AREVA

Kiggavik Project

Environmental Impact Statement

Tier 3 Technical Appendix 4D

Baker Lake Long-term Climate Scenario

December 2011

Baker Lake Long-term Climate Scenario,

Up to 150,000 Years After Present

Report Prepared for

AREVA Resources Canada

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Project Number 0401

August 2011

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1 Context for Climate Scenarios

This study has been prepared to support the thermal modelling that is being undertaken for Areva Resources Canada's Kiggavik-Sissons project. This work is intended to strengthen confidence in long term thermal and related groundwater transport modelling as it relates to potential changes in permafrost conditions over time at the site.

Weather forecasting is not an exact science, with tomorrow's prediction frequently stated as a percentage chance of rain. Trying to find a reliable five day forecast is even more difficult and the better 10 day forecasts are generally so unsuccessful that most people don't bother with them. Contemplating a 10,000 year weather forecast is therefore a real stretch on credibility for almost all observers and scientists. However, it is important to understand the difference between daily weather and climate following long-term trends. Weather is the diurnal range of temperatures, precipitation, wind etc. that occur at a specific time and place; whereas, climate is looking at longer term trends that describe the averages of the weather for larger areas. This report, therefore, focuses on future climatic trends and is not a weather forecast. Specifically, what is presented in this report is a set of future climate scenarios. A scenario in this context is not a prediction nor a projection, but an anticipated climate regime for a period of time in the future. The scenarios are based on extractions of available information and present a particular viewpoint based on that data. Other perspectives may be possible if different data are used. To this end, the most credible data that are generally accepted and cross referenced in the peer reviewed academic journals have been sought, as by implication the scenario will then be more acceptable.

Possibly the most rapidly currently developing branch of climatology is that which looks at future climate. This has partly been driven by the International Panel for Climate Change (IPCC) publications on climate model outputs predicting future climate change due to increases in greenhouse gases. While this field has created considerable controversy and accusations of poor science and political interference, it has given rise to good scientific questioning and research on understanding what drives climate change and what future climates may look like.

In this report, every effort is made not to enter into the debate on greenhouse gas and short term climate change and the validity of model outputs. However to be clear why model output is not used in this report, a review of recent literature demonstrating the concerns associated with the models is presented. In addition, a review of future energy scenarios is also presented to demonstrate why long term scenarios based on CO_2 are unlikely to be realistic. The case presented in this report will use the IPCC model output as a short term indicator amongst other sources of information and will look to recent research to inform a more comprehensive picture of what future climate change may look like. No new data or research are presented in this report, but interpretations of existing reported data are made to create a possible scenario at different time frames up to 10,000 years into the future.

The report has been prepared so as to make it accessible to a wide range of readers. This has been done to ensure all materials are accessible to all readers and that the basis for the scenario is well understood. More experienced readers may want to focus on the climate scenario as the initial materials should be well known to them.

1.1 Data Reliability and Credibility

A report of this nature will no doubt attract many questions about reliability and credibility. These questions are indeed warranted and welcome, as this is what is driving the vast amount of research that is being undertaken in the world at this time. As a result of these questions, there is now a large body of information that is available that details long term historic trends based on non-greenhouse gas data. In many scientific circles, it is now believed that historic planetary and solar forcing mechanisms as captured in evidence in ice core spanning hundreds of thousands of years capture repeating patterns of climate change. By understanding the mechanisms that created these changes it is thought that future climate trends can be inferred and function as a reliable way to develop potential future climate scenarios. As we know from today, weather systems can bring significant swings in temperature, wind, rainfall and snowfall so it must be recognised that individual weather events may vary widely from the average conditions presented in the climate scenario.

With current understanding, it is unlikely that anyone could reliably predict long-term future weather for a particular place or time. It is; however, plausible that long-term climatic trends represented by a scenario such as the one presented in this report will be followed. The scenario presented in this report draws on data collected from a range of indicators including ocean sediments, ice sheets, other sedimentary deposits such as stalagmites, and biological artefacts such as coral. Based on our current understanding of meteorology, it is also possible to suggest the types of ranges that can be expected from weather that will occur under a potential future climate scenario.

It is important to be cognisant of the limitations of developing a future climate scenario when the actual forcing mechanisms are only beginning to be understood. It is also important to recognise that this report uses available data including IPCC model output. Although these model data are controversial, there is a large body of scientific evidence behind it and it is being refined on a continual basis. Using these data provides only one part of the prediction, up to 500 years, and it is recognised that many scientists argue that the extent of greenhouse gas contribution to climate change is not certain nor necessarily the major forcing mechanism. Indeed, these data are not used as a significant contributor after 500 years into the future as the effect is likely to be minimal by comparison to other forcing mechanisms at that time if greenhouse gas emissions are controlled. A key assumption in this document is, therefore, that greenhouse gases are likely to be managed as new technologies become available.

This document is based on the peer reviewed research of others. No new data are presented, but available data are serially packaged to create a reasonably acceptable continuous climate scenario for the next 10,000 years. This is extended to 100,000 years after present, but with limited resolution. The reference list used in the preparation of this document is presented at the rear. Not all references are cross referenced to make reading easier.

1.2 Published Analogues of this Study

A similar 10,000 year study (Miklas et al 1995) aimed at predicting 10,000 years of future climate change, using a panel technique, was conducted for the proposed high-level radioactive waste repository site at Yucca Mountain, Nevada. Specialist panel members prepared predictions on dominant climate controls as summarised below.

Experts identified climatic controls in order of importance for that site as follows for +100 years After Present:

- The rain shadow effect
- Anthropogenic forcing (greenhouse gases).

Effect of anthropogenic warming on the movement of the atmosphere across the site including:

- Storm tracks moving north
- More tropical air incursion on the Yucca Mountain, Nevada site
- The westerlies move south in winter
- More moisture in the west to east moving air
- Greenland Above circulation causing a change in precipitation at the site.
- One expert saw an enhancement of the El Niño Southern Oscillation (ENS0) discussed in more detail later in this document) resulting in increased precipitation at the site.

The experts saw little additional change at the 300 year time slice.

Experts identified climatic controls in order of importance for that site as follows for +1,000 years After Present:

- The rain shadow effect
- Anthropogenic forcing resulting in a warming of the atmosphere
- Offset cooling of the atmosphere resulting from the effects of Milankovitch orbital variations on the climate
- Atmospheric movement across the site.

These controls persisted through the 3,000 year time slice.

Experts identified climatic controls in order of importance for that site as follows for +5,000 years After Present:

- Rain shadow as the dominant control
- Astronomical forcing (Some variation in ranking order by the panel)
- Greenhouse warming due to anthropogenic forcing (Some variation in ranking order by the panel)
- Westerly wind flow (Some variation in ranking order by the panel)
- Remaining controls included remaining controls included shifting of mid-latitude storm (cyclonic) belts, increased availability of moisture, and meridional flow.
- These controls persisted through the 7,500 year time slice.

Experts identified climatic controls in order of importance for that site as follows for +10,000 years After Present:

- The rain shadow effect
- Anthropogenic warming would still be experienced, although in a waning mode (Some variation in ranking order by the panel)
- Milankovitch orbital forcing will have brought colder temperatures to the site (Some variation in ranking order by the panel)
- Remaining controls included Ice sheets, westerly wind belt migration, and increased moisture availability.

The panel predicted a maximum temperature increase of 3.0°C dropping to -2°C between 100 and 300 years After Present and 10,000 years after present respectively. The panel identified wetter winters during periods with warmer weather due to increased availability of moisture and overall wetter conditions once cooling starts after global warming is no longer as significant. Once cooling continues drier conditions would again return.

1.3 Timeframe of Climate Scenario

In order to constrain the study period into reasonable realms of predictability, time frames have been selected as follows:

- <100 years
- 100 to 500 years
- 500 to a 1,000 years
- 1,000 to 2,500 years
- 2,500 to 5,000
- 5,000 to 10,000 years.

