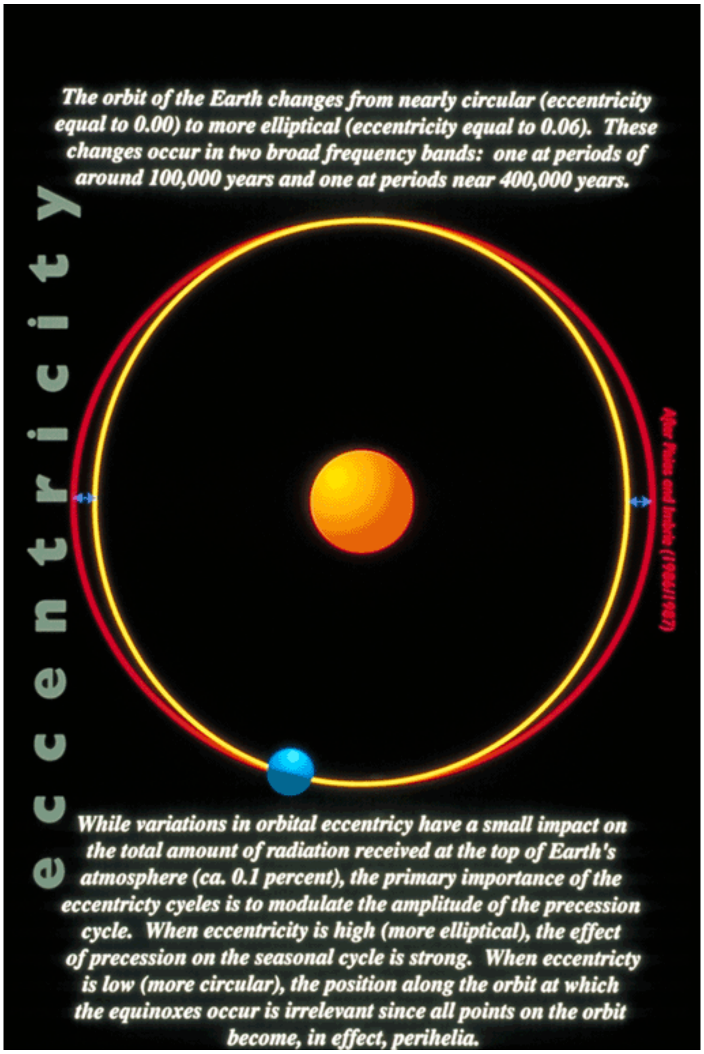


Figure 52: The earth's eccentricity cycle of 100,000 and 400,000 years (After Pisias and Imbrie 1986/1987).

The key issue is whether or not these variations are great enough to cause the significant swings we see on earth as the glacial ages come and go. It is argued that it may be adequate as when the precessional cycle places earth at its aphelion during the Northern Hemisphere‟s winter, the northern winters would be significantly colder if this occurrence was coupled with a period of high eccentricity. It is reasoned that snow would accumulate to a greater degree, leading to the creation of large snowfields and glaciers. As reflective snow and ice cover more of the Northern Hemisphere‟s land area, the earth would absorb less solar radiation (increase albedo). The climate would cool further as glaciers and ice sheets reflect solar energy back into space. Another feedback effect that receives attention is the position of warm currents in the Atlantic Ocean. As the northern latitudes cool, the strength of the trade winds would increase, drawing them southward towards the equator which will reduced the strength of the Gulf Stream as warm currents turn south rather than north as they flow towards the bulge of Brazil. This will cool Europe and lead to a further cooling of the Northern Hemisphere.

4.2.4 Insolation and Orbital Forcing

This section is based largely on materials from Berger (1978) and Perry and Hsu (2000).

Although Milankovitch and many others have calculated the insolation curves as a result of orbital forcing as in the plot below (Figure 53) it is sometimes difficult to match precisely the orbital forcing insolation curve precisely with the glacial advances and retreats. This at first led to the orbital forcing idea to be discarded. In addition the changes in insolation are relatively small and many have argued that they cannot be relevant. Later it was again looked at as it became apparent that there may be thermal lags in the system caused by a latency in heating and cooling of the oceans.

Although there is still some scepticism, it is now considered likely that orbital forcing with a variety of amplification mechanisms is complicit in shaping the cyclical nature of the ice ages. Of particular interest in the figure presented below is that the orbital forcing appears to be irregular as a result of the three orbital mechanisms working together, sometimes cancelling each other out and at other times acting in unison and creating significant changes. There are also periods when two peaks on the curve appear to joined together suggesting there may be longer periods where insolation remains relatively constant and making for an irregular and less repetitively cyclical nature of ice ages.

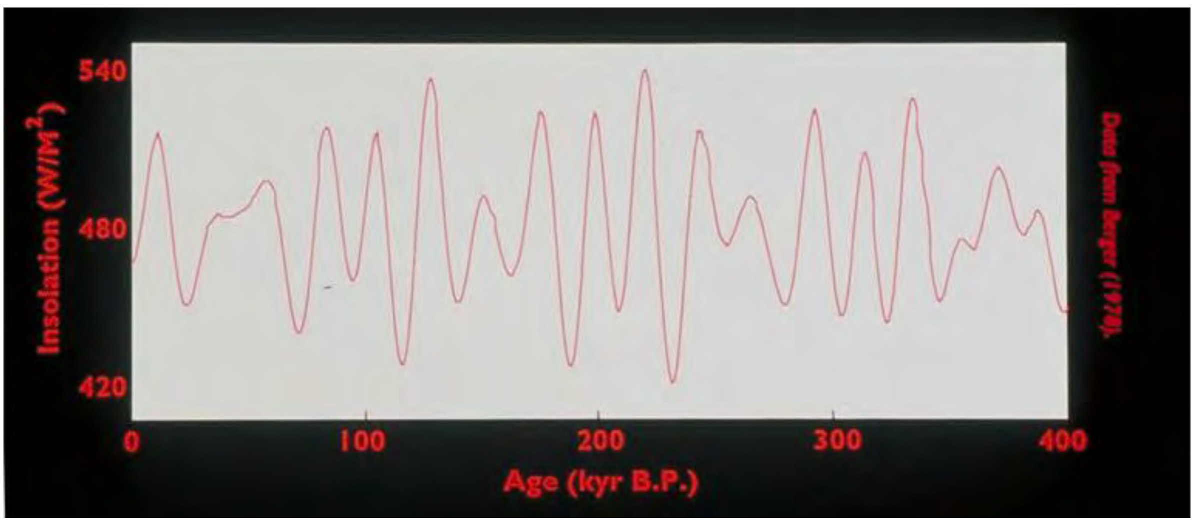


Figure 53: Summer insolation curve for 65°N demonstrates how variations in precession, eccentricity and tilt have affected the amount of solar radiation reaching the surface of the earth.

Furthermore if the work of Perry and Hsu (2000) is considered, where solar luminosity has been compared to ice ages through proxy data and solar modelling, it is apparent that there is reasonable correspondence with the ice ages (Figure 54).

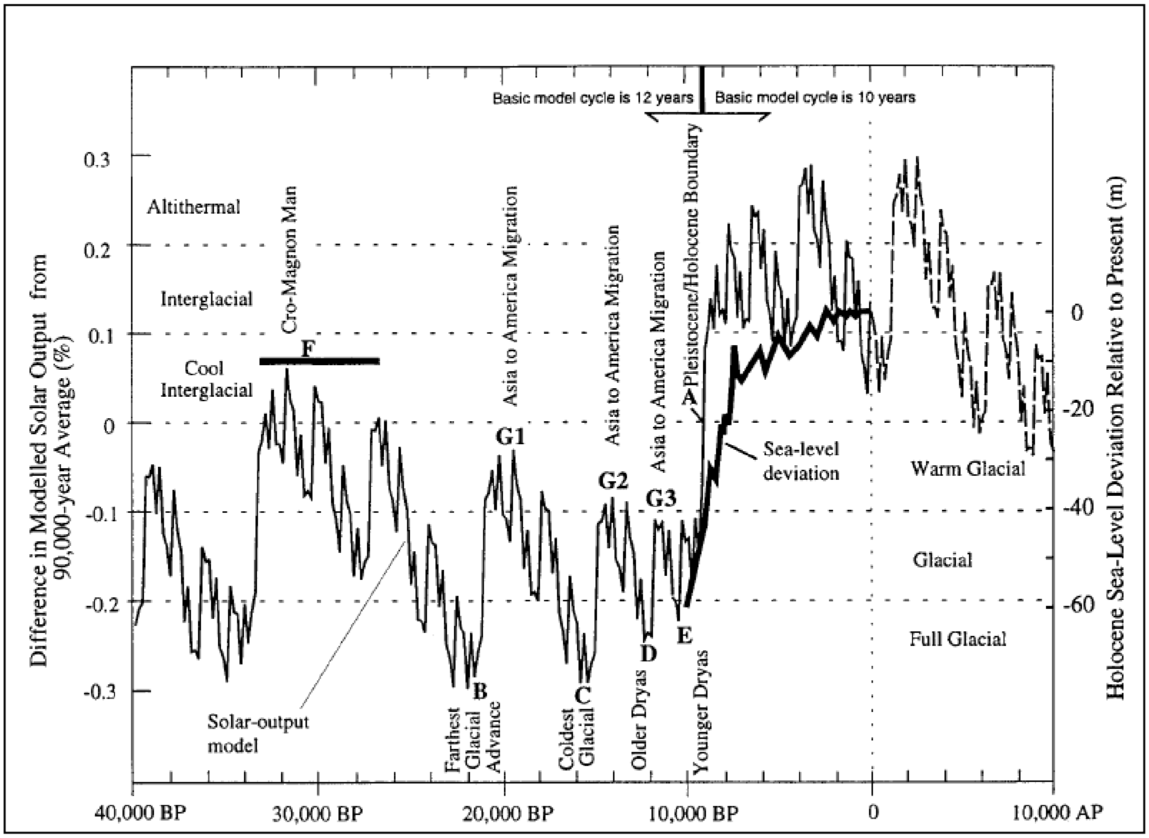


Figure 54: Modeled solar output (Luminosity) from 40,000 YBP to 10,000 Y AP compared with glacial, sea-Level-deviation (24), and archaeological information during the Late Pleistocene and Holocene (after Perry and Hsu, 2000).

Finally, as the solar forcing of ice ages may be crucial to predicting future climate it has been the focus of much research. In a paper to be published in *Science* on 7 August 2009, it is reported that "Researchers have largely put to rest a long debate on the underlying mechanism that has caused periodic ice ages on Earth for the past 2.5 million years – they are ultimately linked to slight shifts in solar radiation caused by predictable changes in Earth's rotation and axis (Figure 55). Researchers from Oregon State University and other institutions conclude that the known wobbles in Earth's rotation caused global ice levels to reach their peak about 26,000 years ago, stabilize for 7,000 years and then begin melting 19,000 years ago, eventually bringing to an end the last ice age".

The melting was first caused by more solar radiation, not changes in carbon dioxide levels or ocean temperatures, as some scientists have suggested in recent years. The known wobbles in Earth's rotation caused global ice to reach their peak about 26,000 years ago, stabilize for 7,000 years and then begin melting 19,000 years ago, eventually bringing to an end the last ice age. (ScienceDaily. Retrieved August 8, 2009, from http://www.sciencedaily.com/releases/2009/08/090806141512.htm).

It is reported that the melting was first caused by more solar radiation, not changes in carbon dioxide levels or ocean temperatures. Changes in atmospheric carbon dioxide levels and ocean circulation also occur, but they happen afterwards and serve to amplify the process. The initial trigger and driving force is a change the Earth's axis of rotaton, the tilt towards the sun varying by about two degrees over long periods of time. The small shifts in solar radiation are reportedly all it took to cause multiple ice ages during the past 2.5 million years, reach extremes roughly every 100,000 years. Based on this, projections of orbital position suggest that the Earth should be changing from a long interglacial period that has lasted the past 10,000 years and start shifting back towards conditions that will usher in the next ice age. It is also suggested by scientists that the amplification of the warming caused by greenhouse gases may delay the onset of cooling temporarily, but when it does occur, it is expected to happen failry abruptly relative to geolocial time scales.

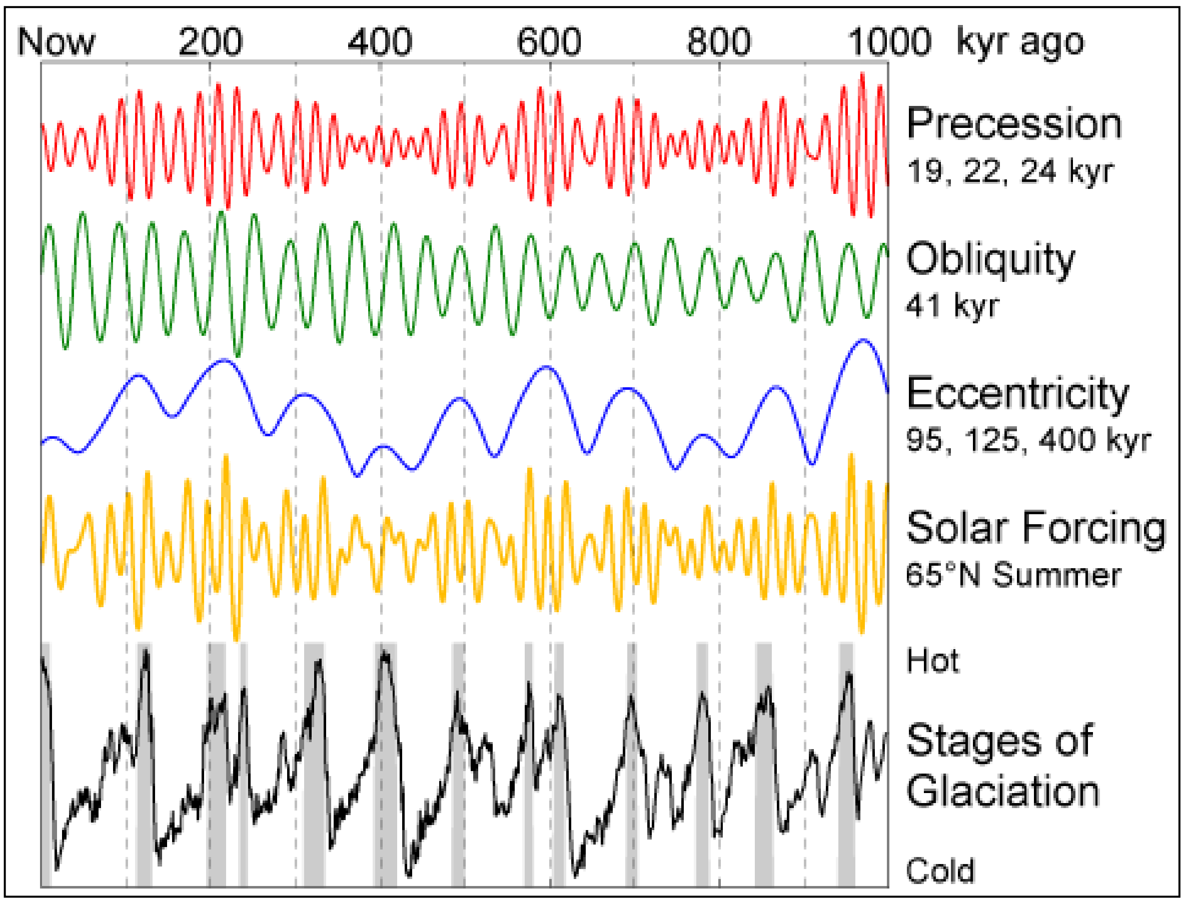


Figure 55: Variations in earth's orbit, the resulting changes in solar energy flux at high latitude, and the observed glacial cycles (Global Warming Art, 2006).

4.3 Solar Variability

This section draws primarily on materials from the NOAA Space Environment Center (SEC) http://www.oar.noaa.gov/spotlite/archive/spot_sunclimate.html.

The total energy output of the sun is nearly constant. At the top of Earth‟s atmosphere the total irradiance from the sun is about 1,366 W/m² or the equivalent of the energy of thirteen 100 Watt light bulbs shined onto a square meter. In the 11-year solar cycle, the average output of the sun changes by about 1-2 W/m² or about 0.1% or a variation between 1,365 and 1,367 W/m² (Figure 56).

Figure 56: Composite showing a sequence of solar x-ray images taken about six months apart from solar maximum (lower left) to solar minimum (upper right), the 11-year solar cycle (Prepared by Lockheed).

In wavelengths such as the ultraviolet and extreme ultraviolet parts of the solar spectrum, the solar variability can be quite large with brightness changing by a factor of 100 or even 1,000 in just a few minutes. These wavelengths typically only affect the upper reaches of the atmosphere.

There is evidence that total solar output may have changed by larger amounts over longer time scales, as low as 1,360 W/m² during the 19th century and even lower than that during the 17th century representing a change of 0.5%. The 17th century coincides with the little ice age. Furthermore, during the last Ice Age (Peaking 26,000 years ago), the globally averaged temperature of Earth was about 6°C colder than today. This was enough to have large parts of Canada, Alaska, and Siberia covered ice sheets up to a mile thick.

