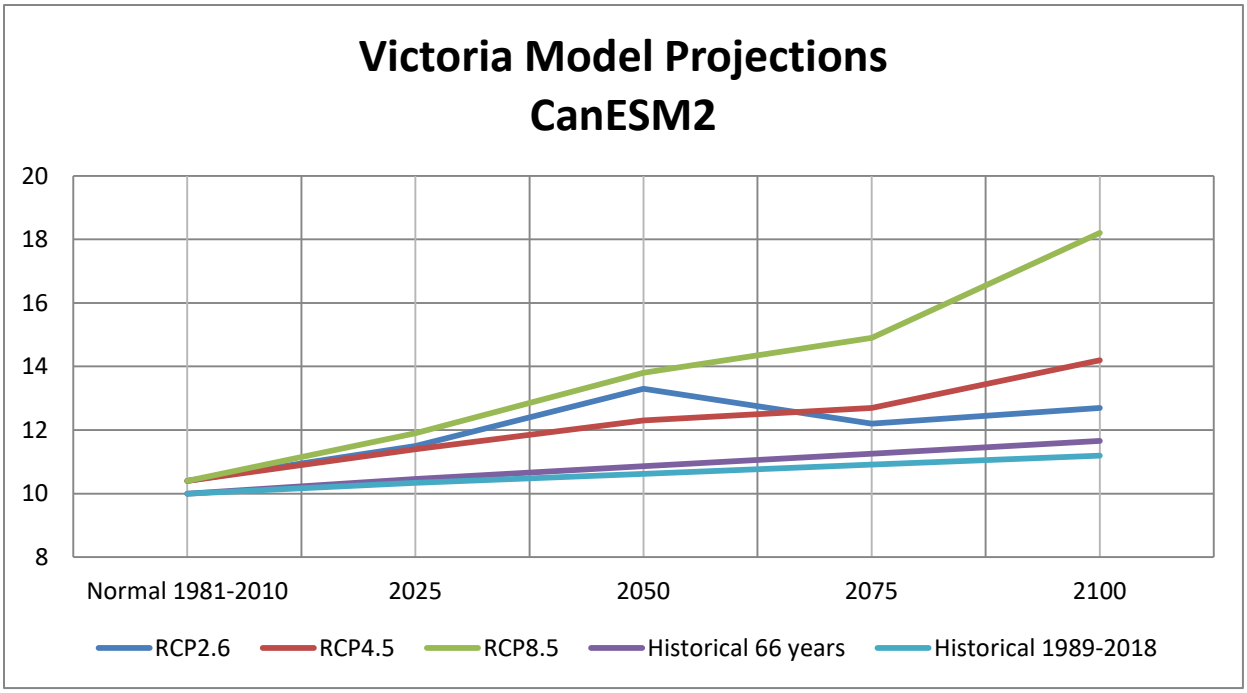


Figure 21 - Iqaluit Model