1.4 Site Location

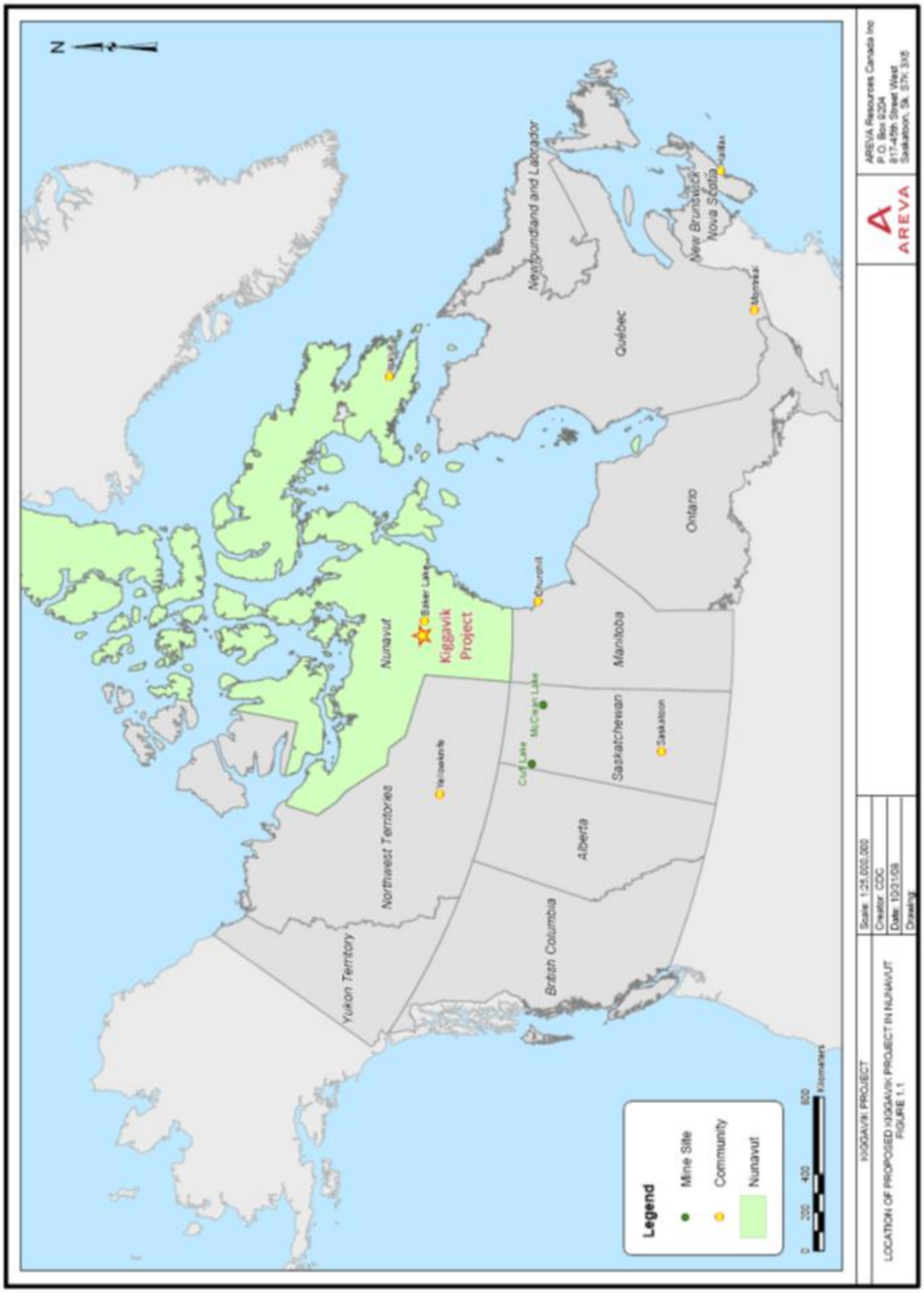


Figure 1: Kiggavik Project Location.

1.5 Existing Weather and Climate

Baker Lake is the closest and longest running weather station in the area. It provides a good proxy for the weather at the site despite the fact that the site does not have a similarly large body of water near it. Data in this section is sourced from:

http://www.climate-charts.com/Locations/c/CN71926023005000.php

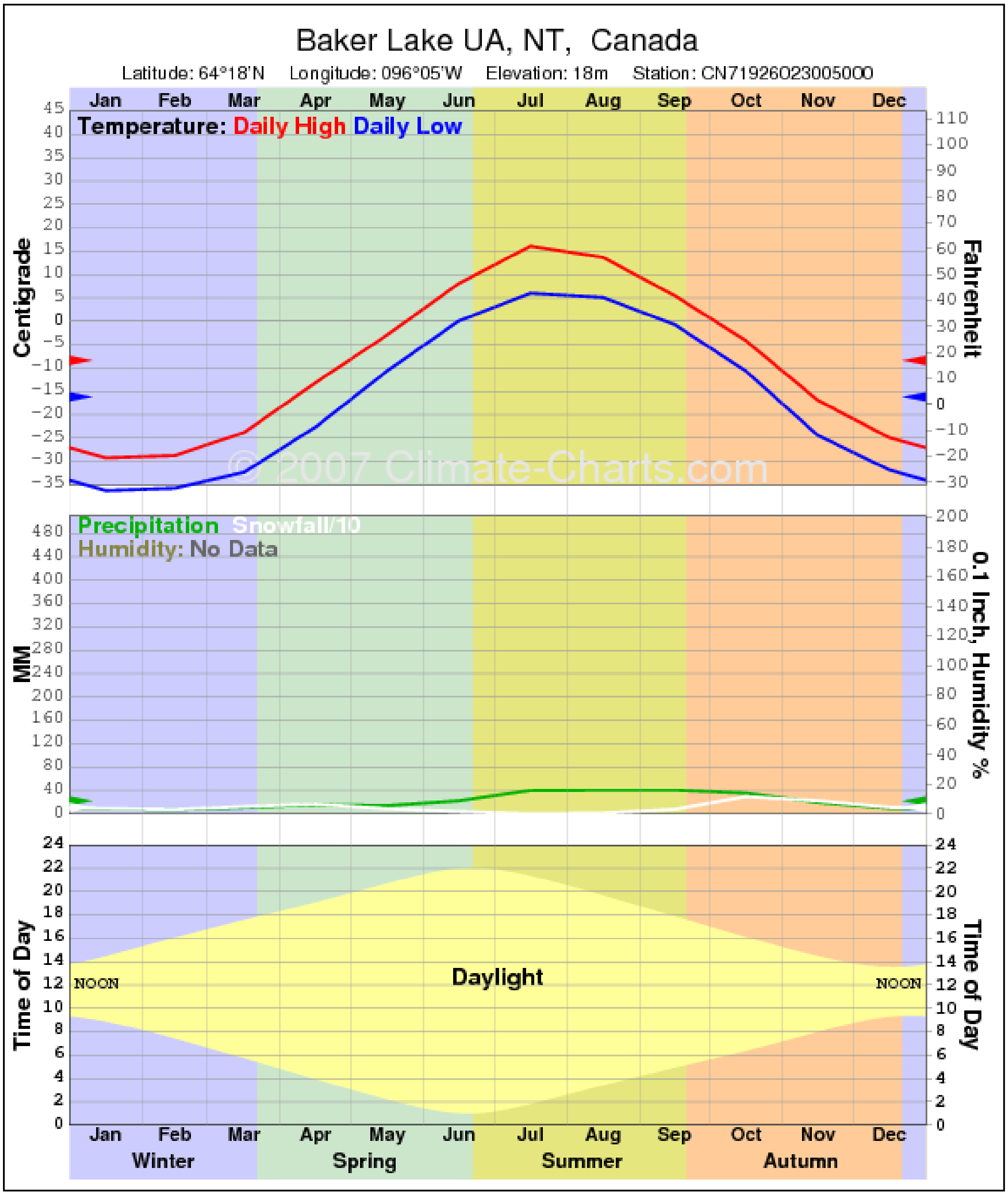


Figure 2: Summary weather charts for Baker Lake.

Table 1: Average Temperature, Precipitation and Snowfall Baker Lake.

NOAA Code	Statistic	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
0101	Temperature Mean Value	F	-26.7	-25.8	-18.4	-0	19.9	39.4	52	48.9	36.3	18.7	-5.1	-18.9	10
0201	High Temperature Mean Value	F	-20.6	-19.7	-10.8	8.4	26.8	46.6	61	56.7	41.9	24.4	1.6	-12.8	17
0301	Low Temperature Mean Value	F	-33.2	-32.3	-26.1	-8.7	12.9	32.2	42.8	41.2	30.7	12.7	-11.9	-25.2	2.9
0615	Precipitation Mean Monthly Value	Inches	0.3	0.3	0.4	0.6	0.6	0.9	1.6	1.7	1.7	1.4	0.8	0.4	0.9
0915	Snowfall Mean Monthly Value	Inches	3.8	3.2	5.1	6.9	3.6	1.7	0	0.5	3.2	12.2	9.2	4.7	4.5
0101	Temperature Mean Value	C	-32.6	-32.1	-28.0	-17.8	-6.7	4.1	11.1	9.4	2.4	-7.4	-20.6	-28.3	-12.21
0201	High Temperature Mean Value	C	-29.2	-28.7	-23.8	-13.1	-2.9	8.1	16.1	13.7	5.5	-4.2	-16.9	-24.9	-8.36
0301	Low Temperature Mean Value	C	-36.2	-35.7	-32.3	-22.6	-10.6	0.1	6.0	5.1	-0.7	-10.7	-24.4	-31.8	-16.15
0615	Precipitation Mean Monthly Value	mm	8.4	6.9	10.5	15.6	13.9	22.1	39.8	40.3	40.5	35.1	19.3	9.4	21.82
0915	Snowfall Mean Monthly Value	cm	9.1	7.7	12.3	16.7	8.7	4.0	0.0	1.3	7.7	29.3	22.1	11.2	10.84

Source: http://www.climate-charts.com/Locations/c/CN71926023005000.php

1.6 Scientific Reports of Canadian Climate Change

The material in this section has been extracted verbatim from the CCME document entitled: *Climate, Nature, People: Indicators of Canada's Changing Climate, 2003*.

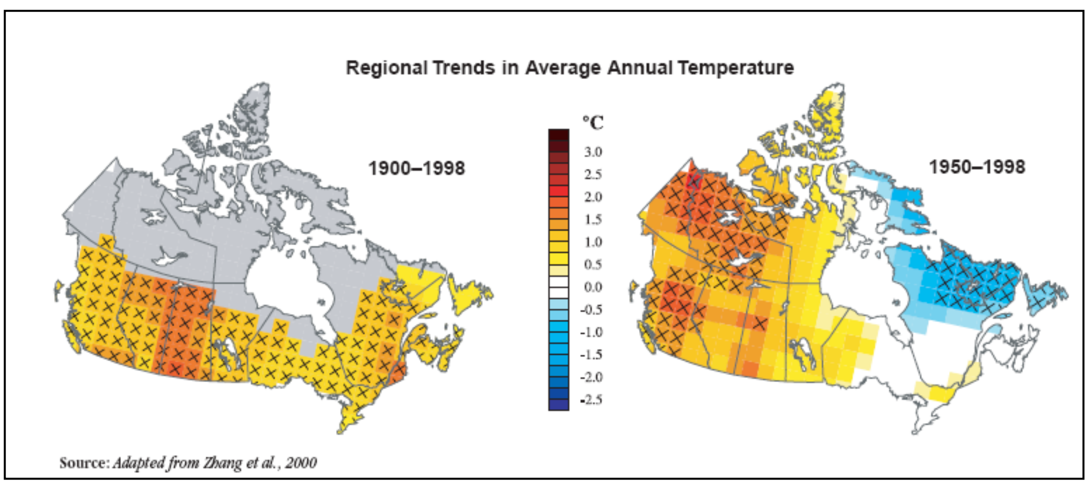


Figure 3: Regional trends in average annual temperature.

Over the course of the twentieth century, all of southern Canada, from B.C. to Newfoundland and Labrador, warmed to some extent. In Figure 4, southern Canada is defined as the region lying south of the 60th parallel (the line that forms the northern border of B.C., Alberta, Saskatchewan, and Manitoba). Over the course of the twentieth century, all of southern Canada, from B.C. to Newfoundland and Labrador, warmed to some extent. In these maps, southern Canada is defined as the region lying south of the 60th parallel (the line that forms the northern border of B.C., Alberta, Saskatchewan, and Manitoba). Since 1950, the greatest warming has occurred in the West and Northwest, while the Northeast has cooled. An x indicates results that are statistically significant. That means that scientists have a high degree of confidence that the changes are part of a real long-term trend and are not just due to chance.