The climate changes of the 20th century also have a significant solar component (Figure 57 and Figure 58). Scientists think that as much as 1/3 of the global warming may be the result of an increase in solar energy suggesting a combination of forcing factors such as orbital forcing, and solar output variations and amplification variations in insolation and greenhouse gases may be working together.

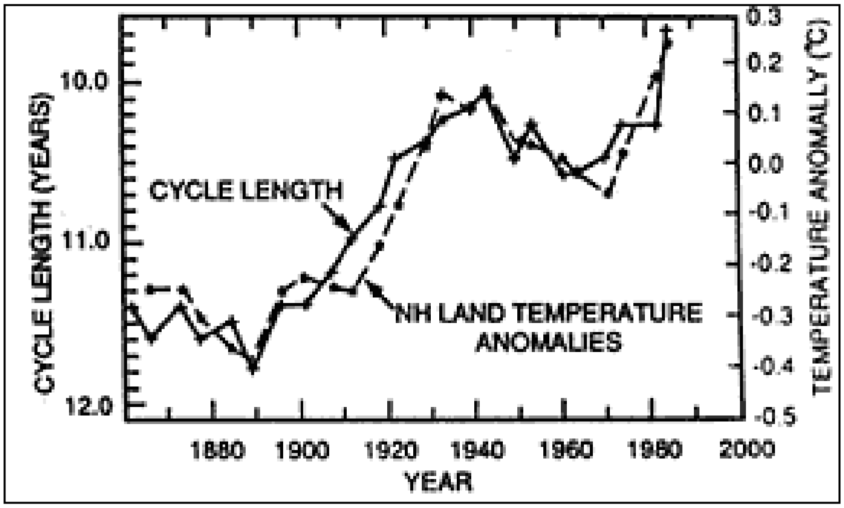


Figure 57: Comparisons of globally averaged temperature and solar activity the northern hemisphere land temperatures are plotted with the solar cycle length (Friss-Christensen and Lassen; 1991) (After NOAA SEC).

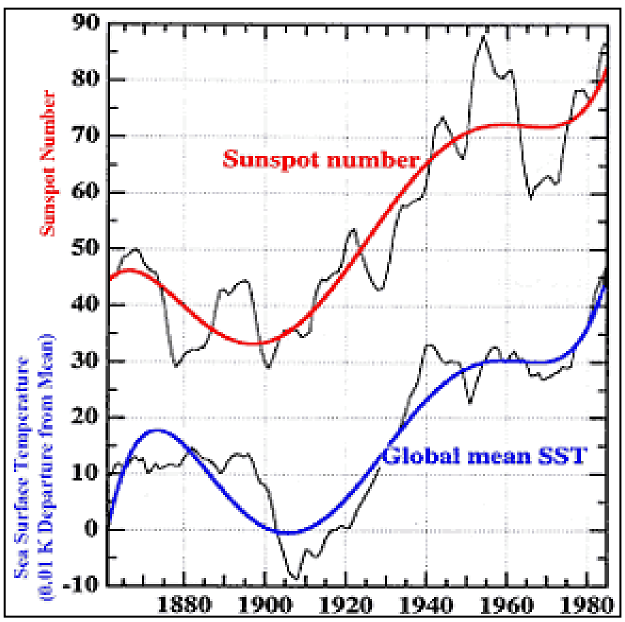


Figure 58: The globally averaged sea surface temperatures are plotted with the sunspot numbers (Reid; 1999) (After NOAA SEC).

From the above discussion it is apparent that even small variations in solar output or insolation due to orbital variations which are less than 1% of normal are enough to trigger or significantly influence variations in surface temperature and lead to climate change. This does not exclude the amplification role of greenhouse gases which are seen as complicit in bringing the full effect of climate change to bear.

5 Potential Scenario

There is a considerable amount of data available that can be used for creating the scenario presented below. The data sources that have been referred to in the preparation of this document are presented in the reference section. Given the number of proxies, the complexity of the climate change system, and the large number of unknown interrelationships and mechanisms, it is very difficult if not impossible to provide a high resolution, high confidence scenario. What is, however possible, is to look at the historic data and understand the trends that occur and then determine what a reasonable future scenario may look like. By inference, the longer period cycles and forcing mechanisms are likely to have the most confidence associated with them and the shorter time periods the least. This does not mean the shorter time cycles will not occur, only that we are restricted in accurately predicting when they will occur and how long they will last for if there is a change to the current climatic system. Furthermore, the various shorter term climatic systems such as ENSO, PDO and NAO may be disrupted and replaced by other systems if the climate changes significantly, say by for example, significant extension of the ice sheets. Given that we do know, with good confidence, the longer term cycles, these are presented first and the shorter cycles overlaid to see what may occur at any specific time.

5.1 Main Assumptions

The main underlying forcing mechanism as presented in this document is assumed to be solar output in its broadest sense and variations therein as received at the earth‟s surface.

The main amplification mechanism assumed to be influencing the weather is assumed to be greenhouse gases in the short term (3000 years).

Anthropogenic greenhouse gases are assumed to be brought reasonably under control in the next 100 years and their influence is assumed to start to reduce after that time, and to be „normal‟ within several hundred years.

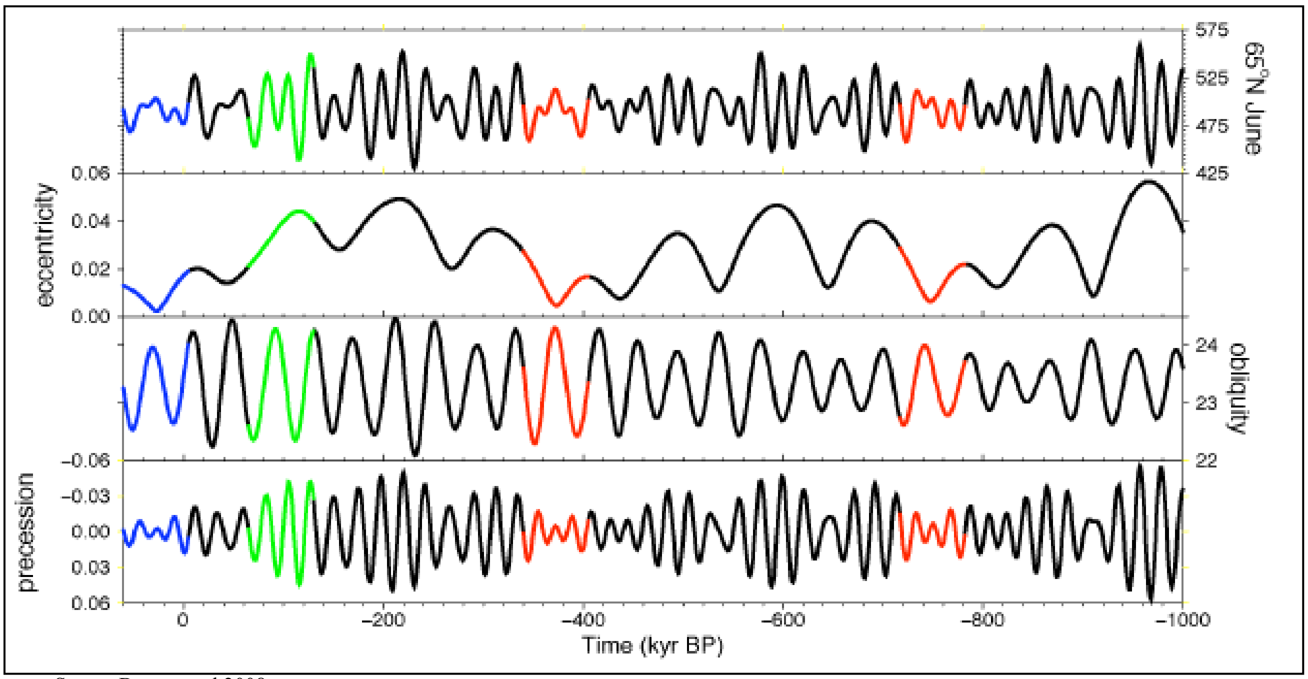
5.2 Predictions from Models and Monitoring Groups

The three main mechanisms that the future climate scenario is based on are insolation variations from sun cycles and from Milankovitch Orbital Forcing, multiple variable reconstruction of Holocene palaeoclimate indicators and greenhouse gas amplification. No new data is presented in this report. All data has been obtained from published sources in various forms, from internet databases to published journals. As far as is possible only credible peer reviewed resources are used, which includes the informal information published at websites such as www.wattsupwiththat.com and www.climateaudit.org.

5.3 Insolation Variations

5.3.1 Milankovitch Orbital Solar Forcing

The 100,000 year cycle is important for developing the future climate scenario, as we are currently in an interglacial, that based on previous glacials and interglacials should last roughly 10,000 to 15,000 years. Based on modelling, the current interglacial will most probably last much longer than previous ones as the Earth‟s orbit around the Sun will be almost circular over the next tens of thousands of years (Berger et al, 2002), based on the 100, 000 year cycle of eccentricity (Figure 59). We are not about to enter into another ice age based on the length of previous interglacials (10,000 years) and having been in the current interglacial for about 10,000 years. The current interglacial can be expected to last for at least another 10,000 to 30,000 years. Climatic variation within this time is however possible. The next glacial is expected to peak between 50 and 100,000 years after present (AP) probably around 80,000 years AP.



Source Berger et al 2008

Figure 59: Anticipated future insolation at 65° N based on orbital forcing.

5.3.2 Insolation

Modelling indicates small irradiance changes of about 2 $W.m^{-2}$ cause a solar induced temperature variation in the range limited to 0.1–0.15°C (1.0C to 1.5°C/20$W.m^{-2}$), or about 0.2°C if a higher climate sensitivity were considered (Ammann et al, 2006). Berger et al (2008) using orbital forcing outputs predict an increase in the order of 30 Wm^2 over the next 30,000 years and approximately 15 Wm^2 over the next 10,000 or 3°C to 4.5°C and 1.5°C and 2.25°C respectively (Figure 60 and Figure 61).

These figures provide he range of temperatures as well as the pattern of solar output based on orbital variation that are used in the preparation of the climate scenario presented in this report.
Source Berger et al 2008

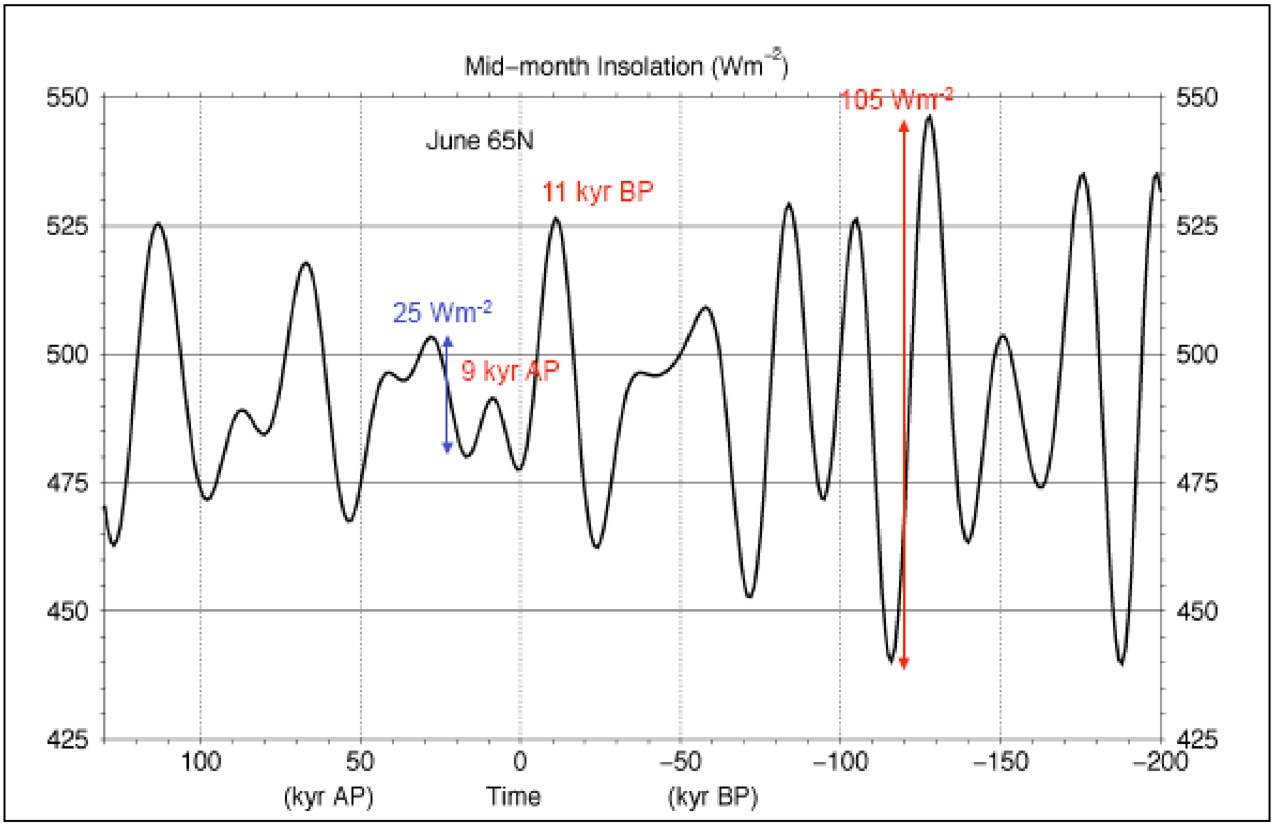
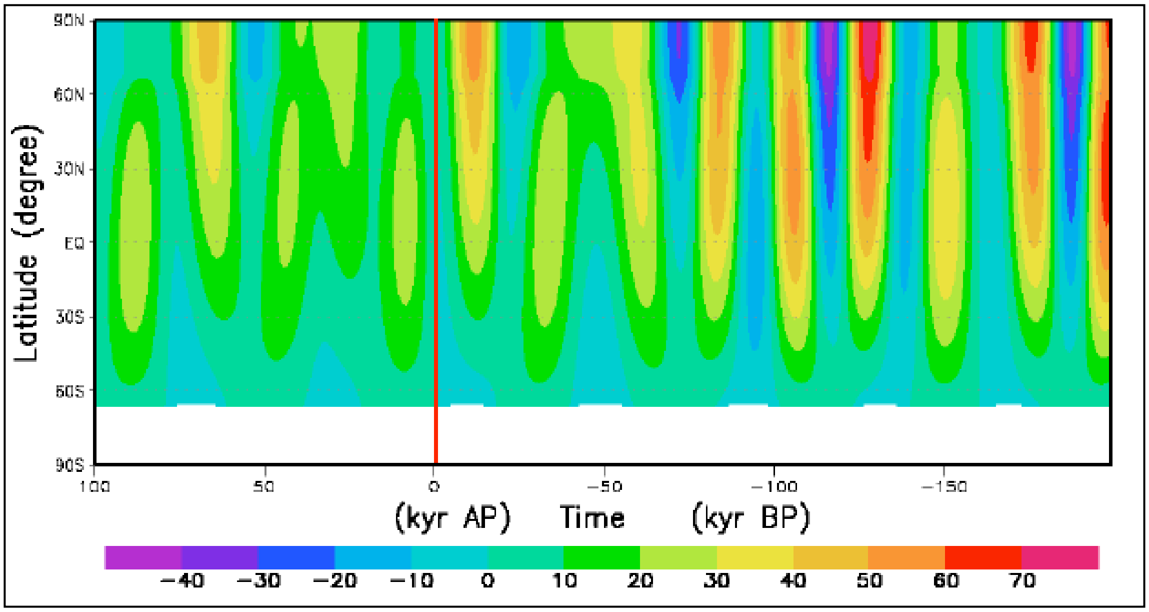


Figure 60: Monthly insolation predictions for 65°N.