Projections

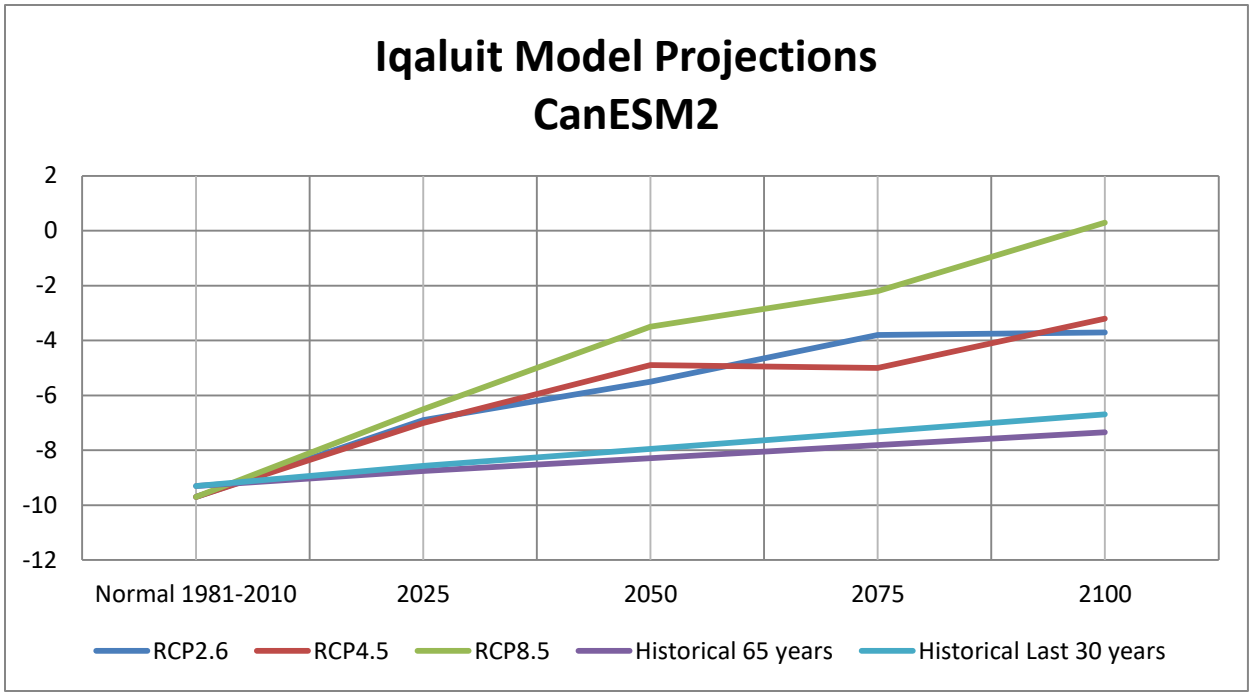