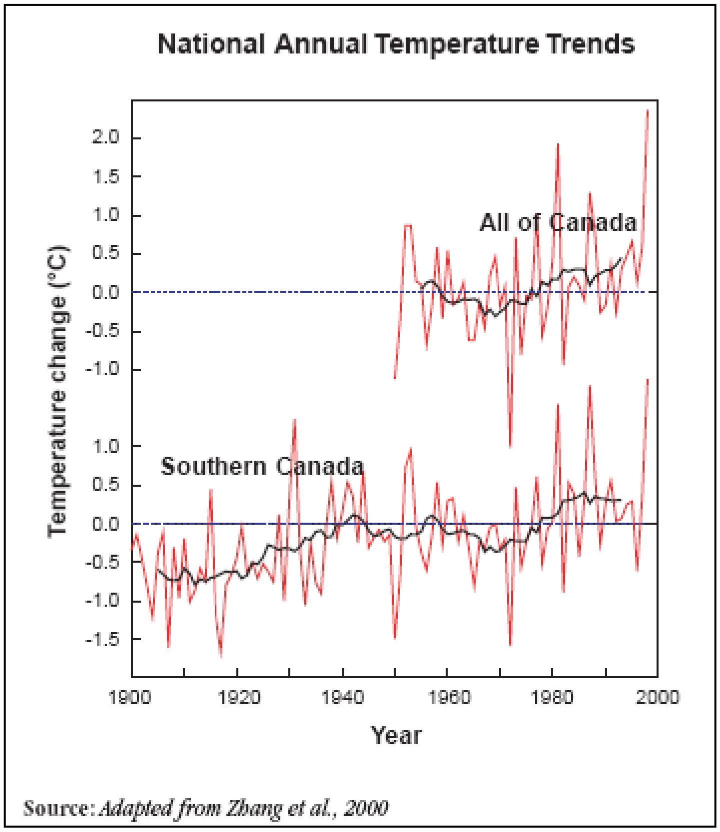


Figure 4: Canadian national annual temperature trends.

Figure 4 shows the difference between each year's average temperature and the average for 1961 to 1990. The dark line running through each plot smoothes out the year-to-year differences and makes it easier to see the general pattern of change over time. In southern Canada, temperatures rose rapidly between the early 1900s and the 1940s. They then fell slightly until the late 1960s but have continued to rise since then.

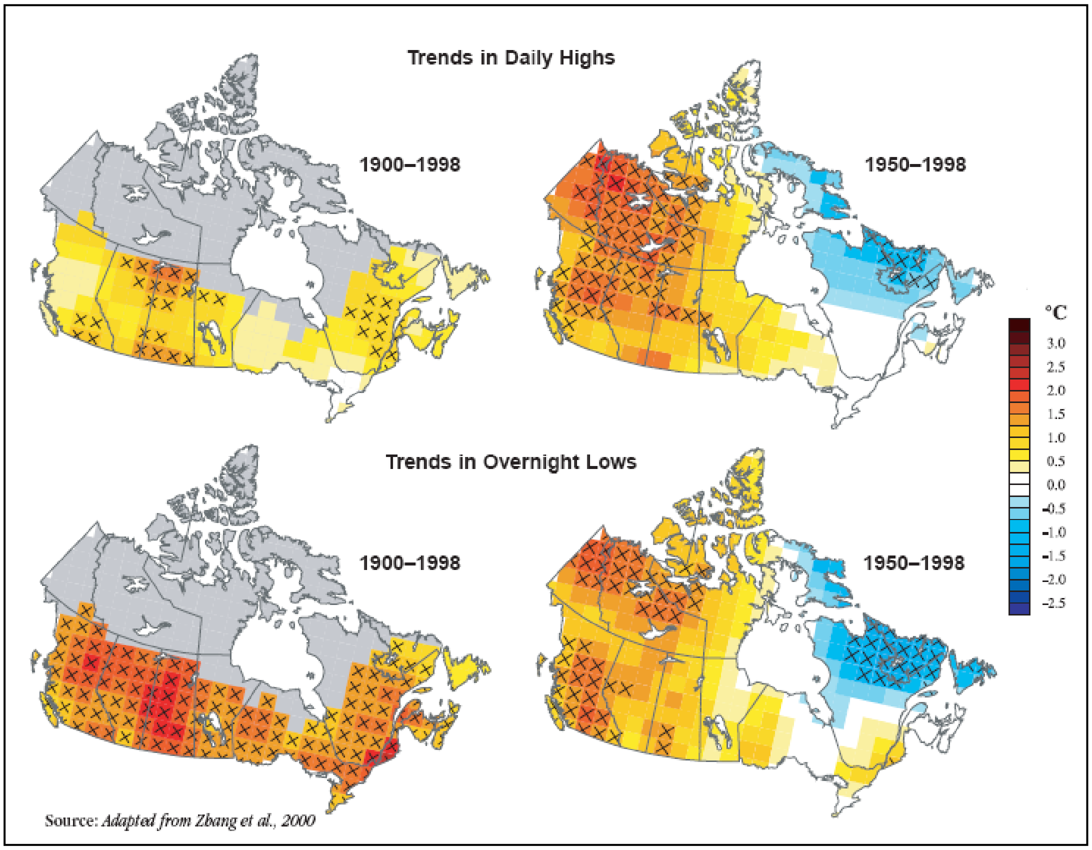


Figure 5: Trends in daily highs and overnight lows.

Over the past 100 years overnight lows warmed than daily highs across all of Canada. For the past 50 years, differences between day time and overnight temperatures have been far less striking. X's indicate trends that are statistically significant.

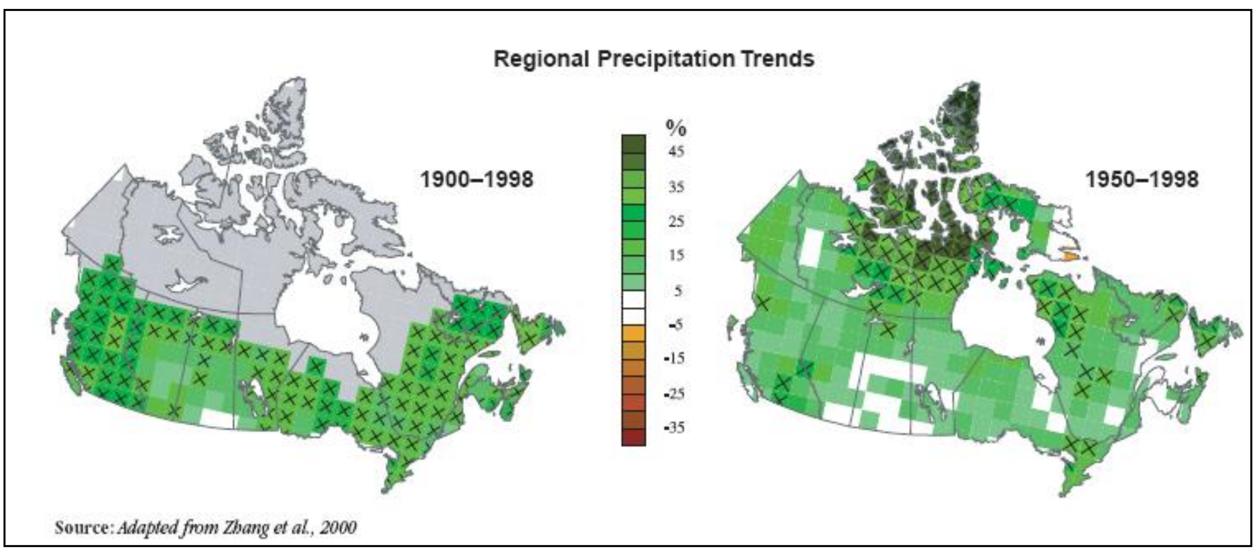
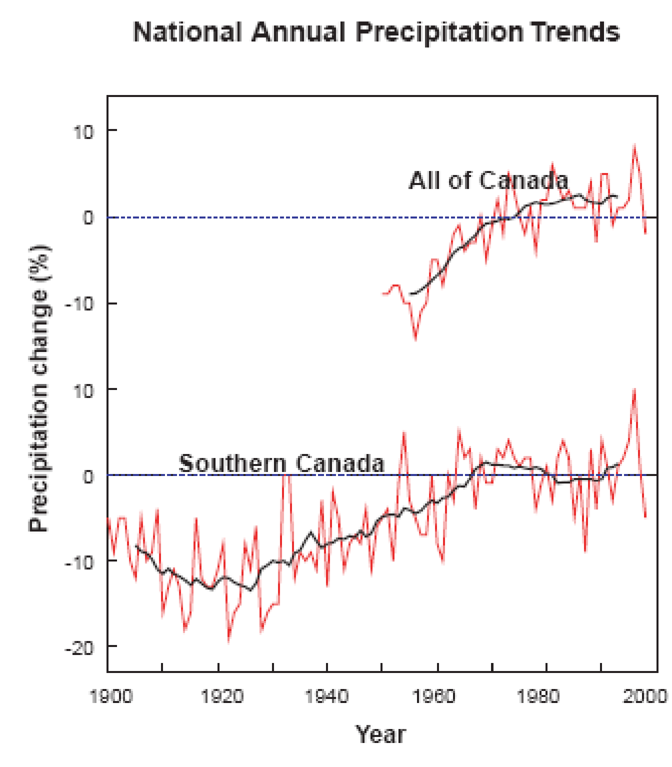


Figure 6: Regional precipitation trends.