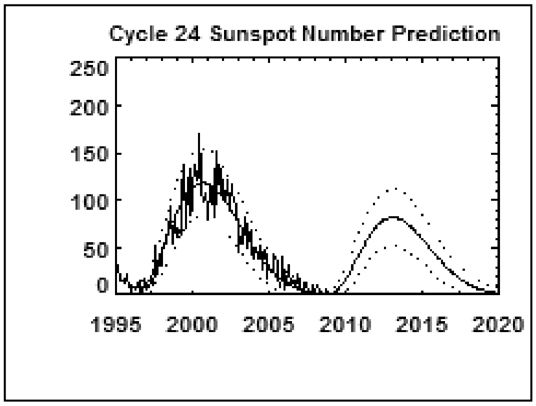


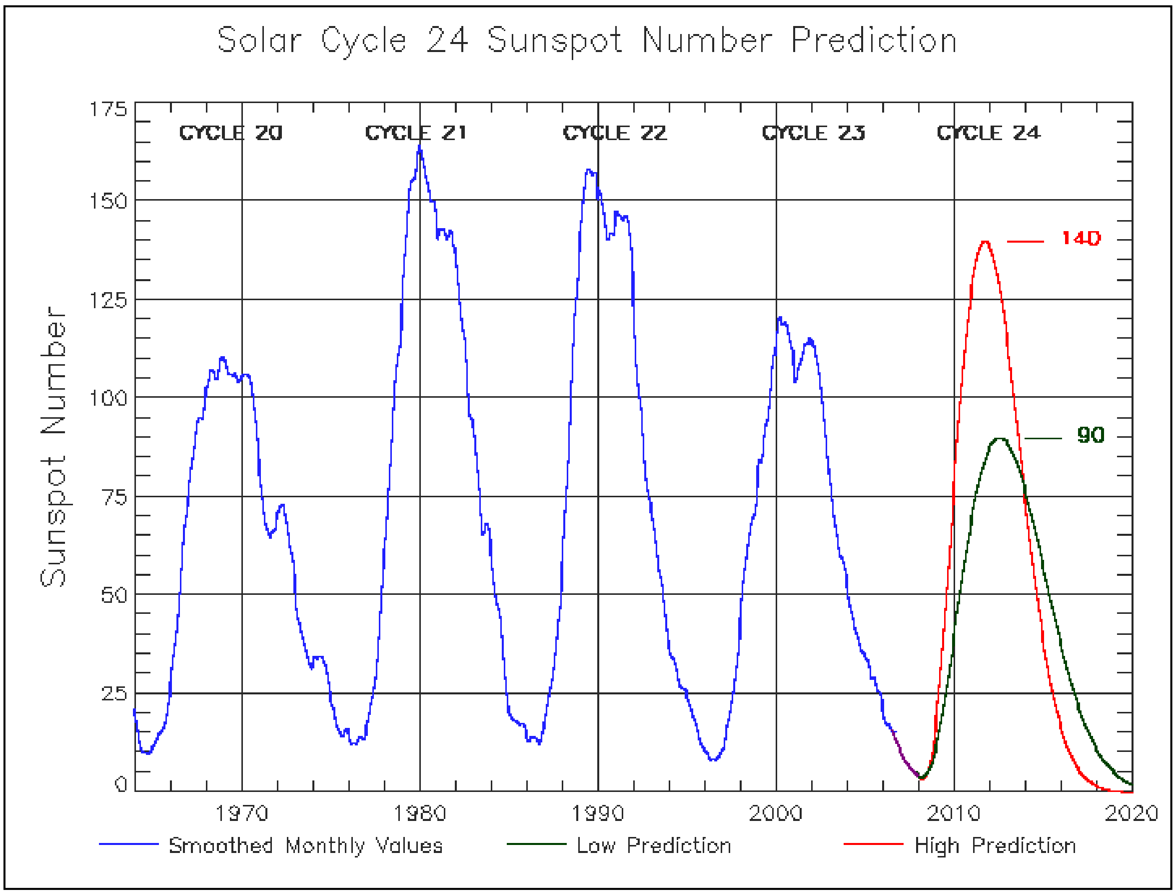
Source Berger et al 2008

Figure 61: 24h mean irradiance (Wm-2) mid-month June insolation predictions by latitude.

5.3.3 Solar Variability and Sunspots

The NOAA Space weather Prediction Centre panel notes that the solar minimum occurred in December, 2008 and has decided that the next solar cycle will be below average in intensity, with a maximum sunspot number of 50 to 70 (Figure 62) and is likely to occur in May, 2013. Insolation appears to be lower when sunspot numbers are lower suggesting we will be cooler than average over the next 30 years.





Source: http://solarscience.msfc.nasa.gov/predict.shtml NOAA Space weather Prediction Centre

Figure 62: Solar cycle 24 sunspot predictions.

5.3.4 Solar Variability and ENSO

The Southern Oscillation Index (SOI) impacts climate and weather in the following ways. The interaction between the directionality in the Sun‟s and Earth‟s magnetic fields causes changes to the incidence of ultraviolet radiation over the tropical Pacific, sea surface temperatures and cloud cover all contributing to changes in the SOI from solar cycle fluctuations. The Sun's magnetic field cycles in particularly the ~11 year sunspot (Schwab) cycle, the ~22 yr magnetic field (Hale) cycle and the ~88 yr (Gleissberg) cycle that appear to impact climate and weather. (Baker et al, 2008; NSF 2009).

5.3.5 ENSO

ENSO has a warm phase El Nino and a cool Phase La Nina each lasting six to 18 months. In Canada ENSO had the following effects in the past, based on information from Environment Canada.

(http://www.msc-smc.ec.gc.ca/education/elnino/canadian/region/index_mean_e.cfm?region=all:)

- 1997-98 El Niño
  - The 1997-98 event caused above normal readings of 2.5°C in the Mackenzie Basin and temperature and precipitation impacts across Canada.
- 1982-83 El Niño
  - The 1982-83 event had significant impacts on temperature and precipitation over Canada
  - A mild winter in most of southern Canada saw one-half the normal snowfall from British Columbia to southern Quebec and temperatures anywhere from 3 to 6 °C above normal in these regions. Vancouver snowfall was only 4 cm, compared to an average of 50 cm, while Ontario had its mildest winter in 30 years and Toronto had its third mildest winter since 1840
  - British Columbia experienced flooding and landslides resulting from strong winds, mild temperatures and wet snow. Avalanches were common in the southern B.C. interior
  - Several people drowned when they ventured onto thinner-than-usual Great Lakes ice, while heavy coastal ice and numerous ice bergs impeded navigation on the Eastern Seaboard
  - The northeastern Arctic experienced bitterly cold weather, with temperatures plummeting to -40°C for prolonged periods.

In general the following patterns are associated with ENSO (Climate Impacts Group, 2009):

- El Nino: Pacific North West winters tend to be warmer and drier c.0.4-0.7°C (Dec –Jun) on average and precipitation 14% (Oct- Mar) lower on average than in La Nina years
- La Nina: Pacific North West winters tend to be cooler and wetter than average.

As the strength of the ENSO varies, so too will the severity of the changes to the climate, as reported in the regular NOAA climate prediction center updates available on the internet at (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/). In addition it is not entirely clear how ENSO and other ocean oscillations will respond to climate forcing mechanisms and whether they will persist as they are today, under glacial conditions for example, and when the various systems will change and how are they are naturally announced. There is some thinking that abrupt changes can occur when tipping points are reached and there is modelling to demonstrate this, but these tipping points have not yet been observed in modern times (Dakos et al 2008).

5.3.6 PDO

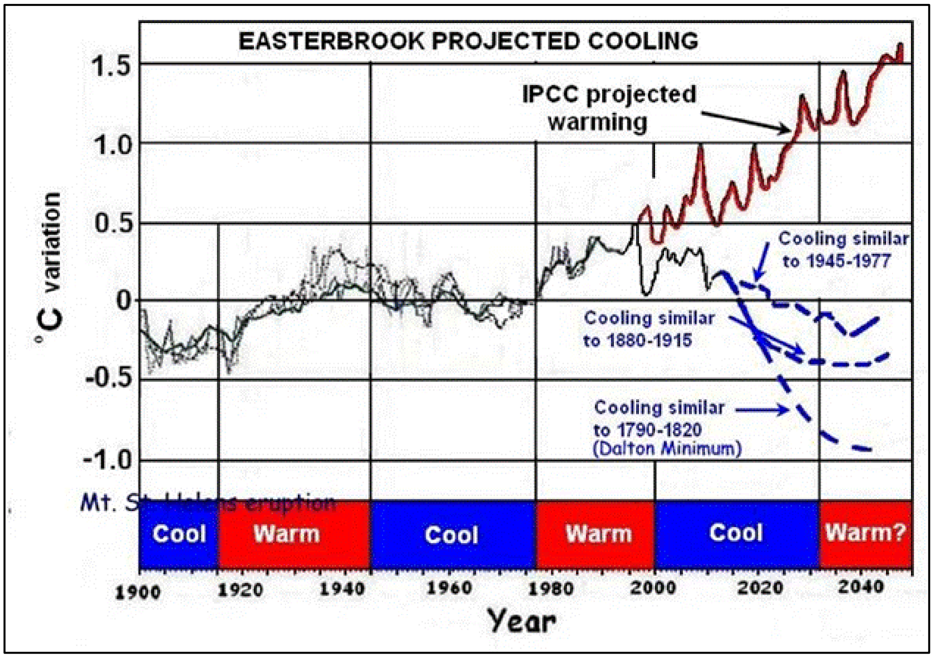
Analysis of the past (1931-1999) PDO shows that warm phase winters tend to be associated with warmer and drier conditions than average, while cool phase winters tend to be cooler and wetter than average. PDO"s typically last between 20 -30 years. The largest differences occur in the fall, winter and spring seasons (Climate Impacts Group, 2009; http://jisao.washington.edu/pdo/):

- Warm phase temperature is on average higher, (c.0.5 ºC) Oct-May and has 10% less precipitation than cool phase
- Cool phase temperature ranges from (+1.3 ºC) in March-April to (-0.25 ºC) in November-December.

5.3.7 Combined ENSO, PDO and Solar Variability

The potential does exist for temperature and precipitation extremes when the PDO and ENSO are in the same phase. The combination of La Nina and PDO cool phase or El Nino and PDO warm phase can lead to reinforcement and extreme weather. ENSO can contribute to a change of between -15% and +9%, to the snowpack, while PDO can contribute between -15% and +17% and records indicate a combined effect of -30 to +26% (Climate Impacts Group, 2009). The extreme weather of these events may be an analogue of weather that could be expected under a climate change scenario that is warmer than present, although the weather patterns are unlikely to be formed by the same processes as during ENSO or PDO.

We are currently experiencing a cool phase PDO. This will be combined with a low sun spot cycle and a current El Nino (2009) followed by a La Nina (2010). Initially the El Nino and PDO (20-30 years) will probably cancel each other out, as neither seems to dominate when they are out of phase, but given it is a low solar activity period (11 years) it is likely that, at least the next 20 years, will be cooler than average and offset the warming trend as a result of greenhouse gases (Easterbrook, 2008; Climate Impacts Group, 2009). In addition as the solar activity during this time is expected to be lower than previous cycles, the amount of energy for amplification by greenhouse gases will be reduced which would probably suggest that there is likely to be a temporary break in the warming trend, resulting in a more thermally stable period and potentially, a short declining trend if all the main influences are in a "cool phase". This cooling is being predicted by various bodies and in some circles and is becoming known as the Easterbrook Projection. It is important to bear in mind that this is still controversial because of a lack of clarity about which systems are driving the patterns and which are merely responses.



Source: http://notrickszone.com/wp-content/uploads/2011/01/Vooro_2.gif

Figure 63: Future pattern of the PDO and anticipated temperature trends.

5.4 Greenhouse Gases (IPCC)

Wolf 2008 and many others have demonstrated through the use of ice cores the atmospheric concentrations have increased for CO_2. The records from Antarctica show that preindustrial concentration of the gas was about 280 ppmv (parts per million volume), and that the concentration has increased to the current level of 375 ppmv. The concentration emerged above its natural range in about 1830 AD. Natural variability of CO_2 in the last millennium was about 10 ppmv. One scenario is that the greenhouse gases could lead to a warming of the atmosphere and oceans and another is that the warming could lead to a melt water influx into the Atlantic, shut down of ocean currents such as the Gulf Stream and potentially start a cooling process across Europe with a potential spread into North America (Adams, et al).

Anticipated global temperatures as a consequence of greenhouse gases primarily, as reported by the IPCC, are presented in Figure 64. It should be noted that some scientists predict temperatures in more Northern regions of Canada to increase in excess of the IPCC predictions.

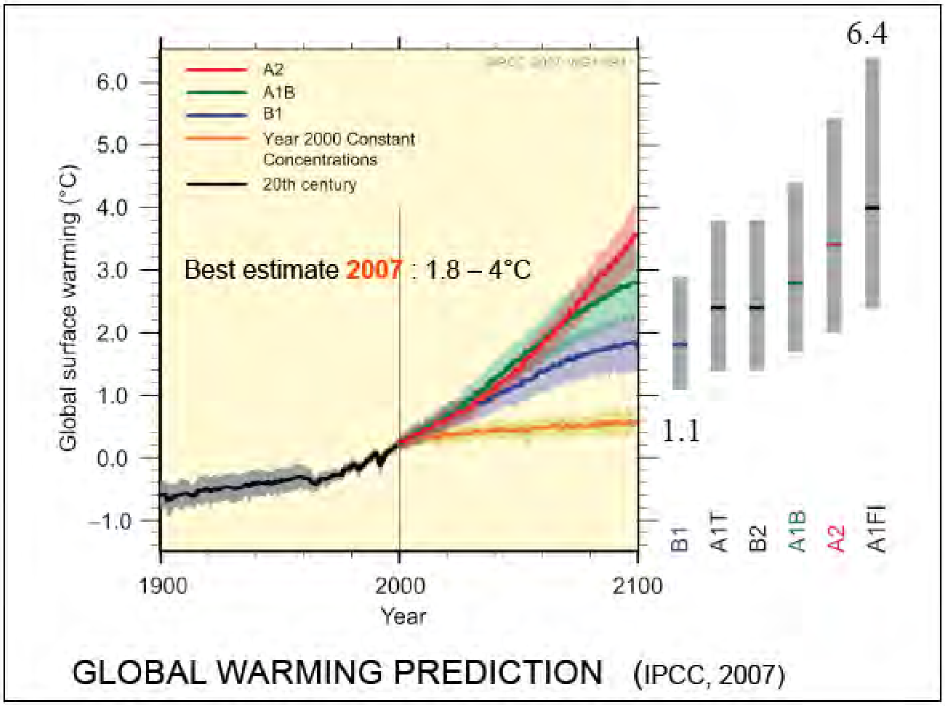


Figure 64: IPCC global warming predictions from AR4.

5.5 Palaeo-Climatic Reconstruction

A review of the literature relating to the paleao-climate of the Baker Lake area and its closest influencer, Hudson Bay along with an understanding of the influence of the Laurentide Ice Sheet focussed primarily on the Holocene is presented in Appendix 1. This reconstruction covers variables such as precipitation, humidity and fire, temperature, solar input, glaciers, general circulation and any other information that was encountered that could have value for establishing an understanding of the climate influences in the area. This reconstruction covers the Holocene which started approximately 12000 YBP (Years Before Present), or around 10000 BC. The Holocene period follows the Wisconsin glaciation. The Holocene can be subdivided into five time intervals, or chronozones, based on climatic fluctuations:

- Pre-boreal (10000 YBP – 9000 YBP)
- Boreal (9000YBP – 8000 YBP)
- Atlantic (8000 YBP – 5000 YBP)
- Sub-boreal (5000 YBP – 2500 YBP)
- Sub-atlantic (2500 YBP – present).

The end of the last major glaciation has two distinct periods which are referred to in the reconstruction developed for this study:

- The Last Glacial Maximum: The time of maximum extent of the ice sheets during the last glacial period, between 26500 and 13000 YBP.

- The Late Glacial Maximum: (ca. 13000-10000 YBP) is defined primarily by climates in the northern hemisphere warming substantially, causing a process of accelerated deglaciation following the Last Glacial Maximum (ca. 26500-13000 YBP).

5.5.1 Past Indicator of Current Conditions

The period 9000 BP is considered to be a good indicator of current conditions in Canada with the following characteristics:

- **Precipitation:** Dry summers and wet winters
- **Temperature:** After glaciation this period experienced circa 1° C warming per 100 years
- **Glaciers:** Generally a declining trend. Ice sheets appear to be one of the drivers controlling temperature due to their albedo. When they disappear temperature ranges tend to increase. When they are present they decrease temperature range
- **Water Levels:** Rising in response to warmer temperatures and melting glaciers after last ice age. Extra input from increased winter precipitation
- **Fire:** Low or neutral fire anomaly probably due to the wetter conditions in winter and drier summers controlling plant growth
- **ENSO:** This was generally weak during this time caused by the boreal summer perihelion
- **Solar Activity:** Appears to be one of the main drivers when ice sheets are waning. Non-linear changes to the seasonal cycle of insolation coupled with Milankovitch cycles is the predominant driver and causes changes in orbitally driven boreal summer insolation in high Northern latitudes
- **Human CO_2:** No human industrial scale CO_2 sources.

5.5.2 Past Indicators of Cooling Conditions

For Canada the periods around 3000 BP and the Little Ice Age starting about 500 BP are selected as cooling periods after a warm period without influence of the Laurentide ice sheet as well as minimal influence of human CO_2 production.