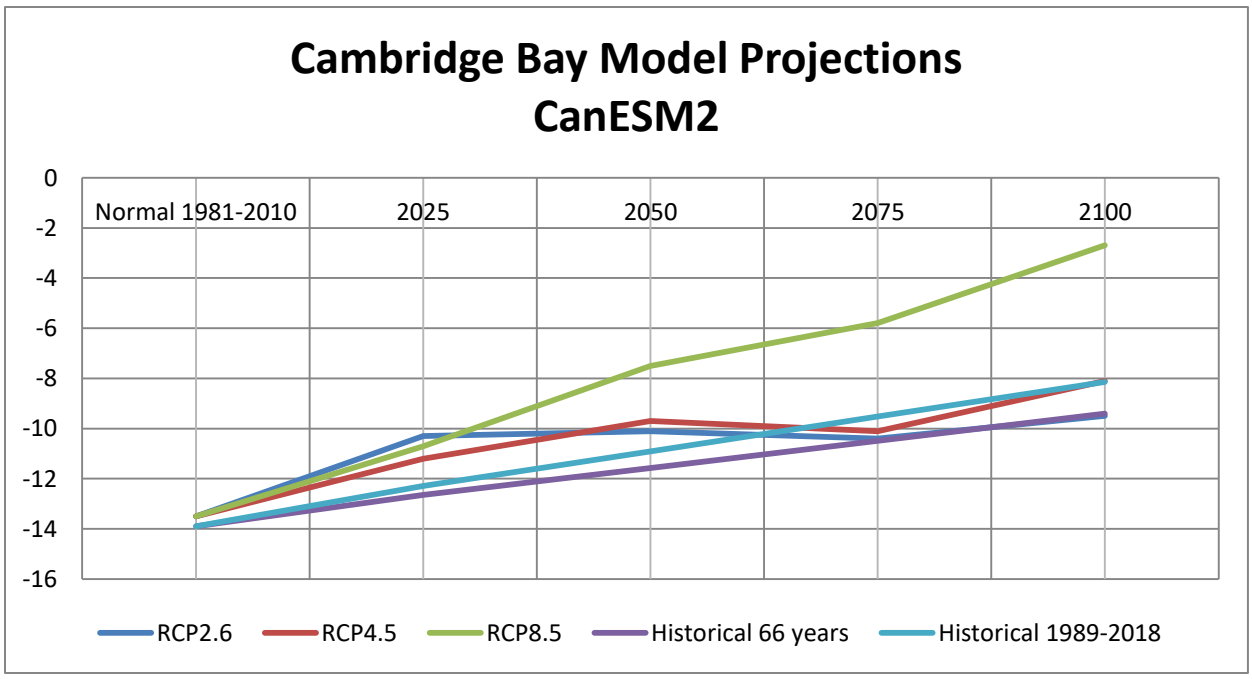
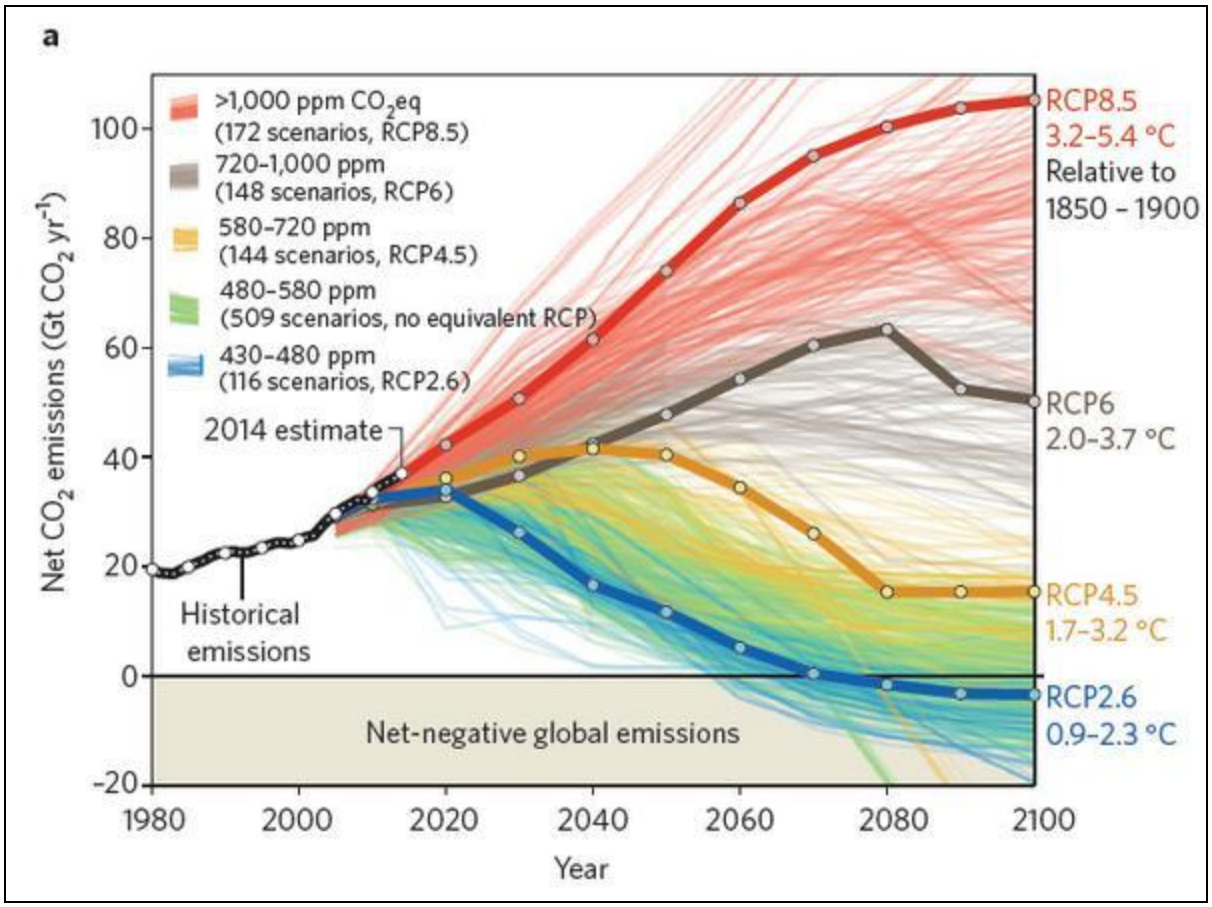