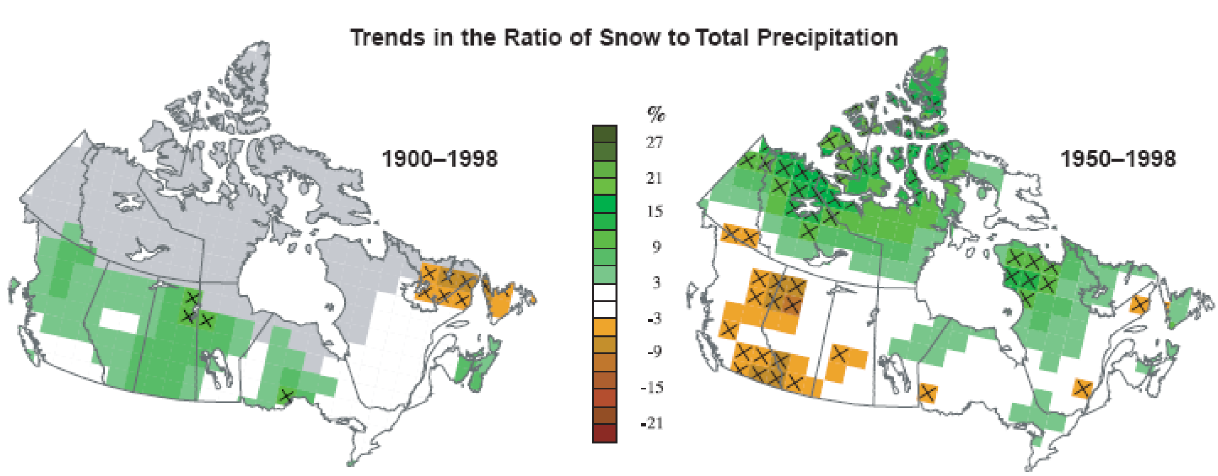
Virtually all parts of the country have seen an increase in Annual Precipitation Figure 6. X's indicate trends that are statistically significant.



Source: *Adapted from Zhang et al., 2000*

Figure 7: National annual precipitation trends.

Canada has become wetter during the twentieth century. The graph shows the difference (in per cent) between each year's average precipitation and the average for 1961–1990. The dark line through the centre of each plot smoothes out year-to-year differences.



Source: *Adapted from Zhang et al., 2000*

Figure 8: Trends in the ratio of snow to total precipitation.

Virtually across the country a greater proportion of precipitation falls as snowfall (Figure 8).

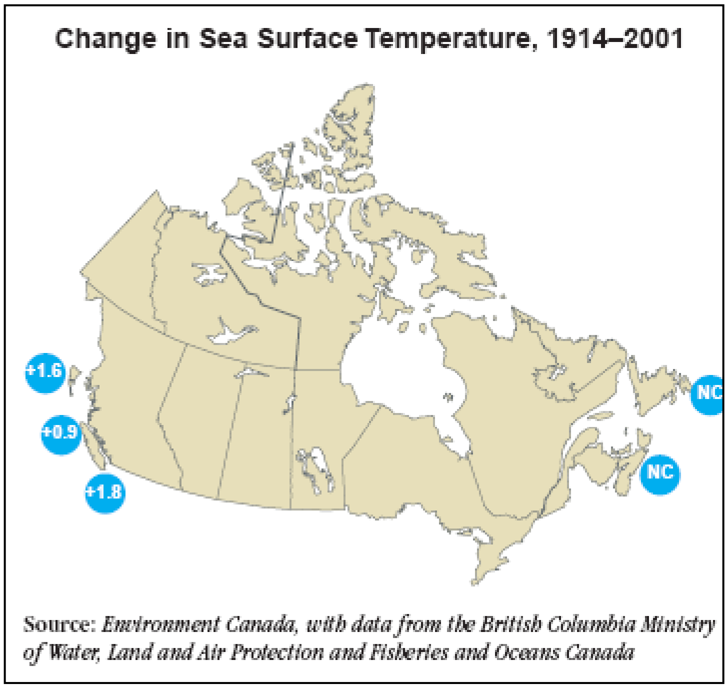


Figure 9: Changes in sea surface temperatures around the Canadian coast.

Sea surface temperatures have risen substantially on the west coast but appear to have changed little on the east (Figure 9). The rate of temperature change (in °C per century) is indicated in the blue circles. NC indicates no change.

1.7 Nunavut People's Perception of Climate Change

In 2005, a survey was conducted by the Government of Nunavut, Department of Environment Environmental Protection Division to determine how people in Nunavut are experiencing climate change. The responses are presented below and in Appendix B:

- Warmer temperatures year-round
- Changes in the length and timing of the Inuktitut seasons
- Unpredictable weather and winds
- Stronger winds
- A change in the direction of the prevailing wind
- Reduced snowfall in Ukiaq (early winter)
- Reduced and more compacted Aput (snow cover) on the land
- Later and slower freezing of the lakes, rivers and the ocean
- Earlier and more rapid melting of ice and snow inland and on the ocean
- Reduced rainfall in Upinngaaq (spring)
- Reduced water levels in the lakes and rivers
- Impaired growth of edible/fruit-bearing plants

- Increased growth of willows and birch
- Movement of the tree-line northward
- Undernourished and diseased species for example caribou and fish
- Polar and grizzly bears encountered over longer time period and in new areas
- Loss of some existing bird species and new insect, bird and mammal species being sighted.

2 IPCC Fourth Assessment Report

The Intergovernmental Panel on Climate Change (IPCC) is an international scientific body for the assessment of climate change established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters (http://www.ipcc.ch/organization/organization.htm).

2.1 Greenhouse Gases

Wolf (2008) and many others have demonstrated through the use of ice cores and direct measurement that the atmospheric concentrations for carbon dioxide (CO_2) has increased. The records from Antarctica show that the preindustrial concentration of the gas was about 280 ppmv (parts per million volume) and the concentration has increased to the current level of 375 ppmv. The concentration is thought to have emerged above its natural range in about 1830 AD. Natural variability of CO_2 in the last millennium was about 10 ppmv.

The information that follows presents the output from the IPCC Fourth Assessment Report. Anticipated global temperatures as a consequence of greenhouse gases, primarily as reported by the IPCC, are presented in Figure 10. In this figure the temperatures for the next century are modelled based on various CO_2 emission scenarios. The emission scenarios project an increase of baseline global GHG emissions by a range of 9.7 to 36.7 $GtCO_2$-eq (25 to 90%) between 2000 and 2030 (Figure 11). In these scenarios, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Hence, CO_2 emissions from energy use between 2000 and 2030 are projected to grow by 40 to 110% over that period.

The A1 scenario assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

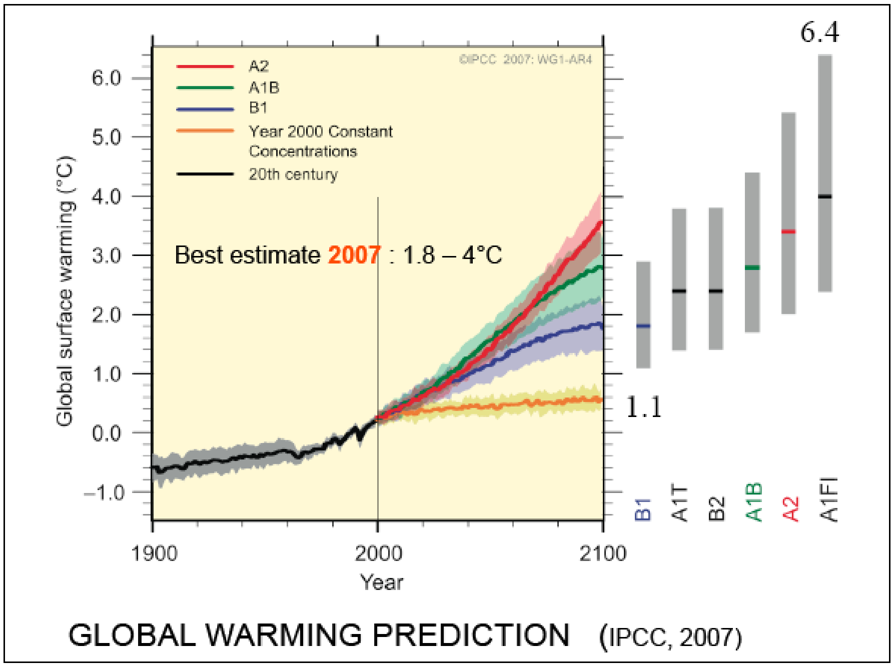


Figure 10: IPCC Global warming predictions based on emission scenarios (2007).

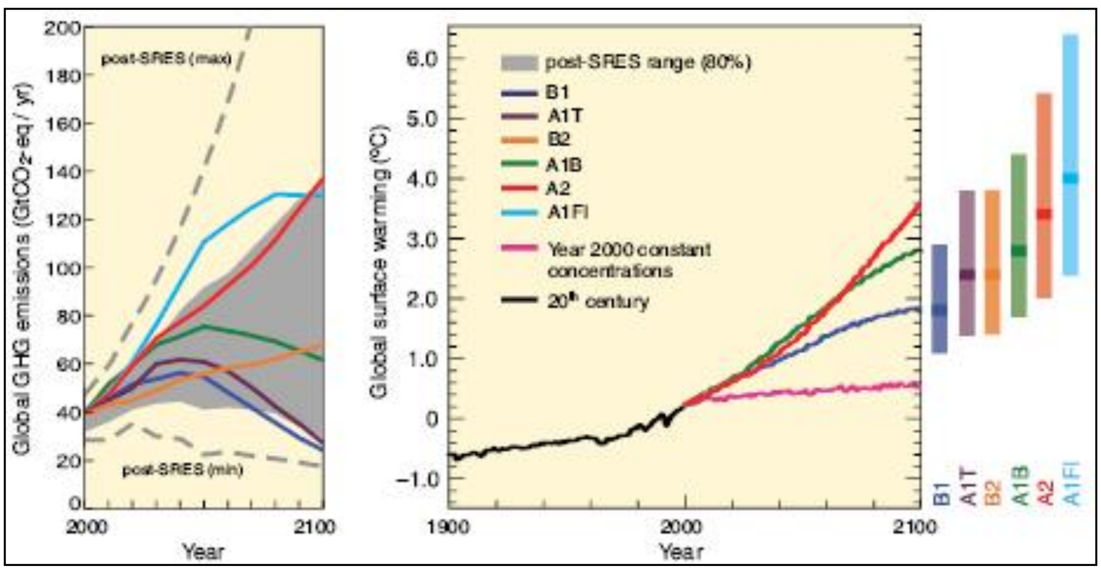


Figure 11: Scenarios for GHG emissions from 2000 to 2100 (IPCC, 2007).