- **Precipitation:** Generally wetter climate with summers wetter and then becoming drier as temperatures start to rise again. Humidity is thought to have decreased during this time
- **Temperature:** An abrupt decrease in temperature with a higher degree of variability most probably related to orbital cycle variation or insolation changes
- **Glaciers:** Tend to stabilise and grow
- **Water Levels:** Water levels initially rise due to higher rainfall, then stabilise and start to decline as conditions get colder
- **Fire:** Neutral to increasing fire anomaly period probably due to the wetter conditions in Summer when plant growth is improved and a general increase of fuel load occurs. Summer rain increases allows increased lightning to be inferred which is mechanism by which fires can be started. As the cooling continues the fire anomaly becomes negative, particularly in eastern Canada
- **ENSO:** NAO, PDO and AO all thought to be in low or cold phase, favouring La Niña type conditions more. Typically these are wetter and cooler conditions for Canada

- **Solar activity:** Orbital influence reduces insolation by $4Wm^2$ in July and increases in January by 2 Wm^2 (High Northern Latitudes)
- **Human CO_2:** No human industrial scale CO_2 sources
- **General circulation:** Reduction of sea surface temperature in northern latitudes and strengthening of polar anticyclone particularly in winter. Slight equatorward displacement of the sub-tropical high pressure centers. Tree line roughly coincides with Polar Front.

5.5.3 Past indicator of Warming Conditions

The period around 6500 BP and the Medieval Warm Period are seen as good indicators of a warming period.

- **Precipitation:** Generally receive an average amount of rainfall
- **Temperature:** General increase in temperature
- **Glaciers:** Tend to decline with warming
- **Water Levels:** Lake levels tend to fall with falls as high as 5-6 m in the south Yukon
- **Fire:** Initially fire incidence decreases and then increases as fuel accumulates and dries
- **ENSO:** Strengthens
- Solar activity: No indication
- **Human CO_2:** No human industrial scale CO_2 sources
- **General circulation:** Atlantic Maritime Tropical humid air mass moves in over southern Quebec in summer - inhibiting fire occurrence. Warming sea surface temperatures.

5.6 Climatology of North Eastern Canada

To be better able to understand the paleo-climate of the Baker Lake area, a brief review of the climatology of the area is presented. The variations that are spoken about are derived from variations to the circulation patterns and should also be read in conjunction with the cycles identified in Section 5.3. This is only a brief review to ensure that there is a common language for understanding the paleo-climatic information presented in Appendix 1.

5.6.1 General Circulation

Canada‟s climate is mainly affected by the polar front which migrates back and forth across the high latitudes of the northern hemisphere according to the seasons and the amount of heating the earth receives (Figure 65). When there is a lot of heating, the polar high expands and cold air is pushed southwards. When there is cooling, the polar high contracts and warmer air moves northwards. The mid latitude jet (Figure 66) drives the weather that is experienced over Canada and matches the position of the polar front. Frequently, there is a low pressure area situated between Hudson Bay and Greenland and a low pressure situated in the area of Alaska (Aleutian Low).

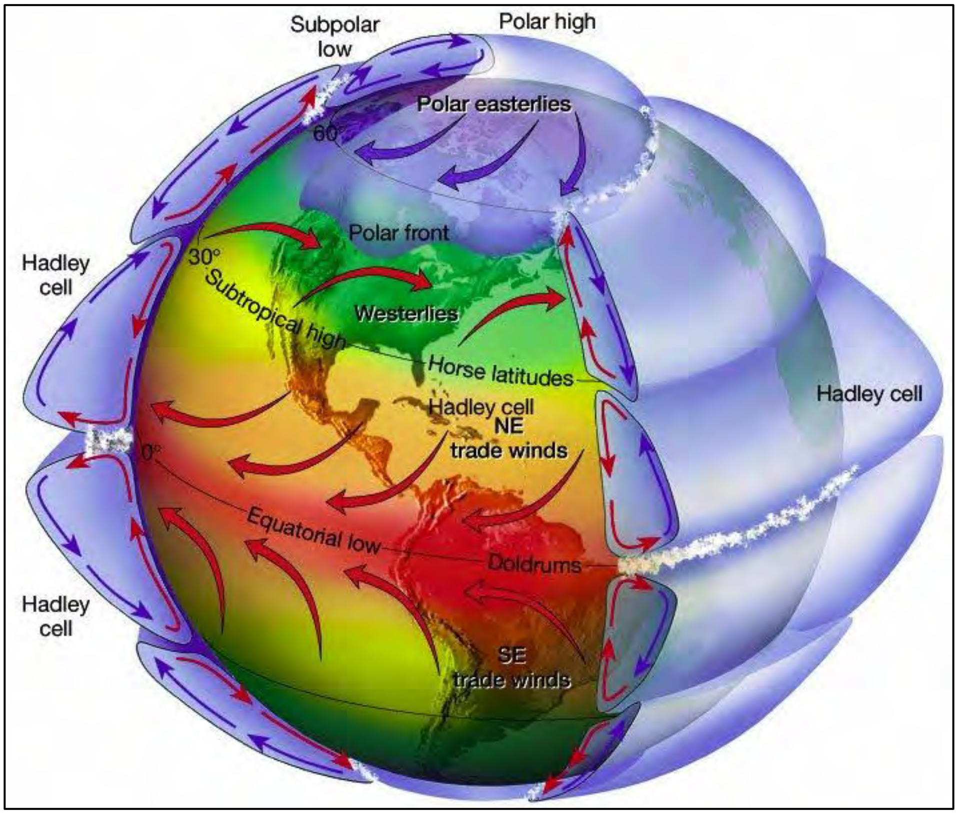


Figure 65: Earths general circulation.

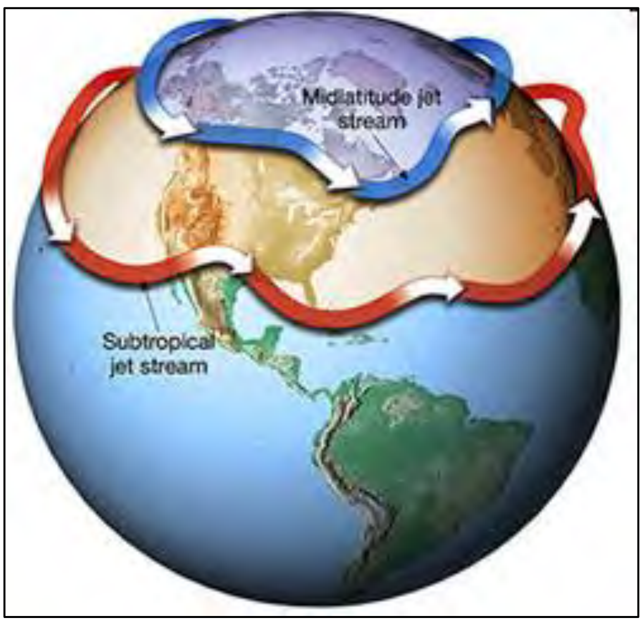


Figure 66: Direction of flow and general position of the mid-latitude jet.

On a more regional scale, Canada is affected by various air masses that have varying properties associated with them. Depending on which air mass is dominant, the weather of a specific area can be influenced.

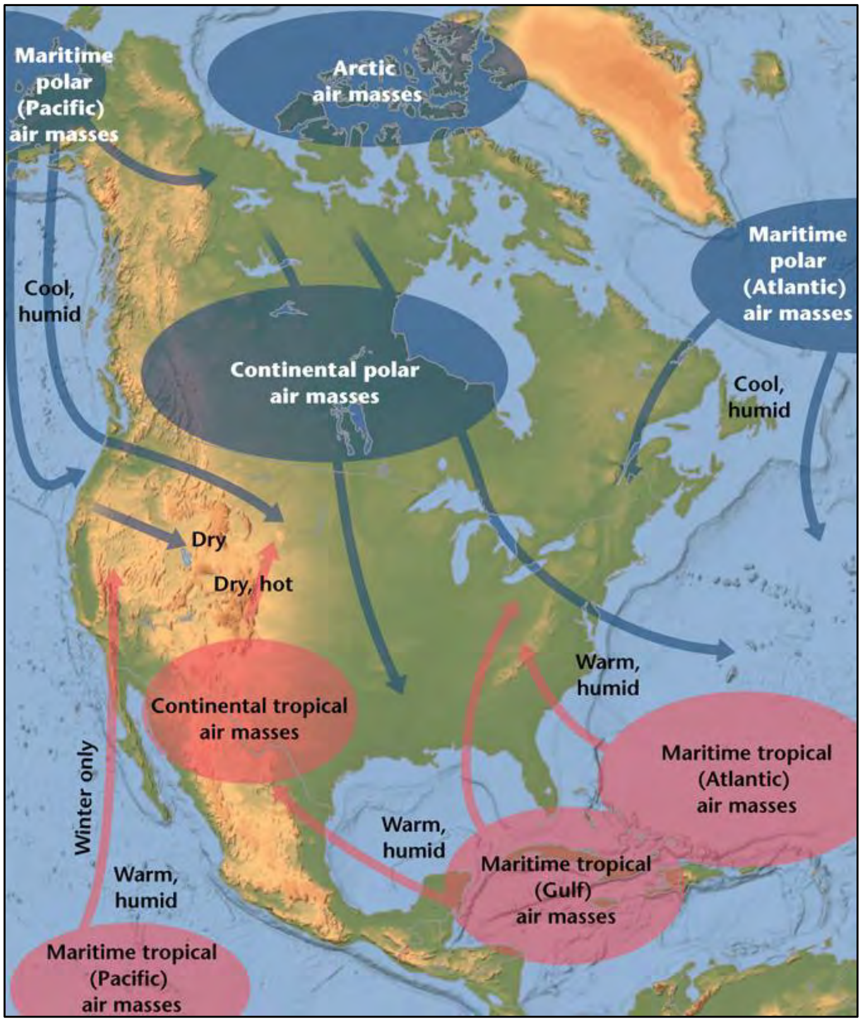


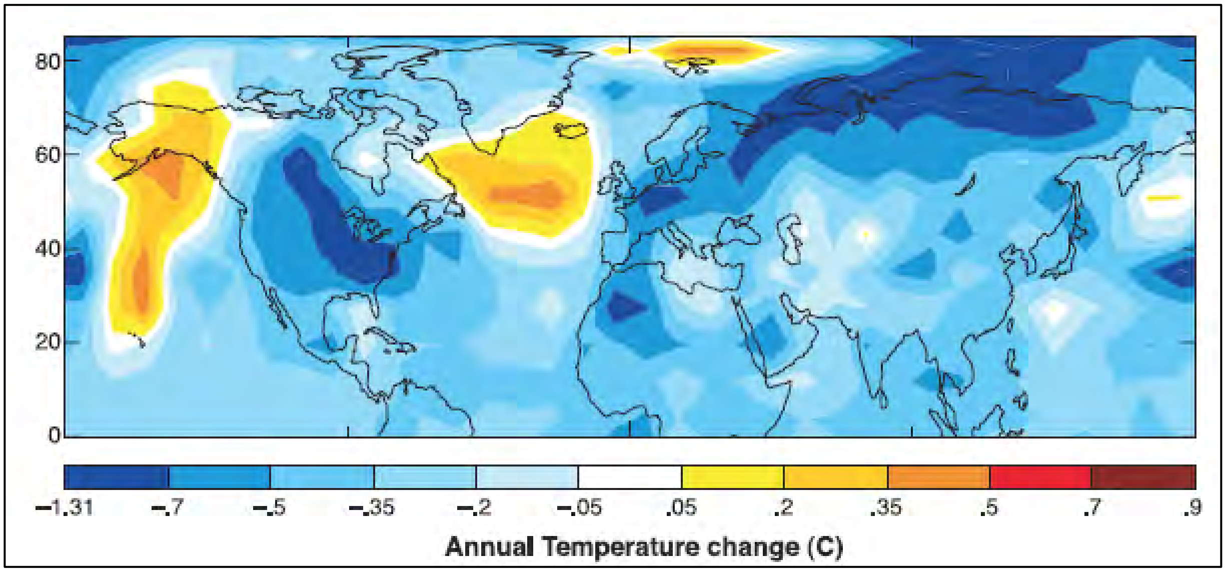
Figure 67: Main air masses affecting weather over Canada.

- Maritime air masses form over water and are moisture laden
- Continental air masses form over land and are drier
- Tropical air masses are warmer
- Polar air masses are cold
- Arctic air masses are extremely cold.

The weather in the Baker Lake area can be affected by the Arctic and the Continental air masses in winter. Both are relatively dry, with the former being extremely cold and the latter, cold. Precipitation is therefore limited mainly to summer as the polar front moves northwards and the moisture laden air can move into the area and result in rain. The shoulder seasons will have warm water bodies losing moisture to the cold air and higher snowfall will occur during these times.

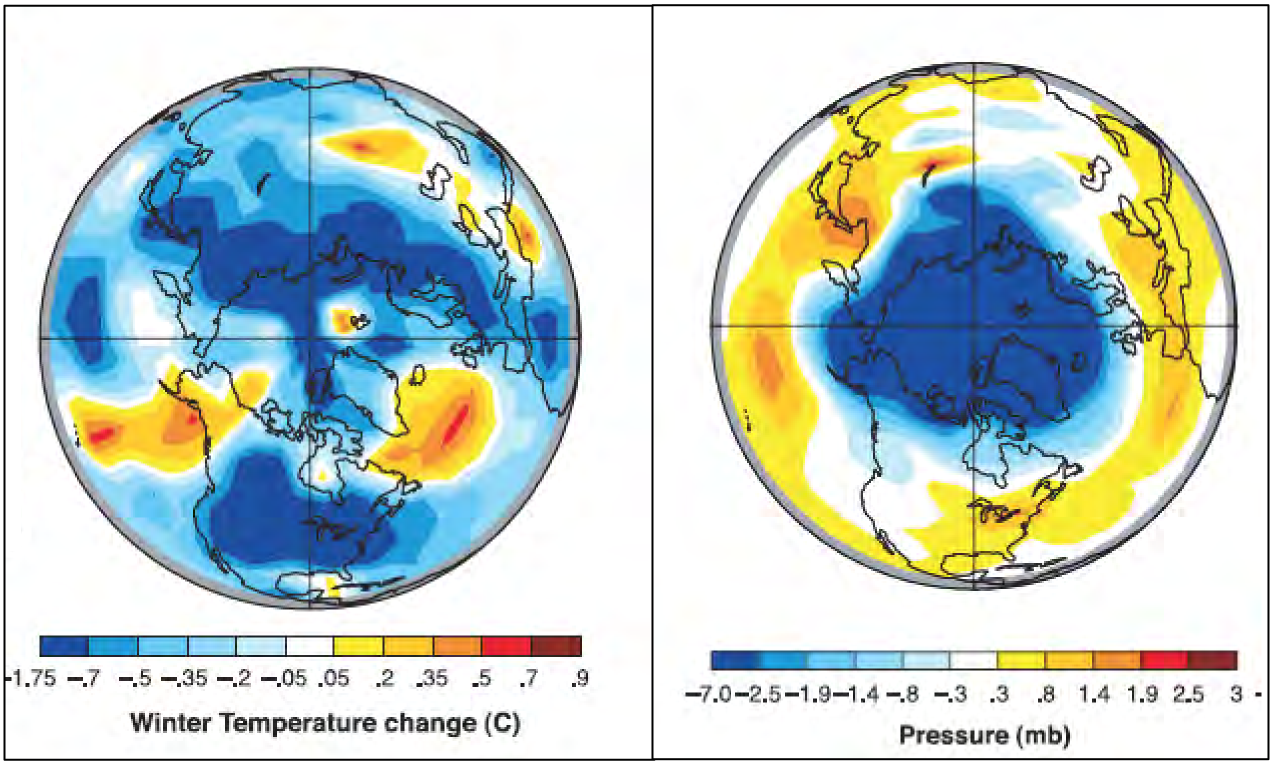
5.6.2 Climatology of the Past

The information presented in Appendix 1 is the main source of data used to describe the past climate in this document. In additon, as presented in this section, Shindell et al. (2001) have run models to determine the extent of cooling and the pressure that is likely to have occurred in the Maunder Minimum. This information is presented here as it gives a good visual impression of the circulation that was experienced during that time, as well as the 1°C- 2°C temperature drop that occurred over northern Canada.



Shindell et al, 2001.

Figure 68: Modelled annual temperature during the Maunder Minimum.



Shindell et al, 2001

Figure 69: Modelled Winter temperature and pressure during the Maunder Minimum.

5.6.3 Climatology of the Future

At a very coarse level, to ensure that the scenario presented in this document does not claim accuracy or high confidence as a weather forecast, the past climate is used to suggest what is possible to occur at Baker Lake. It is plausible that similar cold conditions as occurred in the Maunder Minimum and 6000YBP could exist if there is a cooling in the Baker Lake area. It is also plausible that if temperatures warm, then a period represented by 5500 to 6000YBP could be a good analogue, as this is a period that is outside of the influence of the Laurentide ice sheet and was a known warm period. It is stressed again that the resolution provided here is speculative at best, and is based primarily on conditions and circulation patterns that occurred in the past. It gives an indication of general climate conditions and not the daily weather conditions or the extremes that could occur. It is not believed that any realistic indication of future weather can be provided at this time, by computer models or with paleo records with the current state of knowledge and ability.