Figure 22 - Cambridge Bay Model Projections



All RCP scenarios show an increase in Mean Annual Temperatures by 2100 for all nineteen locations in Canada, although there is a great deal of variation in the extent of the increase. The historical rate of increase based on the actual data from the station from 1953 to 2018 is also projected on the charts. The current radiative forcing value due to $C0_2$ is 1.94 watts/m^2 and due to all GHG's is 3.379 w/m^2. In a few cases, the temperature declines as we get closer to 2100. In the RCP 8.5 scenario, the degree of warming towards 2100 is dramatic, with the models projecting up to a 11 Deg. C increase from the 1981-2010 Normals. This is particularly the case in the Arctic, where average temperatures at Cambridge Bay increase from -13.9 Deg. C, the Normal Mean Annual Temperature 1981-2010, to -2.7 Deg. C by 2100. It should be noted that the RCP 8.5 scenario is seen by many scientists to be extreme, based on GHG concentrations at the level that some say would require almost all of the fossil fuels in the ground to be consumed by 2100. On the other hand, the current trend in emissions is close to that projected by the RCP 8.5 scenario as shown in the chart in Figure 23.

Figure 23 - Warming in Various RCP Scenarios



The trend in the 2014 graph continued, and global emissions were at a record level in 2018 of 37.1 Gt CO_2. https://www.scientificamerican.com/article/co2-emissions-reached-an-all-time-high-in-2018/

Summary

In conclusion, the climate in Canada has warmed at a rate of over 2 Deg. C per 100 years since 1953. This analysis is based on daily data from nineteen stations since 1953, spread across Canada from St. John's to Victoria, and to Cambridge Bay in the high Arctic. Warming is most intense in the Arctic and least intense on the southern prairies. If we considered just the last 30 years, which is a "normal" period of years to assess climate normals, the rate of warming increases to almost 6 Deg. C per 100 years in the Arctic, and to nearly 5 Deg. C in eastern Canada.

Climate warming in Canada is not continuous, either in terms of space or time. There are significant variances in the extent of warming from region to region, and even between stations a few hundred km apart. For example, the extent of warming between Toronto and Timmins is a factor of 2 or 3. And while there is an overall trend of warming since 1953, many of these stations are experiencing a cooling trend since 2009. In eastern and northern Canada since 2009, the temperature trend has reversed and is now cooling at about the same rate as it was warming over the 66 years. A persistent "polar vortex" over eastern Canada in the last decade has drawn colder Arctic air to most of Eastern Canada, while a persistent pattern of a warm high pressure ridge has dominated western Canada. Changes in atmospheric circulation patterns may result from a changing climate, and "warming", or at least the extent of warming, may not be the same in every region, or in every decade.

Climate models project the rate of warming to increase as GHG concentrations increase. In various scenarios where emissions decrease, climate warming levels off or in some cases, mean annual temperatures begin to decline. In the most extreme case of continued increases in GHG concentrations, warming in the Arctic projected by climate models could be as much as 11 Deg. C by the year 2100 over 1981-2010 Normal values.

The most current CO_2 value measured at the Mauna Loa Observatory in Hawaii was 408.55 ppm in September, 2019. This has increased from 315 ppm since 1960 (https://www.co2.earth/).

Countries in the Paris Agreement committed to CO_2 emission reductions with targets set for 2020, 2030, etc. Countries like Canada, with extensive forest resources, may use credits from forestry to meet targets, if they choose to do so, since forests act as carbon sinks.

The latest evidence is that only a handful of countries are likely to meet their targets in the short term, (https://climateactiontracker.org/countries/), implying that RCP scenarios on the higher end of the scale may be appropriate in model projections.