Under these scenarios, a range of 1.1°C to 6.4°C is forecast as the likely increase in temperature over the next century. The best estimate from the IPCC is 1.8°C to 4.0°C warming. Associated with this temperature increase is a sea-level rise based on thermal expansion of sea water and melting snow and ice from only a few glacial sources. This sea-level rise is predicted to be in the range of 0.18 m to 0.59 m over the next century as shown in Table 2.

Table 2: Projected global average surface warming and sea level rise by 2100 (IPCC, 2007).

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:
a) Temperatures are assessed best estimates and *likely* uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.
b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.
c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the Working Group I TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.
d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

The basis for the modelling undertaken by the IPCC is the values or weightings attributed to each of the GHGs that have been included as forcing mechanisms. Each gas is associated with a differing capacity to absorb energy that provides it with a capacity to cause warming. The various strengths the IPCC has attributed to these forcing mechanisms is presented in Figure 12. Particularly notable in this table is the absence of water vapour, a potent greenhouse gas and the low forcing strength of the solar irradiance.

Based on the modelling the IPCC has undertaken, predictions for future temperature and rainfall have been prepared. For 2100, the projection for Northern Canada is approximately a 5°C to 6°C increase of temperature relative to 1980-1999 temperatures (Figure 13). For 2100, the projection for precipitation in Northern Canada is approximately a 10% to 20% reduction in precipitation relative to 1980-1999 (Figure 14).

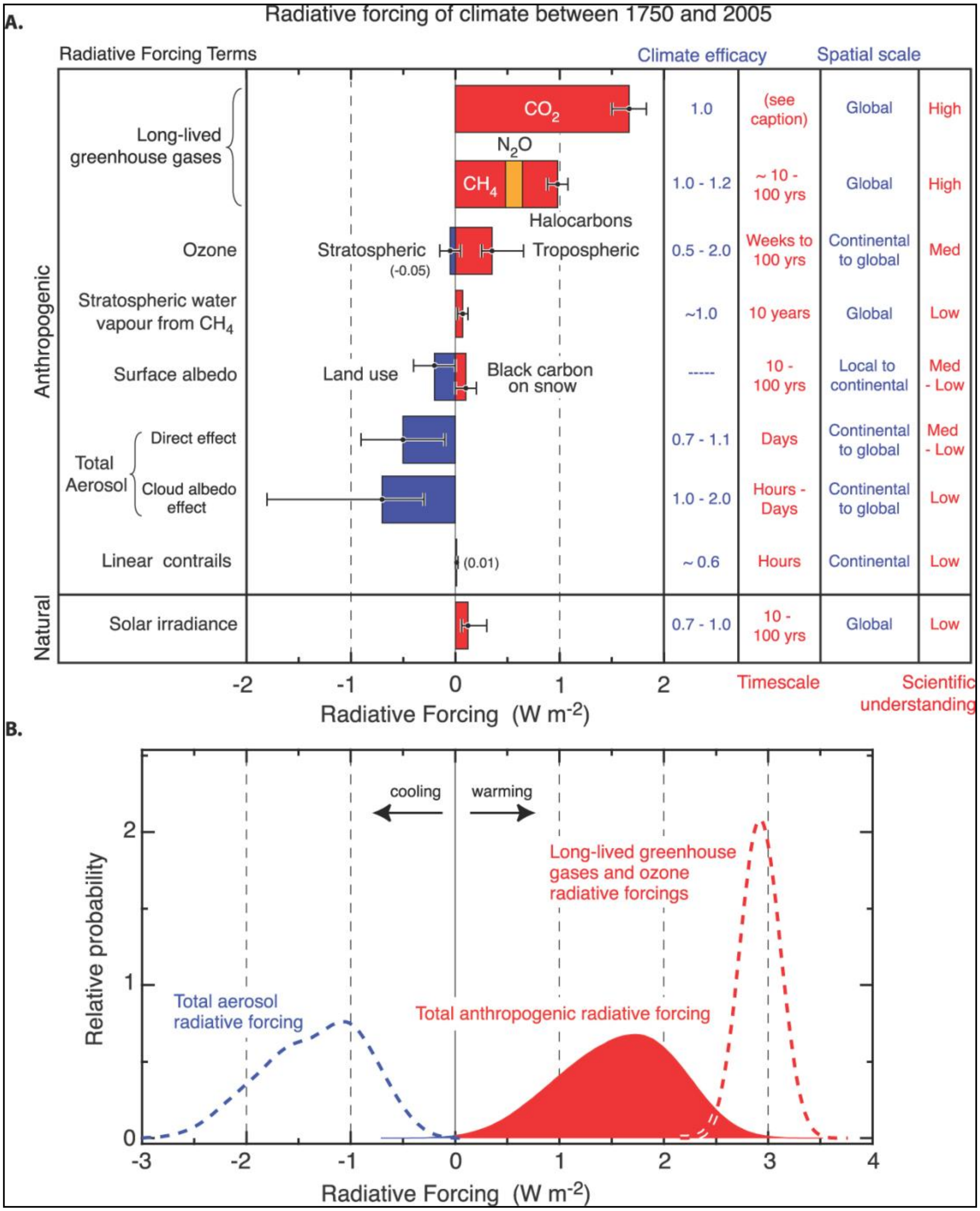


Figure 12: Drivers for radiative forcing (IPCC, 2007).

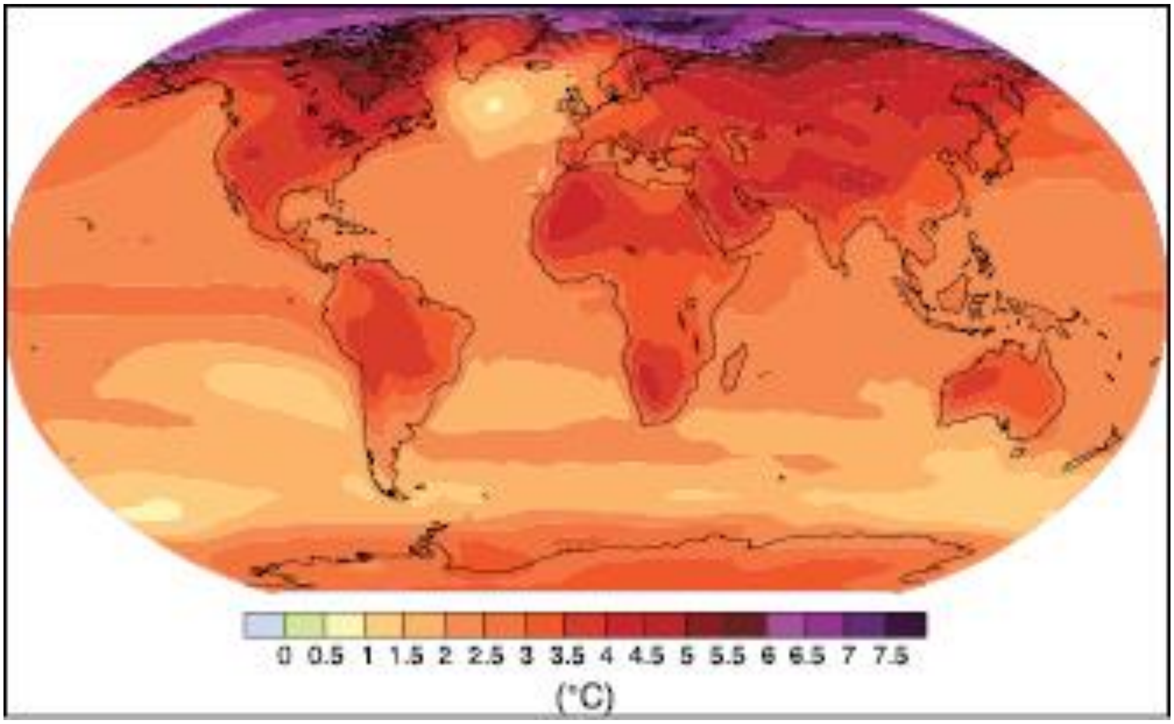
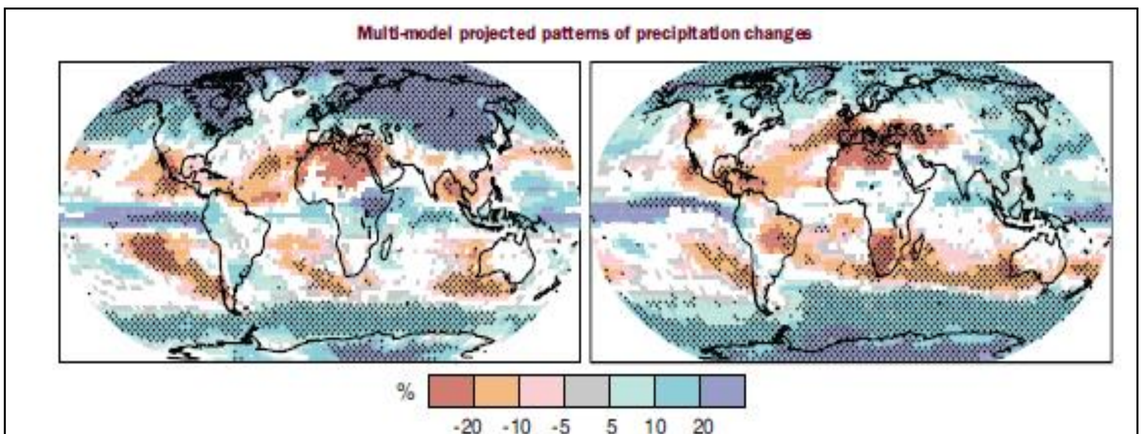


Figure 13: Relative surface temperature changes for 2090-2099 (IPCC 2007).



Left: December to February. Right: June to August

Figure 14: Relative precipitation changes for 2090-2099 (IPCC, 2007).