Cold Conditions

If there is a cooling in the Baker Lake area, moderate to dry conditions can be expected as the low pressure between Greenland and Hudson Bay brings in moisture. As the moisture laden air mass contacts the cooler air, snowfall will be likely. The circulation will possibly be dominated by a circulation favouring La Niña type patterns and negative phase Arctic Oscillation systems. If there is a cooling over the next 30 to 50 years, it is anticipated that the melt season will be shorter, and that the shoulder seasons will experience more precipitation due to the warmer oceans giving up more moisture as they try to reach equilibrium with air temperature. So, for a short decadal-type cooling, predicted due to the cool phase that is thought to have started, temperatures are likely to drop by 1°C to 2°C in winter (Shindell et al 2001), melt season is likley to be shorter, albedo will increase as there will be more snow on the ground and it is likely that glacier growth will occur. The permafrost conditions are likley to be maintained and the rates of evaporation reduced due to generally cooler air. The cooler air is also likely to see a reduction in the rate of increase of CO_2 in the atmosphere. The summer temperatures, due to reduced insolation, are likely to be lower, supported by cooler oceans and additional ice bodies that last longer into the melt season. Summer temperature ranges are likely to reduce due to residual winter ice, as was caused during the melt back of the Laurentide ice sheet.

Warm Conditions

If conditions warm, temperatures could increase by between 1°C and 2.5°C under conditions without CO_2. With CO_2 influence, it is possible that temperatures could increase by up to 5°C. Under warming conditions, El Niño-type circulation will possibly dominate, along with positive phase Arctic Oscillation circulation pattern. The Polar high pressure will contract and more moist air will be drawn into the area, resulting in increased precipitation. Snow cover will melt back faster in spring and the melt season will possibly be longer. Winds may be stronger due to the greater pressure difference that occurs and this is likely to result in greater evaporation. The albedo for the area is likely to decrease, favouring warming and increasing CO_2 levels. Plant mass production is also likely to increase. Glaciers and permafrost are likely to decrease in extent and seasons will be more pronounced, with a greater temperature range in summer. Winter temperatures will remain below 0°C, suggesting very little change in winter conditions, barring the possible increase in the amount of winter snow. If there is a warming period, the rate of change is likely to be in the range of 0.5°C/100 years, if CO_2 is in equilibrium with temperature. In 200 to 300 years" time, there is unlikely to be a major influence from CO_2 and warming rates will revert to natural change rates, which will be lower and modulated primarily by the solar input.

5.6.4 IPCC and CCCSN Models for Canada

The Canadian Climate Change Scenarios network (CCCSN) has produced a summary of findings from the most recent IPCC AR4 (2007) modelling assessment for Canada. Twenty-four international modelling centres have contributed to the international dataset and the output presented here is a mean ensemble from all available international modelling centres. The models used are outlined below:

Bjerknes Centre for Climate, Norway	BCM2.0
Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	CGCM3T47
Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	CGCM3T63
Centre National de Recherches Meteorologiques, France	CNRMCM3
Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia	CSIROMk3.0
Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia	CSIROMk3.5
Max Planck Institute für Meteorologie, Germany	ECHAM5OM
Meteorological Institute, University of Bonn Meteorological Research Institute, Germany	ECHO-G
Institute of Atmospheric Physics, Chinese Academy of Sciences, China	FGOALS-g1.0
Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDLCM2.0
Geophysical Fluid Dynamics Laboratory (GFDL), USA	GFDLCM2.1
Goddard Institute for Space Studies (GISS), USA	GISSAOM
Goddard Institute for Space Studies (GISS), USA	GISSE-H
Goddard Institute for Space Studies (GISS), USA	GISSE-R
UK Meteorological Office, United Kingdom	HADCM3 UK
Meteorological Office, United Kingdom	HADGEM1
National Institute of Geophysics and Volcanology, Italy	INGV-SXG
Institute for Numerical Mathematics, Russia	INMCM3.0
Institute Pierre Simon Laplace, France	IPSLCM4
National Institute for Environmental Studies, Japan	MIROC3.2 hires
National Institute for Environmental Studies, Japan	MIROC3.2 medres
Meteorological Research Institute, Japan Meteorological Agency, Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research (NCAR), USA	NCARPCM
National Center for Atmospheric Research (NCAR), USA	NCARCCSM3

The use of an ensemble approach (multi-model means/medians) has been demonstrated in recent scientific literature to likely provide the best projected climate change signal. Results between models can vary widely, and models each contain their own inherent biases. The use of a mean or median of many models reduces the uncertainty associated with any individual model. In effect, the individual model biases seem to 'cancel' out one another when considered as an ensemble. Compared against historical observed gridded data, ensemble results come closest to replicating historical climate. Although not a guarantee, an ensemble collection which can best represent historical climate, is more likely to represent future climate conditions (http://cccsn.ca/?page=ensemblescenarios-a1b).

The mean monthly temperature and precipitation values are calculated for each model for the periods of 1971-2000 and 2020s, 2050s and 2080s. The results represent three periods of projected climate change in relation to the baseline of 1971-2000 for the "middle of the road" A1B emission scenario. The maps indicate the change in temperature in degrees Celsius, and for precipitation, the maps show the change in precipitation in percent from the baseline period across Canada.

In addition, ensemble projections can have uncertainty measured which is shown in Figure 70 and Figure 71, as the standard deviation for the annual precipitation and temperature variables. Areas of low standard deviation indicate model projections that are more closely in agreement with each other.

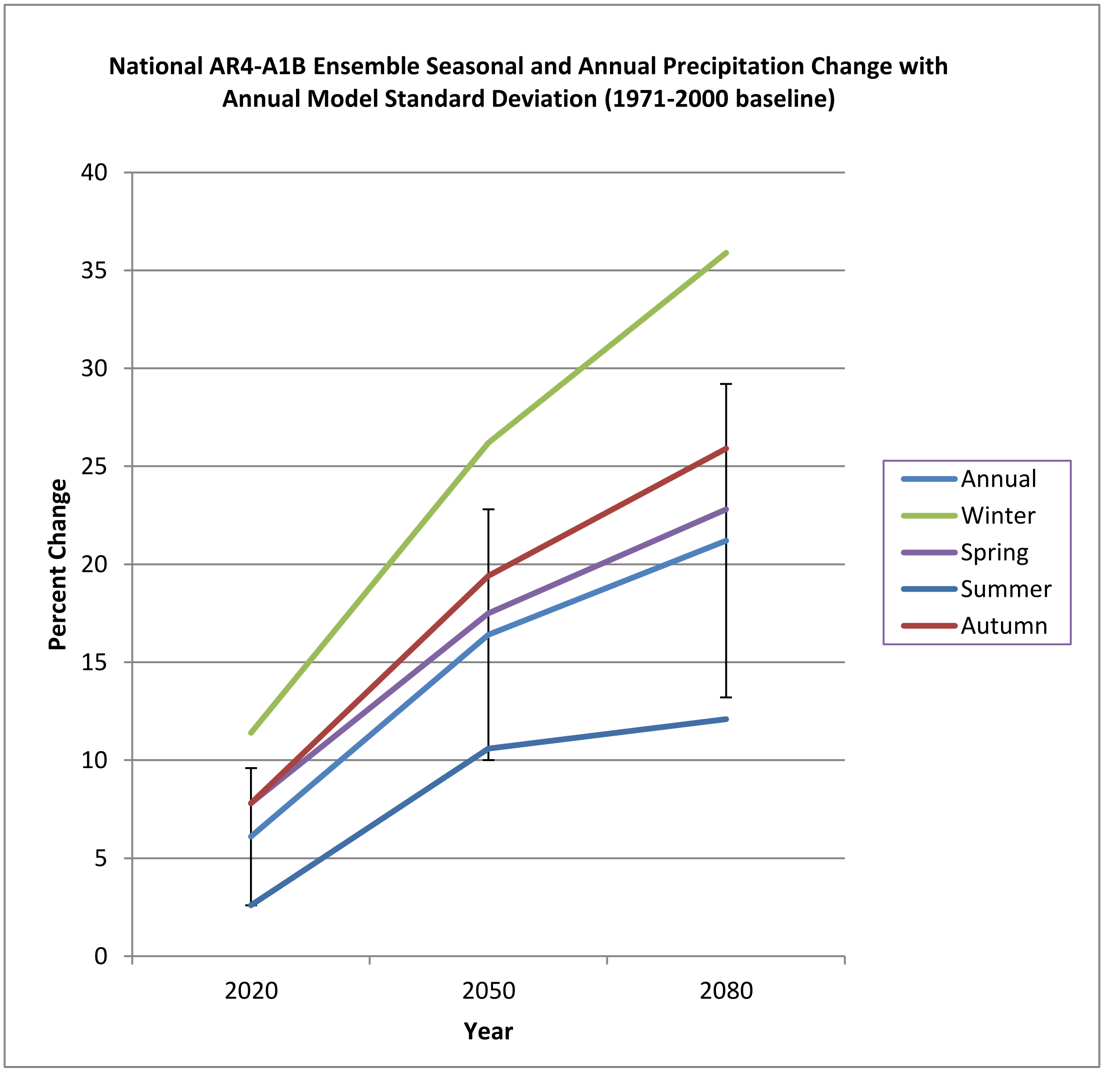


Figure 70: CCCSN AR4-A1B Ensemble Seasonal and Annual Precipitation Change for Canada.

The output from the ensemble approach suggests that rainfall will increase by approximately 10 to 25 % over the period 2020 to 2080 for various seasons and annually. Summer rainfall is expected to change the least and winter rainfall the most. This can be compared to the rainfall experienced at Baker Lake over the last 25 years as presented in Figure 80 in the sections below.

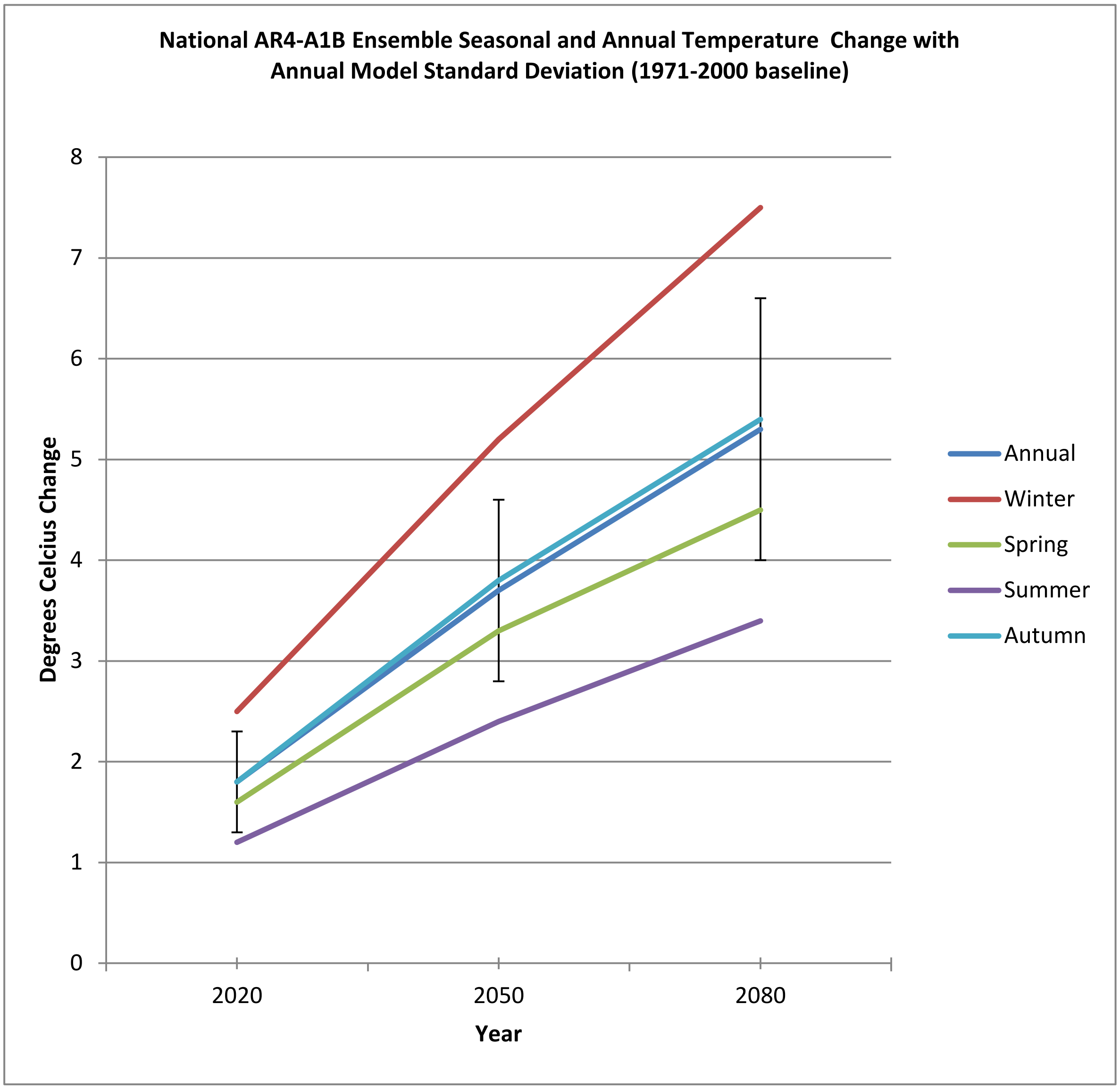


Figure 71: CCCSN AR4-A1B Ensemble Seasonal and Annual Temperature Change for Canada.

The output from the CCCSN ensemble approach suggests a general increase in Canadian annual temperature of between 2 °C and 5 °C for various seasons and annually over the period 2020-2080. This gives a decadal annual rate of increase for Canada about 0.35 °C or 3.5 °C per century. Winter is expected to experience the greatest increase in temperature and summer the least. Northern Canada and the Baker Lake area are expected to increase by 5°C over the next 100 years from a mean annual surface temperature of -7 °C to -2 °C. These predicted trends can be compared to the actual observed temperature changes that have been plotted for the global temperature against the IPCC projections in Figure 75.

5.6.5 IPPC for Canada by CCCSN

The CCCSN has produced a summary of findings from the most recent IPCC AR4 (2007) modelling assessment for Canada. Twenty-four international modelling centres have contributed to the international dataset. The output used in this analysis is a mean ensemble from all available international modelling centres. The mean monthly temperature and precipitation values are calculated for each model for the periods of 1961-1990 and 2050s (2041-2070).

Monthly GCM model output is interpolated to a common grid at 2.5 x 2.5 degrees across Canada. The GCM model ensemble produced does not include the Canadian Regional Climate Model (CRCM), which is included separately.

The results represent three levels of projected climate change for the 2050s period (2041-2070) in relation to the baseline period of 1961-1990: 'low', 'medium' and 'high'. The results are graphed and presented in Figure 72 and Figure 73. The graphs provide an indication of the change in temperature in degrees Celsius, and for precipitation show the change in precipitation in percent from the baseline period.

The 'low' projection represents the all-model mean resulting from the least aggressive emission assumption. This is the result from the commonly referenced SRES-B1 scenario. Correspondingly, the 'high' projection results indicate projected changes with the most aggressive emission assumption. The main purpose of a 'high' projection was to indicate an upper boundary, and additionally all modelling centres generated A1B output versus A2, the A1B results were used for the 'high' projection. The 'medium' projection then represents the mean of the combination of low (B1) and high (A1B) projections. Importantly, there is no implied recommendation that one of the three emission assumptions is favoured over any other, nor would the results vary significantly if the A2 scenario was substituted for the A1B. By the 2080s projection time period (2071-2100), the A1B scenario mean temperature is surpassed by the A2 mean temperature (http://cccsn.ca/?page=ensemblescenarios-2050s).

From the graphs presented below it is apparent that the winter temperature is expected to vary the most with a winter temperature increase of approximately 5.5 °C for the Baker Lake area. This roughly equivalent to a rate of about 0.5 °C per decade which is higher than the mean for Canada at 0.35°C. These predicted trends can be compared to the actual observed temperature changes that have been plotted for the global temperature against the IPCC projections in Figure 75. This can be compared to the rainfall experienced at Baker Lake over the last 25 years as presented in Figure 81 in the sections below. The comparison suggests that the rates that have been predicted by the CCCSN for Baker Lake may be too high. If the 30 year cooling period that has been predicted and appears to be starting does actually occur, then these rates may not be experienced until after 2030 with temperature peaking in the next century if CO_2 and other greenhouse gases are the main driver for climate change. The CCCSN figures are useful as they can be used as an upper bound of what can be expected to occur at Baker Lake as shown in Figure 84.