2.2 Concerns with IPCC 2007 Report

In the latter part of 2009, coinciding with the IPCC Copenhagen conference, a series of email leaks were released on websites. These emails drew attention to a group of sceptical scientists who had been questioning the claims of the IPCC. The leaked emails were those of IPCC authors, and many emails suggested that the modelling and the process followed by contributing authors of the IPCC may not have been robust, transparent or taking into consideration all views on climate change. The emails suggest that data was cherry picked and some data excluded to result in an enhanced warming prediction. Furthermore, several subsequent reviews of the IPCC reports have indicated that statements and time series used in the IPCC modelling may have been without basis, such as claims of Himalaya ice melting by 2020. These emails and close scrutiny of temperature records used have brought into question the validity of the IPCC report and process. A comprehensive evaluation of the emails is presented at http://climateaudit.org/ along with in depth analysis of IPCC model code and statistical techniques. In many cases, both code and statistical techniques have been shown to need improvement to avoid producing incorrect modelling results.

In particular, the following main concerns, partly discussed by Giorgi and Mearns (2002), have been made of the IPCC modelling predictions:

- Over estimation of the effect of CO_2 and under estimation of water vapour.
- Under estimation of the effect of the sun.
- Failure to recognise the medieval warm period and the little ice age. These periods show that current conditions are not abnormal conditions (Soon and Baliunas, 2003).
- Over reliance on models which are tuned on past climate to predict future climate.
- The models inability to predict the levelling off and decrease in temperatures since about 2000.
- The models poor ability to predict precipitation, widely regarded as the key measure of successful models.
- The models limited ability to simulate the long-term oscillations in the climate system.

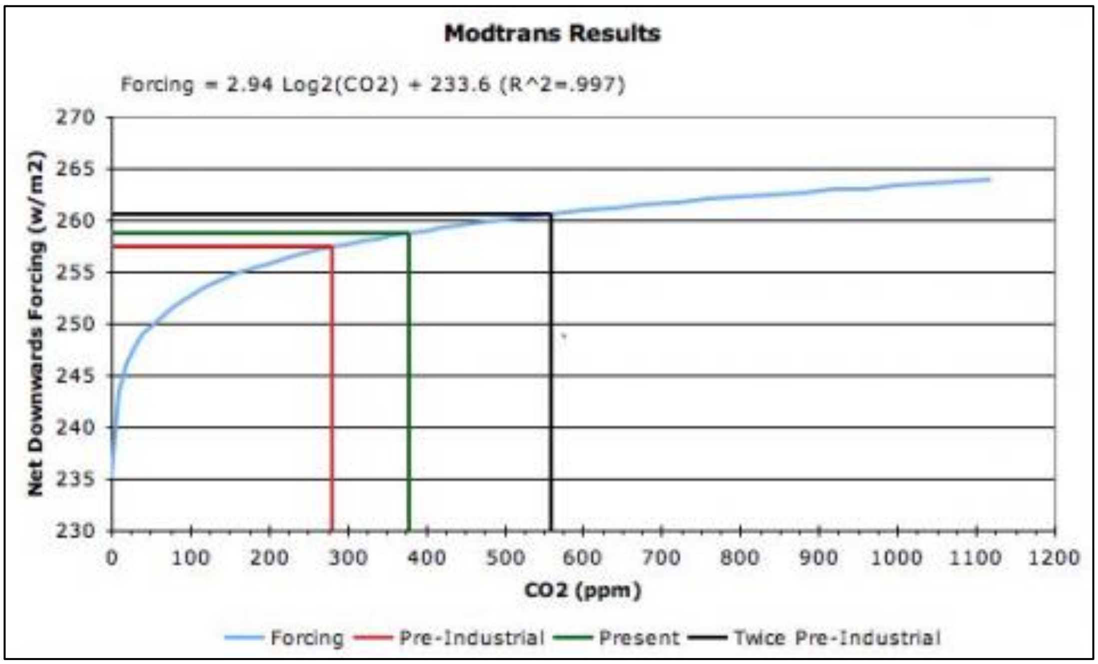
These criticisms suggest that the IPCC 2007 model predictions may be unreliable for predicting future climate and that the over emphasis on CO_2 may have skewed modelling. The IPCC notes that it has confidence in its models, but recognises the models do have problems (http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter8.pdf). The typical arguments against the models are presented at http://www.john-daly.com/forcing/moderr.htm. Some of the key issues with the IPCC reports, models and data are briefly presented below.

2.2.1 Carbon Dioxide (CO_2) and Water Vapour

CO_2 is considered by the IPCC to be one of the main “Greenhouse Gases” (GHG’s) which leads to a warming of the earth and its atmosphere. The IPCC reports are focussed on CO_2 as a greenhouse gas, which is reportedly increasing in atmospheric concentration by comparison to pre-industrial concentrations. The pre-industrial concentrations are, to a large extent, derived from ice cores.

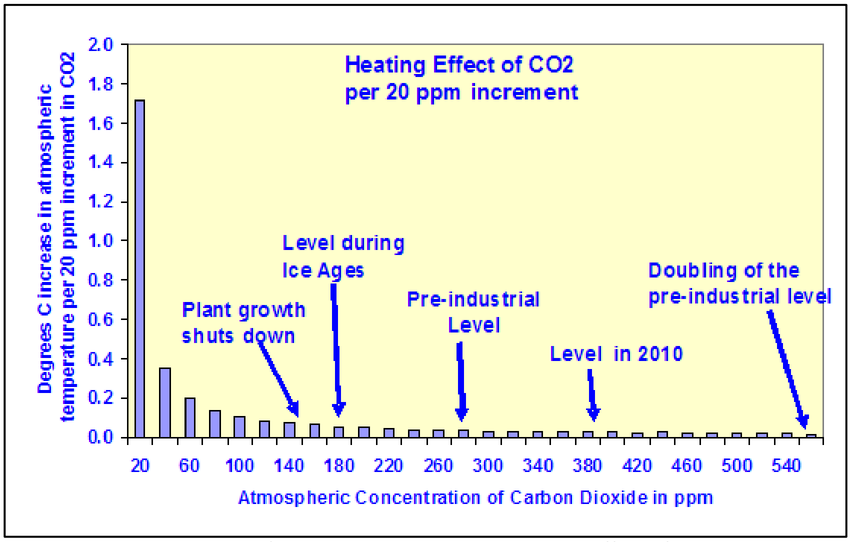
There are, however, scientists who think that the reliance on ice cores to determine CO_2 concentrations is flawed, as they have shown that CO_2 and other greenhouse gases escape from the ice cores once they are drilled and that this leads to lower than real CO_2 concentrations for the past. In essence, they argue the ice cores are not a reliable source of information relating to historic greenhouse concentrations as they under report the atmospheric conditions that really occurred. CO_2 may therefore not be increasing at the rate that scientists generally accept (Jaworowski, 2007), suggesting it is not as important for climate change as suggested by the IPCC.

CO_2 functions as one of many greenhouse gases that keep the earth about 30°C warmer than the minus 15°C it would otherwise be. CO_2 contributes about 10% of that warming, or roughly 3°C. The relationship between CO_2 and temperature is, however, not linear, but logarithmic.



Source: http://wattsupwiththat.files.wordpress.com/2010/03/co2_modtrans_img1.png

Figure 15: Logarithmic temperature response of CO_2.



Source: http://wattsupwiththat.files.wordpress.com/2010/03/heating_effect_of_co2.png

Figure 16: Temperature response to 20ppm increment increases in CO_2 concentration.

From Figure 15 and Source: http://wattsupwiththat.files.wordpress.com/2010/03/heating_effect_of_co2.png

Figure 16, it becomes apparent that the first 20ppm of CO_2 results in over half of the heating that the gas is capable of causing. Even if CO_2 concentration increases further in the atmosphere, there is, because of this logarithmic relationship with temperature, a diminishing capacity for it to cause warming. So, as a doubling to pre-industrial concentrations is unlikely to cause a run-away temperature scenario, the sensitivity of climate to CO_2 as claimed by the IPCC is not accepted by all (Scafetta, 2010).

The IPCC (FAR, 2007) and NASA (Spencer, 2010) claim that the CO_2 will cause a positive feedback with water vapour and that is how the temperature will become elevated. Water vapour is also regarded as one of the greenhouse gases, and in a linear relationship there should have already been 2°C of warming (Archibald, 2010). However, the earth has only experienced about 0.7°C of warming over the 20^{th} Century, the period since this positive feedback should have been detected (Archibald, 2010). This means that either the relationship between water vapour and warming is not coupled with $CO_{2,}$ or the positive feedback mechanism of CO_2 with water vapour is not well understood. The warming predicted from these two gases is therefore not matching the low warming that has been recorded in reality. Consequently, the models are over predicting the temperatures in response to the CO_2 and water vapour. Spencer (2010) goes further, noting that water vapour becomes a negative feedback mechanism, not a positive feedback, as clouds reflect incoming solar radiation. An increase in water vapour does not necessarily mean more heating, but could lead to more cooling if there are more clouds formed.

Furthermore, the role of CO_2 as a driver of climate change is also questionable. In recent papers, Soares (2010) and Bastardi (2010) report that temperature is not linked to CO_2, but to water vapour, and that CO_2 follows temperature change and does not lead it. The main mechanism for the lag in

CO_2 is warming of sea water, which causes CO_2 to be liberated about six months to a year behind the warming. Soares goes further to demonstrate that the areas with high humidity and increasing humidity are the ones that also indicate a warming of the air temperature. Humidity is reported to have increased by 2% over the past 20 years. The areas that are revealing this warming are the mid to high latitude continental areas. Soares notes that the disconnect between CO_2 and warming, the low increase in humidity and the declining intensity of the sun, suggests the near multi-decadal future will be cooler and the last decade of stable temperature was the turning point from warming to cooling.

2.2.2 Computer Modelling

The IPCC has relied extensively on climate models to predict future climate under different CO_2 and greenhouse gas emission scenarios. The results of these circulation models differ widely with outputs, suggesting that the greenhouse gases could lead to a warming of the atmosphere and oceans and 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., 1999).

However, the data that is fed into these models and the processing of that data has been closely scrutinised (e.g. www.climateaudit.org) and the model outputs verified against reality. This has led many to conclude that the data produced is unreliable at the local, regional and global scales for multi-decadal periods.

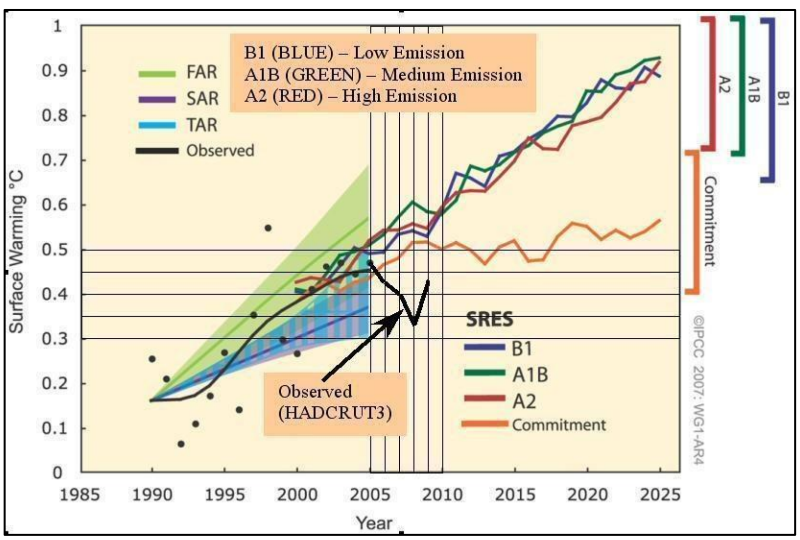
Anagnostopoulos et al. (2010) report their work on validating a model which was claimed to be very accurate at the continental scale and above. "Examining the local performance of the models at 55 points, they found local projections did not correlate well with observed measurements. They also found that the correlation at larger spatial scales, i.e. the contiguous USA, was worse than at the local scale."

Increasing numbers of studies (Anagnostopoulos et al., 2010; Rial et al., 2003; Maue, 2010; Goddard, 2010; Giles, 2007; Pielke et al., 2009; Smith, 2010; Scafetta, 2010) are showing that climate models are not able to model future climate realistically at any scale, as they have too many degrees of freedom and because the climate is complex, uncertain and affected by sources such as nonlinearities, feedbacks, thresholds, etc. Climate is inherently uncertain; models produce unpredictable results with a constant external forcing, suggesting there is limited or no causality relationship between its state and the forcing. In essence, they conclude that climate is unpredictable and uncertain with too many variables to be able to model reliably.

Eschenbach (2010) has also evaluated model performance to determine how they operate and has interesting observations relating to model reliability. Two key findings of the work are that the models will always predict an increase no matter what level of CO_2 is used. Furthermore, it was found that the modellers made up parameters to tune their models in the hind casting verification exercises, and that this action essentially means that the models will appear to predict future climate well, because they performed well in the past. Eschenbach suggests that if tweaking was required to make hind casting match historical temperature trends, then it is unlikely the models will realistically model future climate, as the mechanisms driving the climate are not well accounted for in the models.

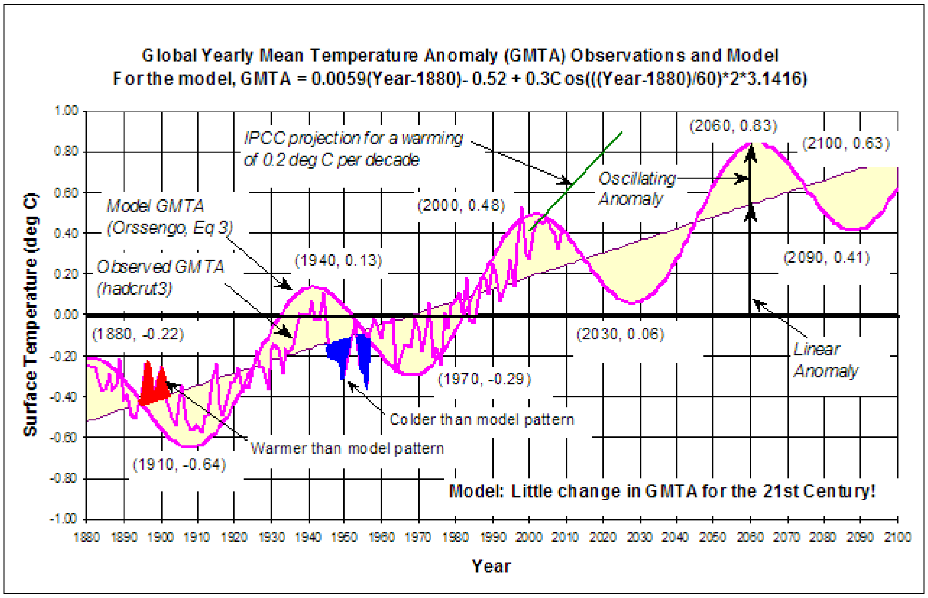
NASA has also recently undertaken modelling studies, showing that plants and trees in a world with doubled atmospheric CO2 would create a new negative feedback, or cooling effect, of -0.3°C to -0.6°C over land (Watts, 2010). Without this feedback, NASA models predicted a warming of 1.94°C globally when CO2 is doubled. This is just one of many examples where the models are currently deficient and overestimate the warming.

Orssengo's (2010) research has shown that the IPCC claim for global warming is that "for the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios." This claim is not supported by observations, as shown in Figure 17. Global mean temperature trend has plateaued for the last decade and is lower than the commitment temperature that would be followed if CO_2 was held at year 2000 concentrations. Orssengo goes further and demonstrates that the IPCC rate of warming projection is overestimated. Orssengo's modelling has produced the output, shown in Figure 18, to address the shortcomings of the IPCC modelling approach by including known cyclical functions. This modelling approach begins to show the 60 year cycle thought to exist in the climate system. The warming under this model scenario is also less than the IPCC model predictions.



Source: http://wattsupwiththat.files.wordpress.com/2010/04/orssengo1.jpg

Figure 17: Actual temperatures compared to model scenarios.

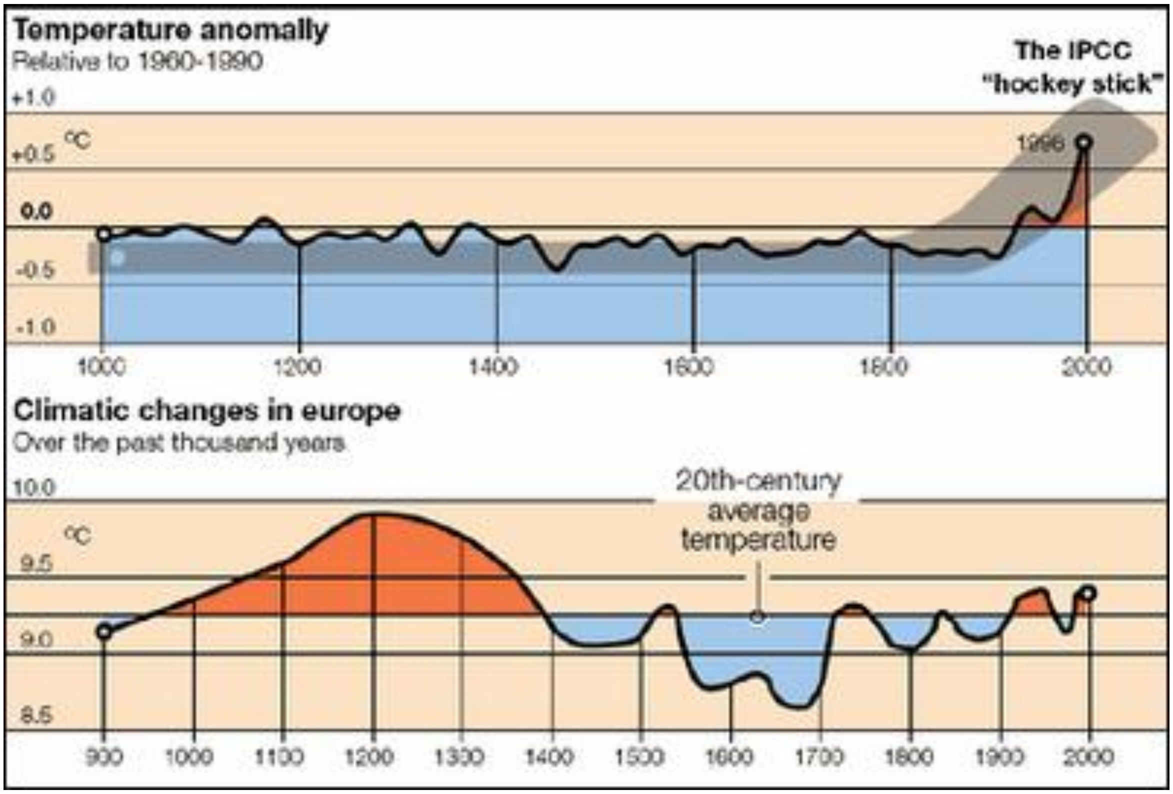


http://wattsupwiththat.files.wordpress.com/2010/04/orssengo3.png

Figure 18: Simple model with 60 year cycle added in comparison to IPCC model output.

2.2.3 Temperature Data

The integrity of the raw temperature data set that is used as the historical basis for refining the IPCC climate models has also been brought into question, as shown in recent reviews (Scafetta, 2010; D'Aleo, 2011) and generally at www.climateaudit.org. Not only is the integrity of this data important for modelling, but it is also important for determining the trend and rate of climate change. The IPCC has used, in many of its reports, a graph that has become known as the "Hockey Stick" graph because of its shape (Figure 19). This graph which is based on data used in the models gives no recognition to the Medieval Warm Period (1000 -1300 AD) nor the Little Ice Age (1500-1800 AD). The Little Ice Age is particularly important, as many argue that the earth is in a recovery period from that ice age and is why increasing temperatures are being experienced. Akasofu (2010), having identified a temperature increase rate of 0.5°C/100 years since the Little Ice Age, suggests we are still on the rebound, and the warming currently being experienced is part of that. The Medieval Warm Period is also important in the debate, as it was a time when Greenland hosted Viking villages and farms on the coastlines, suggesting a warmer climate than today. The IPCC graph does not show either of these periods.



Source: http://3-b-s.eu/michael-mann-hockey-stick-graph-p-571376.html

Figure 19: IPCC anomaly hockey stick graph and graph of temperatures in Europe.