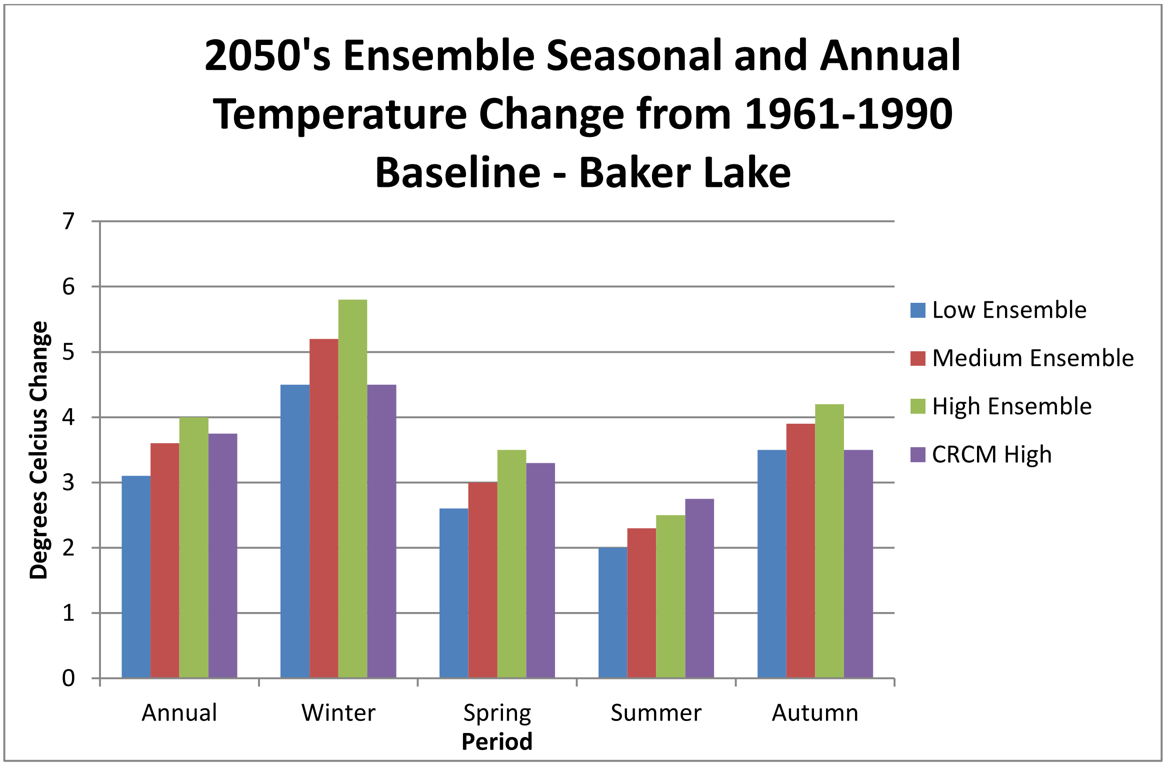


Figure 72: CCSN temperature change predictions for Baker Lake for 2050`s.

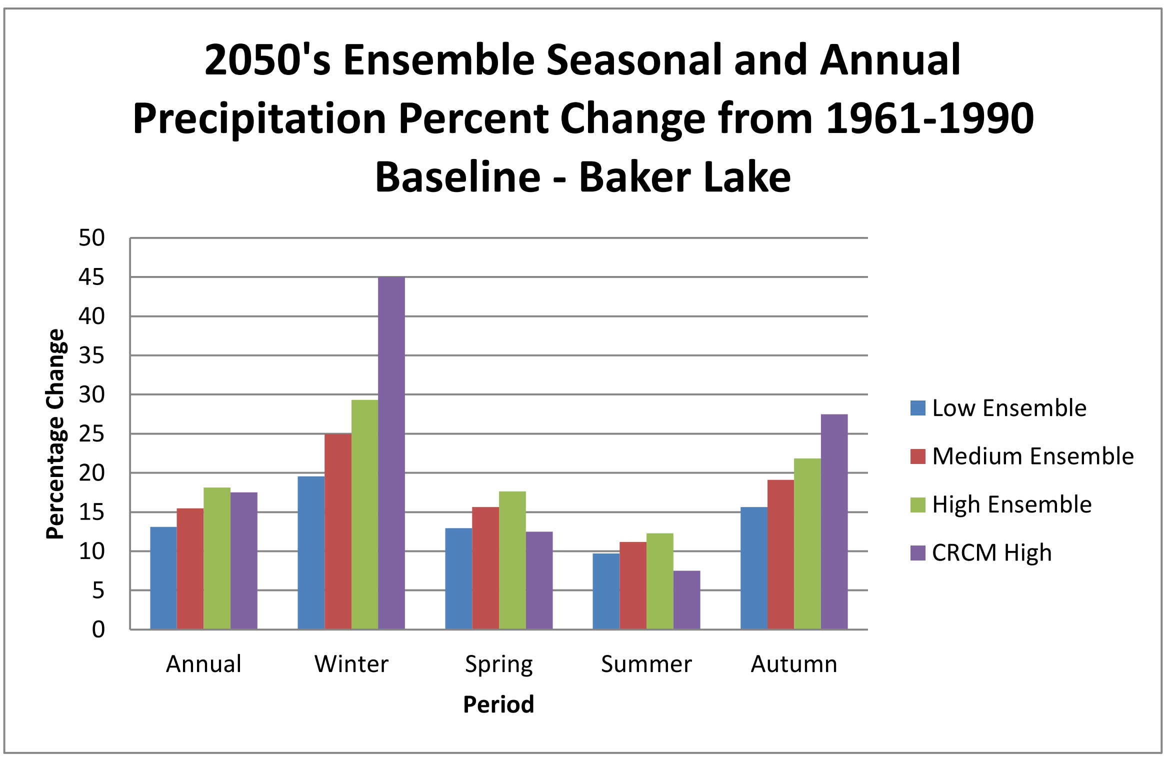


Figure 73: CCSN precipitation change predictions for Baker Lake for 2050`s.

5.6.6 Nunavut Climate Change Strategy Projections

In section 1.7 of this document, the People of Nunavut"s perception of climate change was reported. This is echoed in the *Nunavut Climate Change Strategy* (2003) document. Here it is reported that "Researchers believe that, in the northern regions of the world, the effects of climate change are already being seen. Ice in the Arctic is estimated to have thinned by nearly 40% in the last 30 years".

Furthermore it is reported, "Serious impact on animals dependent on cold climates - such as polar bears and high Arctic caribou are predicted as changing weather patterns disrupt their habitat and activities". The following information and map (Figure 74) are also drawn from the report.

Potential impacts of global climate change in Nunavut may be as follows:

- General increases in of temperatures by 5 °C to 7 °C in the next 100 years with shorter winters, more rain and more extreme weather;
- Disappearance of over one-half of existing permafrost;
- Flooding of low-lying coastal areas as a result of the rising sea levels;
- Loss of glaciers and possibly all permanent sea ice;
- Introduction of new diseases; and
- Loss of wildlife, fish and plant species and the introduction of new species.

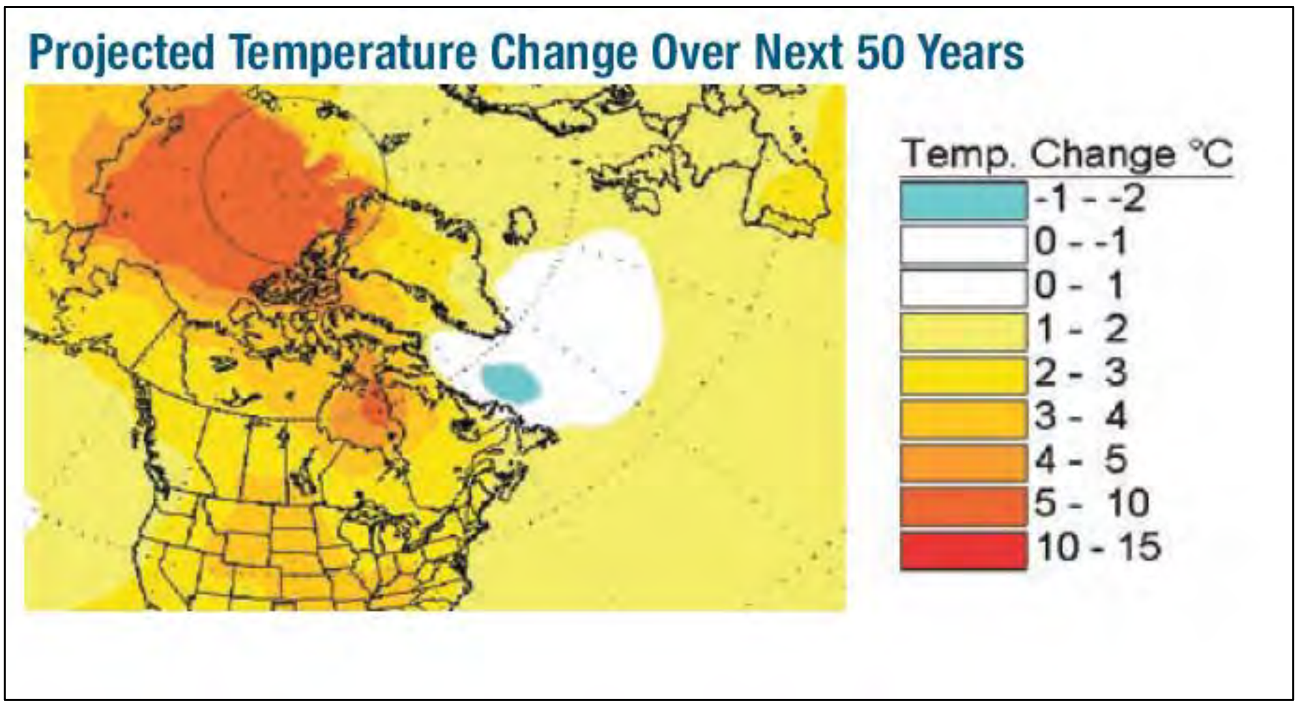
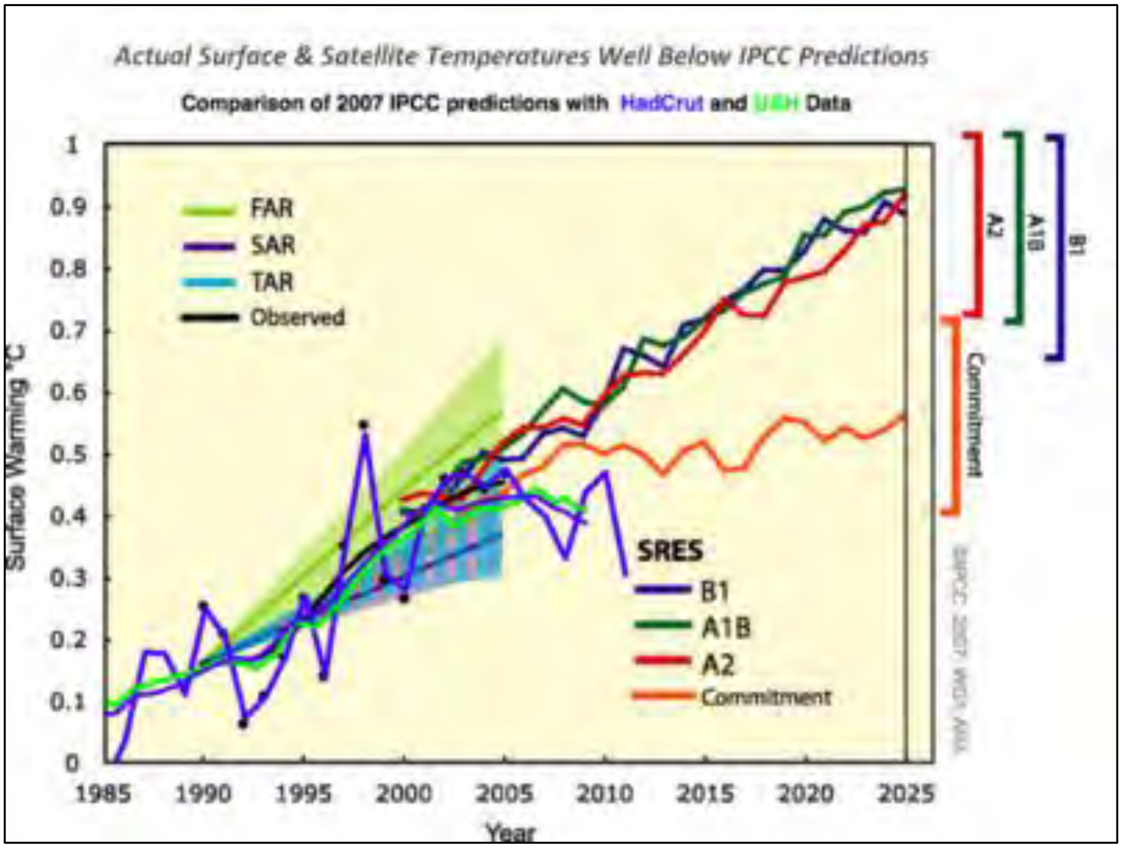


Figure 74: Nunavut Climate Change Strategy projected temperature change over the next 50 years.

5.6.7 Validation of IPCC Models Against Observation

The IPCC began making predictions about climate change with the release of the First Assessment Report (FAR) in 1990, followed by the Second Assessment Report (SAR) in 1995, the Third Assessment Report (TAR) in 2001 and the Fourth Assessment Report (AR4) in 2007. The predicted trends from these four reports as well as the HadCrut and UAH observed temperature trends are presented in Figure 75.

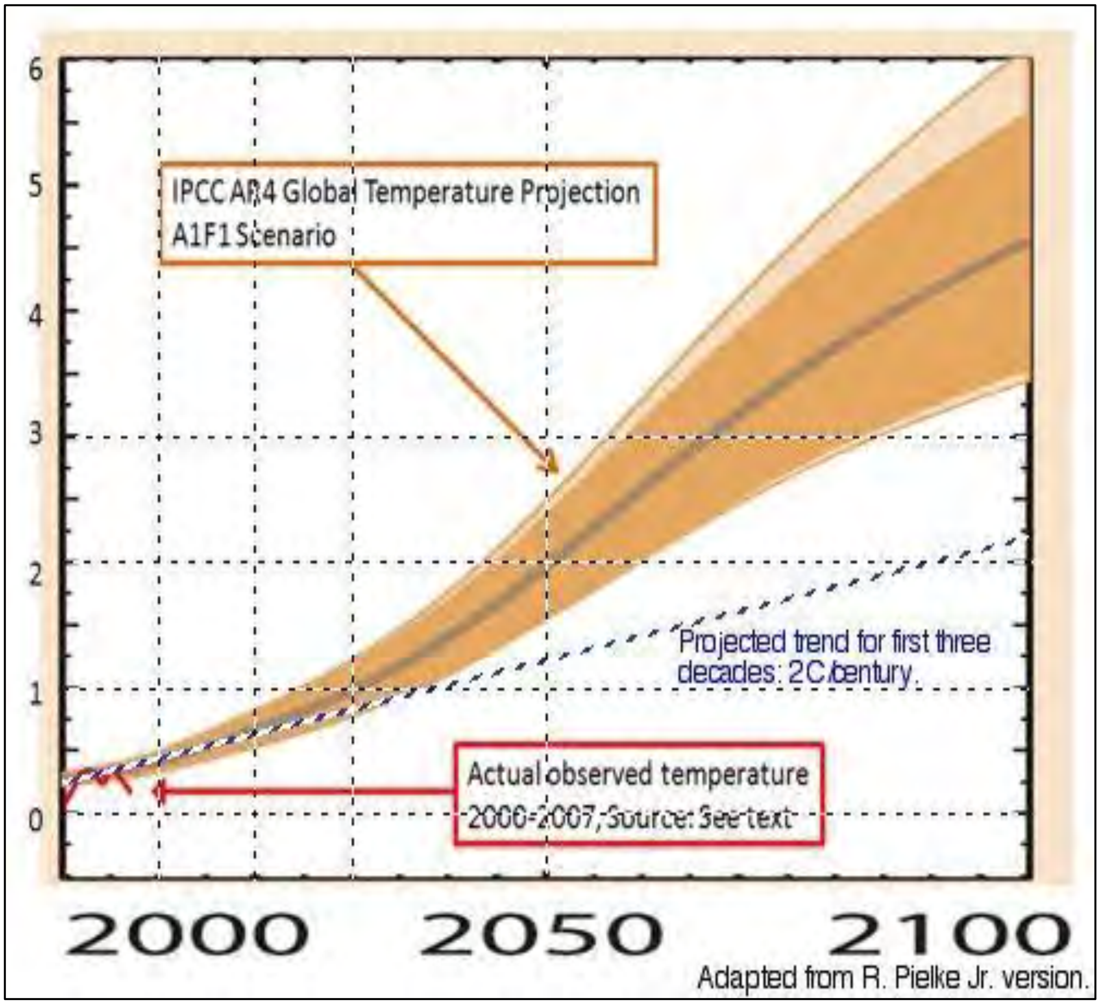


http://c3headlines.typepad.com/.a/6a010536b58035970c01538f6ce0f7970b-400wi

Figure 75: IPCC Far, Tar, Sar and AR4 predictions against the HadCrut and UAH temperature series.

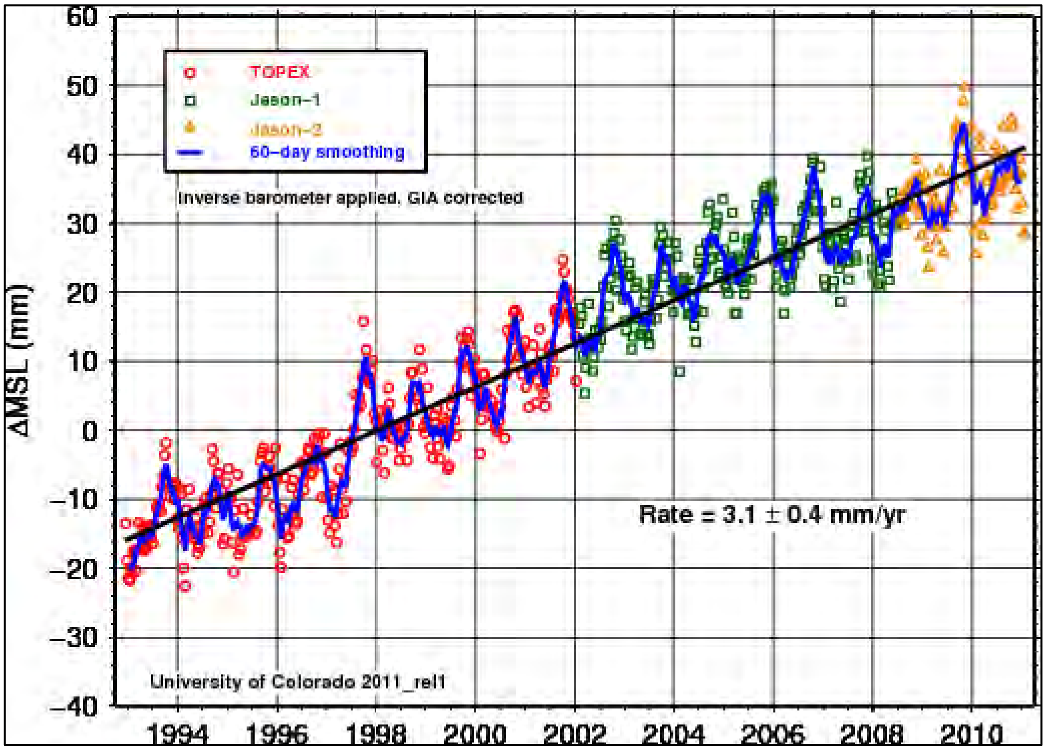
From this graph it is apparent that actual surface and satellite temperatures are below the IPCC predictions in all cases. It is clear that there has been increasing temperature from 1995 till about 2000, but that at that point the predictions and observed temperatures appear to diverge. During this time CO_2 has continued to increase but the observed temperature has not continued to increase at the same rate and there is an indication of a stabilisation of temperature if not a slight decrease. This would be consistent with projections presented in this report of the start of a 30 year cool period possibly related to solar changes. The most important of these is that cosmic rays are suspected to seed low level cloud formation which changes the earth`s albedo and causes surface temperatures to drop. In the following figure the IPPC AR4 A1F1 Scenario is plotted against actual temperature along with a trend for the first three decades of the 21st century 2000-2030. Again the actual temperature is lower than the IPCC temperature. The plotted trend for the next 30 years of less than

1 °C warming is plotted for comparison. If this trend is actually followed, then the likely warming for northern Canada and Baker Lake may not follow the IPCC projection. Furthermore this stabilisation trend is apparent in sea surface change as shown in Figure 77 where the rate of sea level change appears to be slowing if not stabilising at this time. An actual decrease is also apparent in the global ocean heat content.



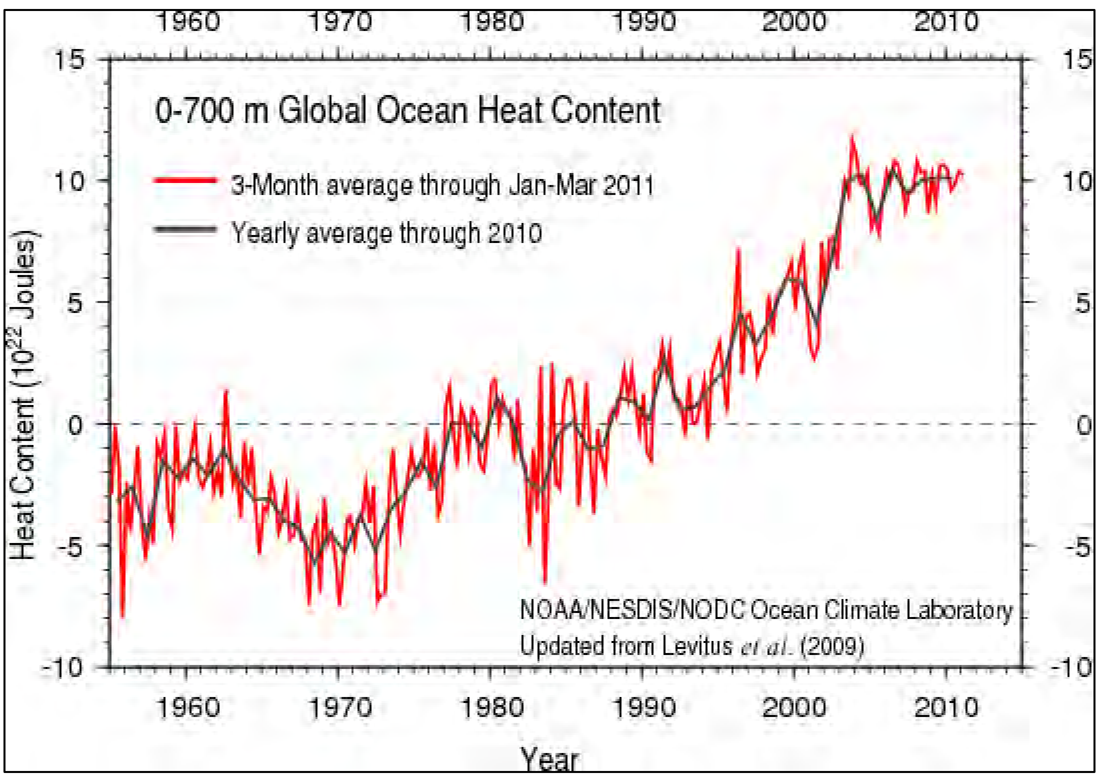
Http://rankexploits.com/musings/2008/what-are-the-ipcc-projections-and-how-not-to-cherry-pick/ipcc-projections/

Figure 76: IPCC AR4 plotted against actual temperature with a projected trend for 2000-2030.



http://sealevel.colorado.edu/current/sl_noib_global.jpg

Figure 77: Slight slowing or stabilisation in the rate of sea level increase.



http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/heat_content55-07.png

Figure 78: Stabilisation of the global ocean heat content.

5.6.8 Validation of IPCC Trends against Baker Lake Observation

Considering that higher rates of change that have been predicted for northern Canada and the Arctic by the IPCC and the ensemble model output presented above, it may be possible to find an indication of these changes in the past 25 years of weather records for the Baker Lake area (Figure 79). For snowfall Baker Lake does appear to be receiving less snow than the late 1980`s, but this trend has not continued after the initial decline. From about 1993 snowfall has not continued to decrease but appears to have stabilised at an annual level lower than the 1980`s. When reading these graphs bear in mind that 2011 is not yet complete so only read up to 2010 for full year data. All weather statistics presented below are derived from Environment Canada at: http://bakerlake.weatherstats.ca/.

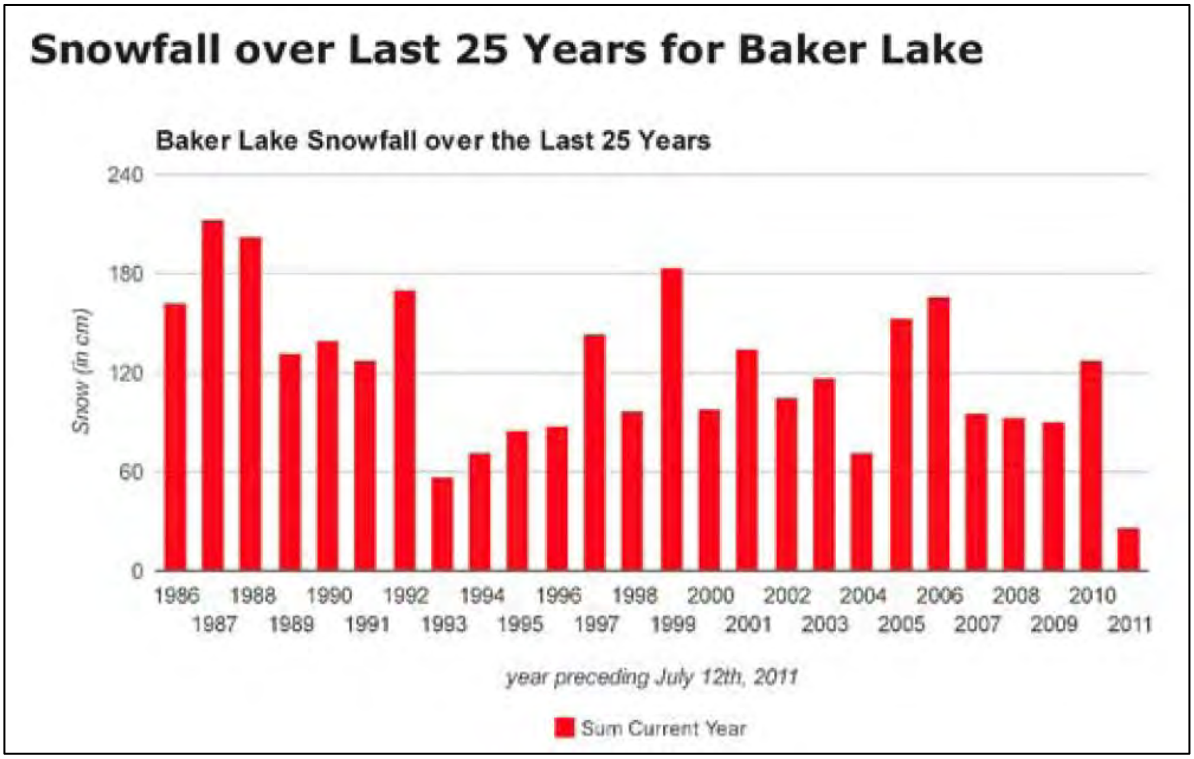


Figure 79: Baker Lake snowfall for the last 25 years.

The IPCC models also predict increased precipitation for most of Canada and specifically in the Baker Lake area. The rainfall record for Baker Lake as presented in Figure 80 indicates a slight decrease in rainfall from the 1980"s, however there also appears to be greater variability in the year to year amounts of rainfall being received. For total precipitation presented in Figure 81 again the expected increase in total precipitation that would be expected as predicted by the IPCCC is not evident. By comparison to the 1980"s however there does appear to be more variability. Baker Lake snow on the ground decreased from the 1980"s, but has stabilised from 1995 (Figure 82). In Figure 83 the heating degree days are presented. This measure reflects the demand for energy and is defined relative to a base temperature - the outside temperature above which a building needs no heating. There does not appear to be much change though a slight down trend is apparent. Consistent with warming of the outside temperature.

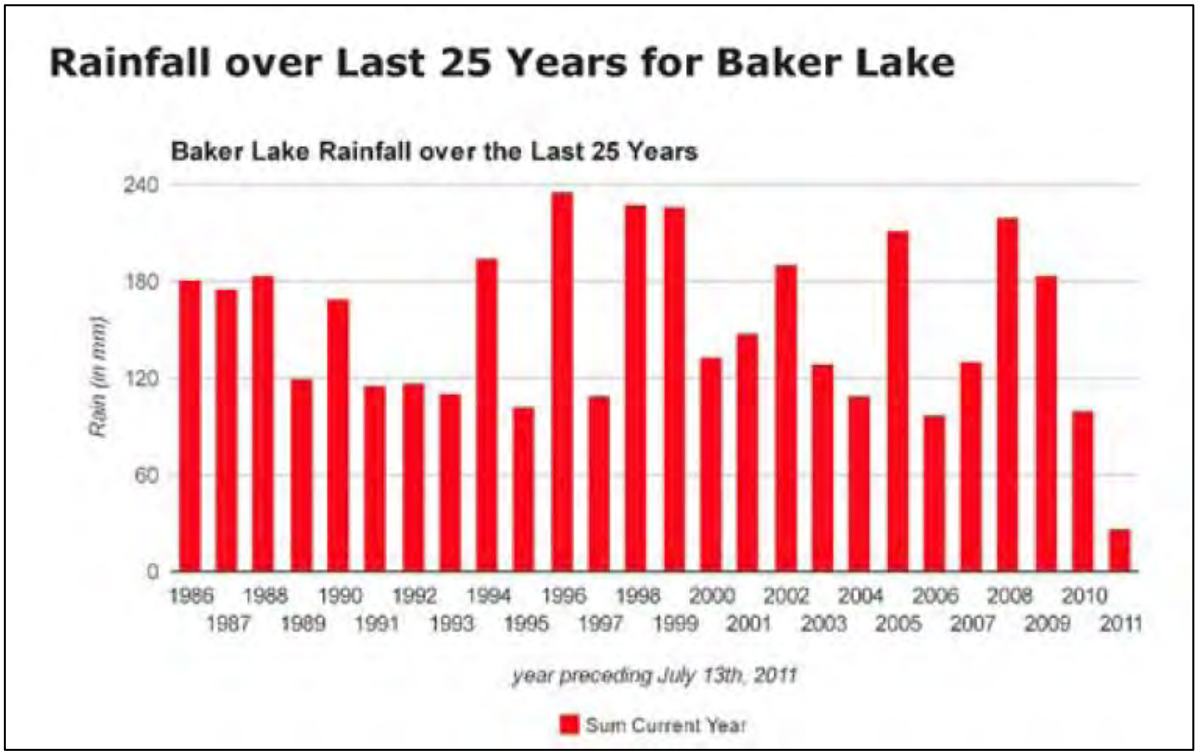


Figure 80: Baker Lake rainfall for the last 25 years.

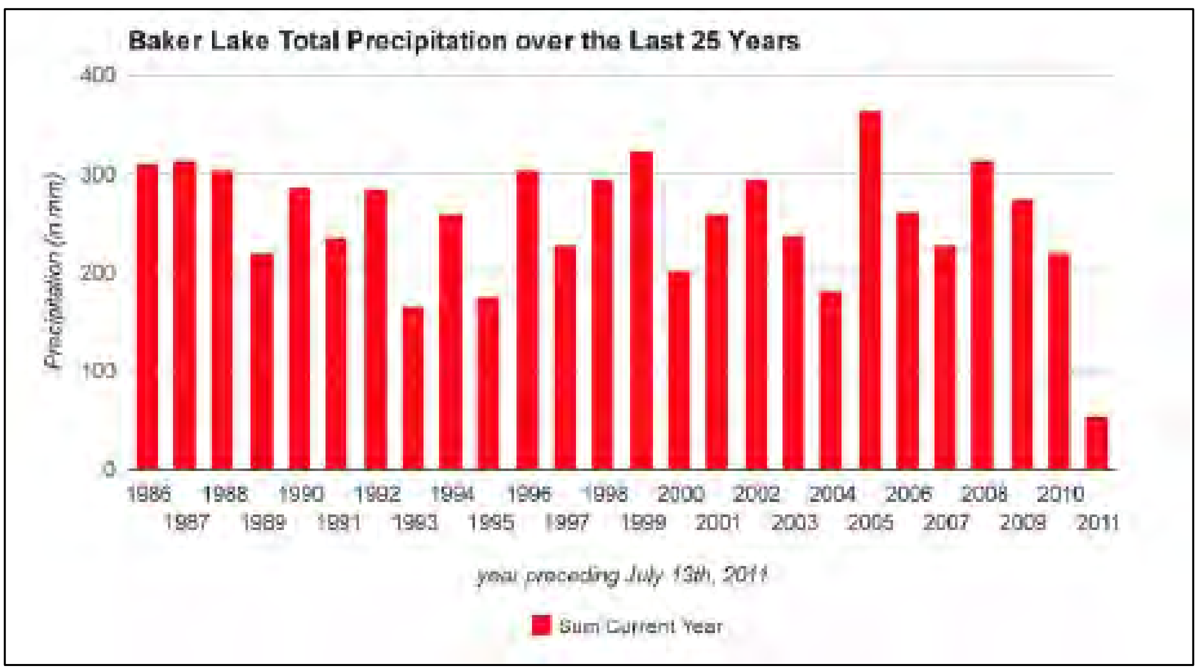


Figure 81: Baker Lake total precipitation for the last 25 years.

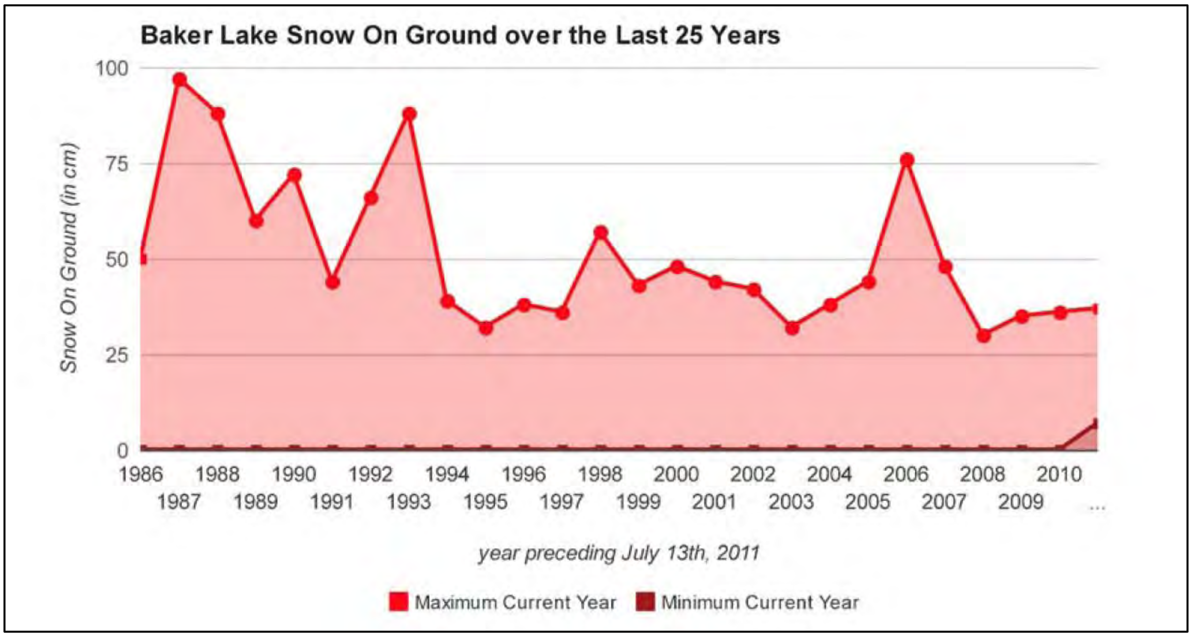


Figure 82: Baker Lake snow on the ground for the last 25 years.

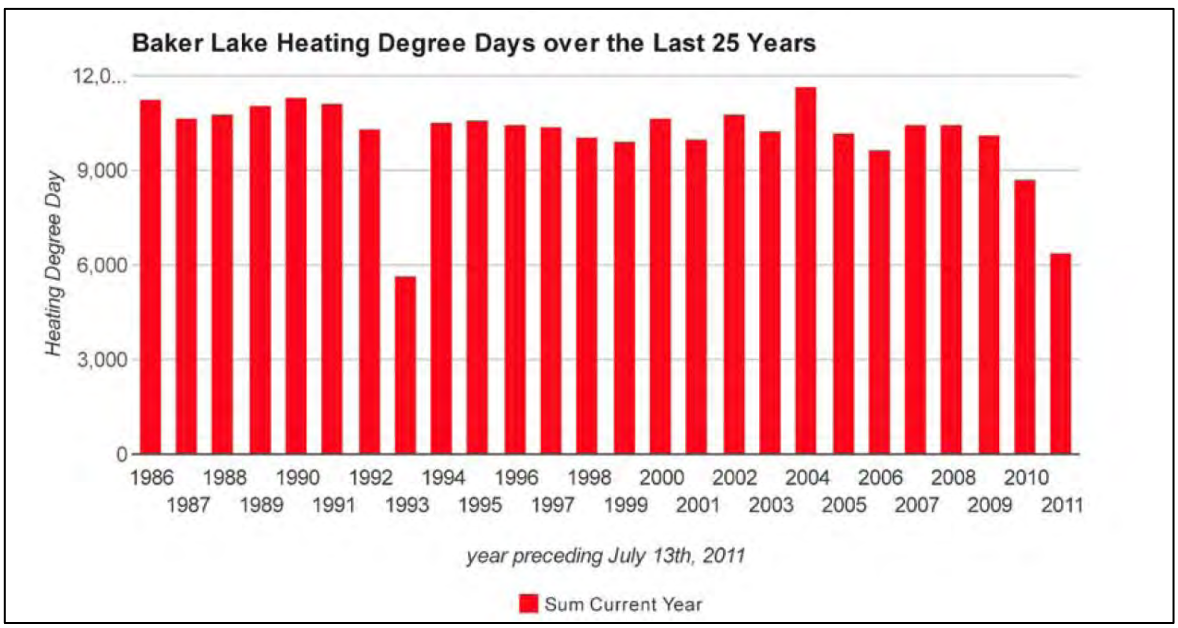


Figure 83: Baker Lake heating degree days for the last 25 years.

In all the above cases for the 25 year records for Baker Lake, there is no instantly recognisable correlation between IPCC predictions and actual observed weather patterns. This may be because the weather data does not span over a long enough period or it may be that the changes are not occurring as rapidly as the IPCC predicted. It is hoverer, clear that by comparison to the 1980"s change has occurred, primarily with regards to the variability. How this variability will play out in the future is not entirely certain, however it seems that there is a weaker correlation between increasing greenhouse gases and increasing temperature than the IPCC models may reflect. If this is the case, then there may be other driving forces such as solar variability that play a role in climate change.

Using the information presented in this report along with the palaeo-climatic reconstruction, it is possible to develop a potential scenario for the future Baker Lake climate. Incorporated in this scenario are the predictions for the next 30 years, IPCC predictions for the next 100 years as well as solar and orbital variations that allow reasonable general climate predictions to be made for the next 150 000 years.

5.7 Summary of Scenario

In Table 3 below, a summary of the information is provided. This information is graphically presented in Figure 84. The table identifies the climate regime, major forcing mechanism, potential dominant weather pattern and the potential temperature for each defined period. A reference to the source of the information is provided in each case. The list of references is not exhaustive but indicative of researchers who have identified trends that are likely to occur at 65N or across Canada.

Table 3: Climate change scenario from now to 10,000 YAP.

Period Years After Present (AP)	**Climate Regime**	**Major Forcing Mechanism**	**Potential Dominant Weather (Refers to difference from current)**	**Potential Temperature (Refers to temperatures above or below current temperatures)**	**Data Source**
<100	Interglacial	Greenhouse gases	0-50 (Koerner) Cooler weather, increased moisture with slight reduction in precipitation event numbers, but higher intensity of events. Higher strength wind events likely. Insolation likely to decrease. Completely open sea ice conditions unlikely before 2020-2030. Upper Atlantic warm water flow reduces by 25%-30% (USGS). 2°C cooling of mean annual air temperature since 1940 at Tuktoyaktuk results in -40% thickness of the active layer (Harris). 50-100 (Maxwell) Warmer weather with higher moisture and precipitation (+20-30%) from fewer events but of higher intensity. Fall and winter increased snowfall, but the snow-cover season shorter by 30 days at 70°N latitude. Increased accumulation means spring run-off and flooding may increase. Diurnal temperature ranges higher variability and amplitude. Insolation likely to increase. Higher strength wind events likely. Ice covers duration on lakes and rivers reduced by an average of 30 to 35 days. Warming occurs in the second part of the century. Summer glacier ablation offset by stormier winters with greater accumulation. Smaller mountain glaciers and ice-caps decrease in mass. Large ice-caps (e.g. Greenland), 3 times rise in iceberg calving (currently 20,000 to 25,000 yearly into Baffin Bay).	0-50 years Slight cooling over the next 50 years of about 0.5°C to 1.0°C. Summer cooling in the next 50 years may be slightly more than this (Koerner). 50-100 years “Best estimate (IPCC+2.5°C)”: +5.4°C winter, +4.0°C spring and +1.2°C summer and fall, mean annual ambient temperature +3°C at Kiggavik latitude (IPCC, EC). “Worst case (IPCC +4.5°C)”: +9.6°C winter, +7.0°C spring and +2.1°C summer and fall, mean annual ambient temperatures +5.2°C at Kiggavik latitude (IPCC, EC). “Potential extreme” (Maxwell) + 8°C to 10 °C winter, 1°C to 2°C summer, +11C winter in Lower Mackenzie Valley based on past climate (Maxwell).	Koerner; IPCC; Environment Canada, Maxwell, USGS, Harris

Period Years After Present (AP)	Climate Regime	Major Forcing Mechanism	Potential Dominant Weather (Refers to difference from current)	Potential Temperature (Refers to temperatures above or below current temperatures)	Data Source
			Glacial melting adds 0.2m to 0.5m to world mean sea level. Sea-ice season shorter, summers likely to be ice-free in the Canadian archipelago. 35% decrease in winter ice thickness (current 2.5m average), substantial northward retreat of the southern limits of sea ice. Scenario implies complete disappearance of multi-year ice. Permafrost areas decrease and disappear. Active layer deepens, increased slope movement, mud flows, skin flows and slumping, fewer ice wedges and pingos. 2°C warming moves the outer boundary of permafrost to the metastable permafrost region. 5°C warming melts permafrost everywhere except in the Far North (Maxwell; Harris).		
100 - 500	Interglacial	Greenhouse gases begin to rebalance with orbital patterns in terms of climate forcing potential	Ice caps unlikely to be completely melted in Arctic Islands by greenhouse gases (Koerner). The permafrost is likely to continue degrading during this time but will slow in degradation by the end of this period.	Temperatures will initially be 1.5°C warmer than today and then rise to 3.5°C warmer by 250AP.Temperatures will then start to decline to -1.5°C by 500 AP.	Koerner
500 – 1,000	Interglacial/ Potentially colder periods	Waning of greenhouse gases and more dominant role of orbital patterns	Cooling and drying. Permafrost is likely to start reforming, but not where there is a close proximity to water. There is likely to be a greater incidence of ground fogs and low level cloud cover as the air temperature will respond to cooling more rapidly than water. The fog is likely to manifest as freezing fogs leading to significant vegetation damage. Precipitation will fall more as snow than as rain.	Annual Temperatures can expect to rise from -1.5°C up to 1.5°C relative to current temperatures by 1,000 AP.	
1,000 – 2,500	Interglacial/ Potentially first warmer then colder periods/ Potential for glacial onset	Orbital patterns are dominant.	1,000 to 1,800: The permafrost is likely to initially continue degrading during this time, but degradation will slow by the end of this period and is likely to start reforming. 1,800 to 2,500: Annual temperatures will start to cool. Autumns will tend to be warmer as perihelion starts to move to this time. There is a likelihood of severe wind and wave damage as storms are whipped up to dissipate the energy in the system. First snow falls are likely to	Annual temperatures will continue to increase and peak at +4.5°C relative to today by 1,800AP and then drop to -1°C by 2,500AP.	

Period Years After Present (AP)	Climate Regime	Major Forcing Mechanism	Potential Dominant Weather (Refers to difference from current)	Potential Temperature (Refers to temperatures above or below current temperatures)	Data Source
			melt and smooth icy conditions are likely to form. Winters will be longer and colder and there is the potential that significant snow accumulations will collect. Snow is likely to pack after a smooth dense layer of ice has formed leading to a high risk of avalanches and tree damage. Cooling and drying. Will be the general trend. Spring will be slow to start thawing and early summer will be cool Summers will tend to become relatively warmer by comparison to other seasons.		
2,500 – 5,000	Potentially colder periods within overall period with slight warming trend	Orbital patterns	This will be a relatively stable period with a gentle warming over the period. Precipitation can be expected to increase. The seasonal trend noted in 1,000 – 2,500 will become more apparent.	Temperature expected to increase from -1°C to +2°C.	
5,000 – 10,000	Potentially colder periods/ Potential for glacial onset/Period of significant fluctuations as the seasonal warming pattern shifts.	Orbital patterns	This will be a period with gentle warming and cooling over the period. Precipitation can be expected to increase. The seasonal trend noted in 1,000 – 2,500 will become more apparent. Summers will become relatively warmer to other seasons as Perihelion starts to coincide with late summer early Autumn. There are likely to be a lot of ground fogs and a lot of variability due to the seasonal range increasing, suggesting more intense storms in Autumn and early Winter and periods of wet alternating with periods of extreme dry.	Temperature is expected to range from -1.5°C to +2°C.	
10,000 – 50,000	Potentially glacial with higher certainty for glacial at 50,000 years AP	Orbital patterns	Cold and frozen desert. Permafrost will extend. Tree line moves south. Winters are extremely cold. Snow expected to accumulate into deep ice fields. Summers will be relatively warm, but albedo will prevent ice fields from melting.	This period will initially start with a warming of approximately +4°C. Temperatures in the range of -7°C to -15°C are anticipated.	

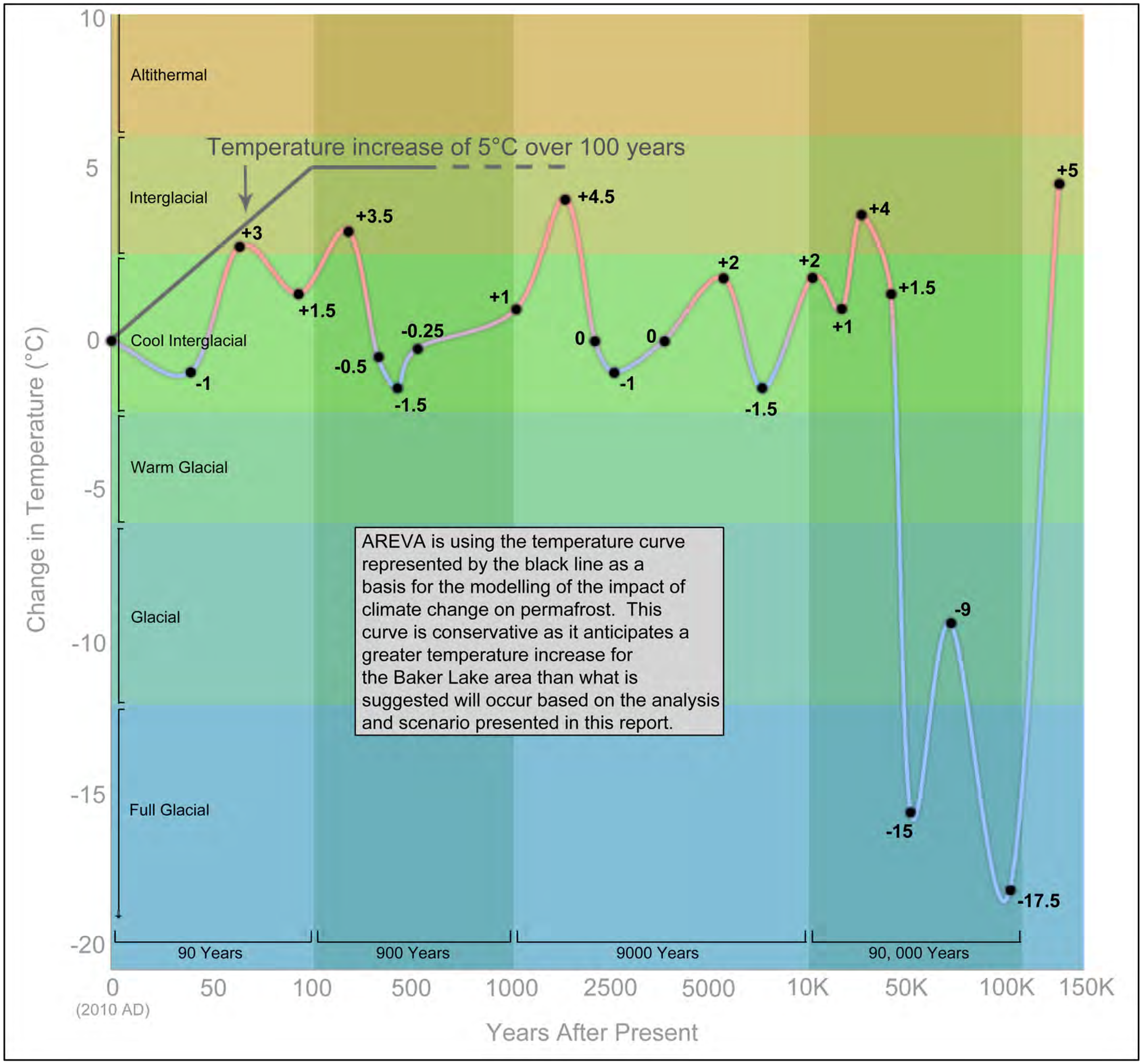


Figure 84: Projected Future Temperature Relative to Current Temperature for the Period 0 (current) to 150,000 Years AP

This updated report, "**0401– Baker Lake Long-term Climate Scenario, Up to 150,000 Years After Present, Canada**," was prepared by Consult 5 Inc.

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6 References

The references presented in this section have been used in the preparation of this scenario. They are not all cross referenced in the text as it makes reading cumbersome. Where cross references are provided they represent the main source only.

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Appendix 1
Paleo-climate Reconstruction