Temperature measurement is another aspect that has been brought into question and is reviewed by D'Aleo (2011), Scafetta (2010) and Frank (2010) and is presented as an extensive database populated with USA data at http://www.surfacestations.org/. There is considerable evidence that most of the weather stations in the USA (69%), the most weather instrumented land on earth, do not meet the minimum requirements for weather stations, and that the potential error from many of these stations (≥2°C) is greater than the climate variability that has been measured over the past century (0.8°C). A paper recently posted at Wattsupwiththat.com (2011) looks at the physical reading error associated with thermometers and concludes that a ±1.3°C error on mercury and alcohol thermometers is possible. A recent paper by Frank (2010) raises another issue with the measurement of temperature at weather stations. Evaluating sensor measurement uncertainty (±0.2°C) and systematic measurement errors, "a representative lower-limit uncertainty of ±0.46°C was found for any global annual surface air temperature anomaly." The consequence of this is then stated as: "This ±0.46°C reveals that the global surface air temperature anomaly trend from 1880 through 2000 is statistically indistinguishable from 0°C, and represents a lower limit of calibration uncertainty for climate models and for any prospective physically justifiable proxy reconstruction of paleo-temperature. The rate and magnitude of 20th century warming are thus unknowable, and suggestions of an unprecedented trend in 20th century global air temperature are unsustainable."

The analysis undertaken by D'Aleo (2010) suggests location changes, externalities and changing land use and land cover around weather stations has functioned to increase the temperature of the earth surface. In particular, urban heat island effects have been identified in many urban stations. To correct this, D'Aleo (2011) and Long (2010) claim rural stations were adjusted upwards to match the urban stations, and in doing this, the warming at the earth surface was caused. D'Aleo's analysis also claims that the early 20th Century and late 19th Century were cooled and more recent years warmed, in effect showing an exaggerated rising temperature for the 20th Century (Figure 20). With regards to Arctic temperature, D'Aleo also shows that the data extrapolation in the NASA GISS dataset extends land based temperature records into the Arctic area by as much as 1200 km and causes the Arctic temperature in this dataset to be artificially warm. The warming reported by NASA in GISS is not corroborated by actual station measurements. In summary, D'Aleo claims that the adjustments made by NOAA and NASA to the temperature datasets account for virtually all of the trend in the data. D'Aleo concludes his review with this statement: "These factors lead to significant uncertainty and a tendency for over-estimation of century-scale temperature trends. A conclusion from all findings suggest that global data bases are seriously flawed and can no longer be trusted to assess climate trends or rankings or validate model forecasts. And, consequently, such surface data should be ignored for decision making."

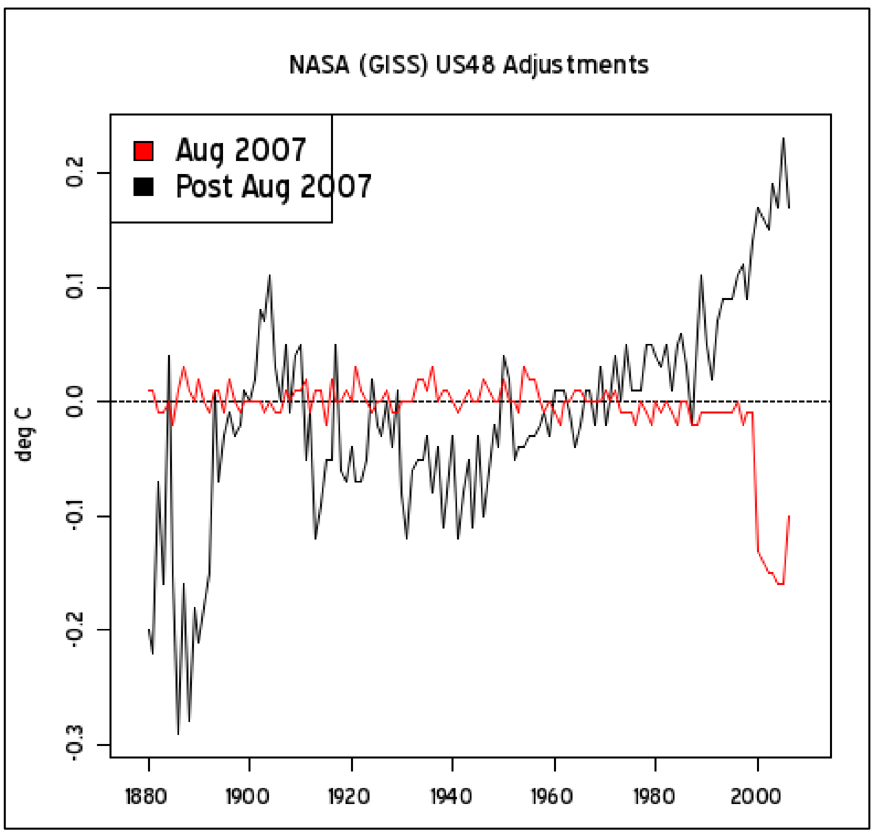
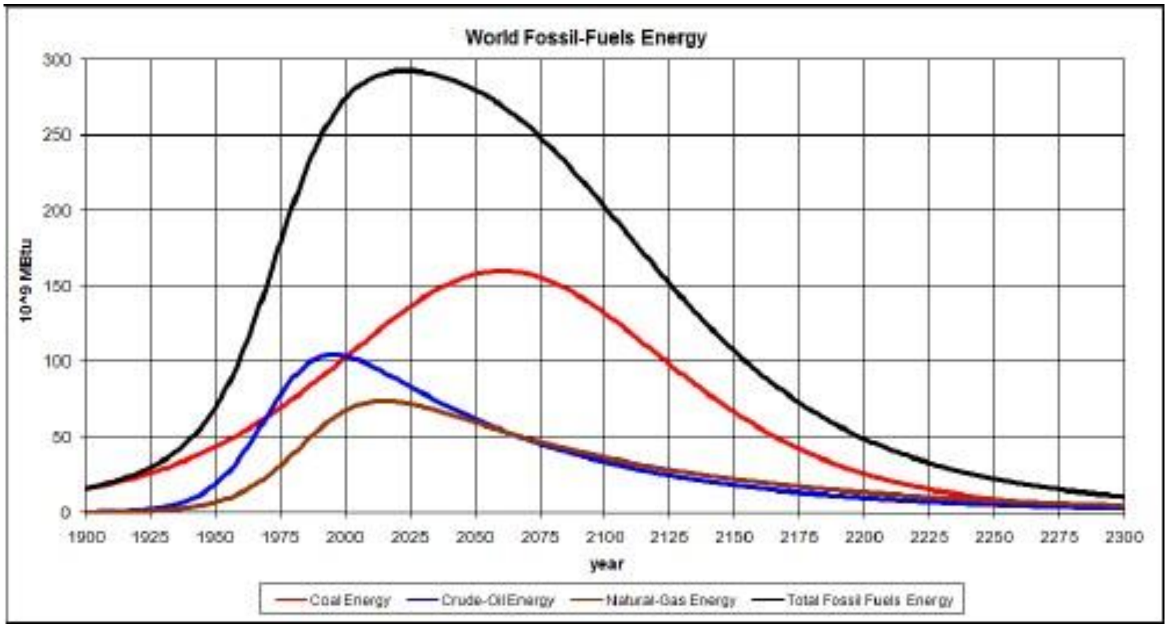


Figure 20: Example presented by D'Aleo to show NASA GISS data adjustments (Red data original data, Black line adjusted data).

2.2.4 Future Energy

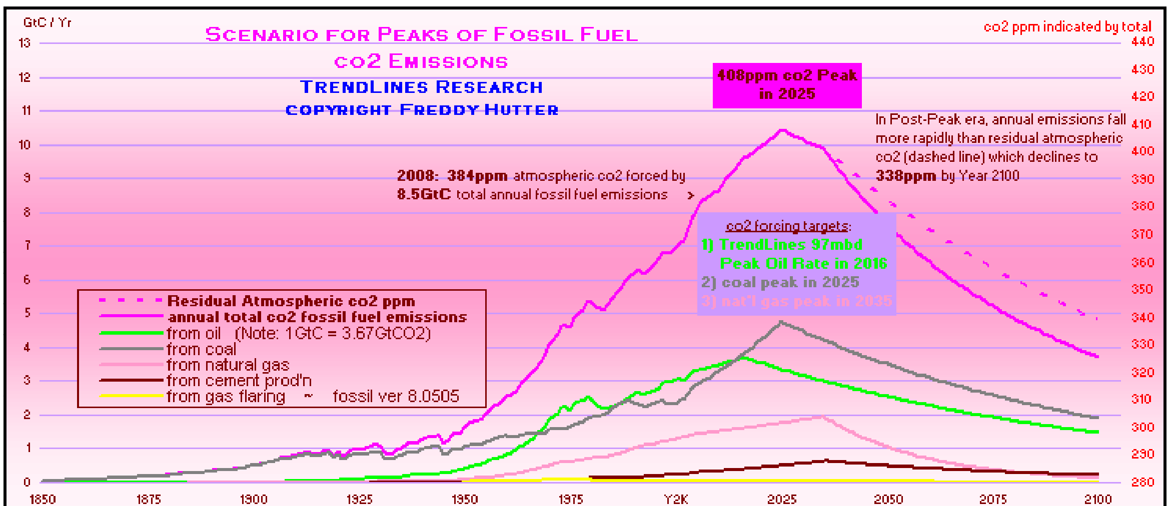
The Greenhouse gas emission scenarios used by the IPCC (Figure 11) are considered by some to be unrealistic, however not all of that debate is of relevance here. One aspect that is of relevance to this report is the long-term emission profile and residual atmospheric residence time of CO_2. It has been noted above that CO_2 has a logarithmic influence on temperature and that a future is predicted by the IPCC to have increasing CO_2 concentrations. From this, it is inferred that increasing amounts of CO_2 in the future will cause limited warming.

It is predicted that CO_2 will peak in the atmosphere in the range of 600-1000 ppm between 2030 and 2200 (Motl, 2011) (Figure 21 and Figure 22). The fossil fuel based fuels will be replaced over time (Nezhad, 2009; U.S. Energy Information Administration, 2010; Shell, 2008; World Energy Council, 2007; Andersen and Nilesen; Mintzer et al., 2003; Kram et al) and the atmospheric CO_2 concentration will start returning to equilibrium with temperature, which Motl describes as being in the range of 2°C to 4°C higher than today. It is anticipated from evidence presented by Motl that the atmospheric CO_2 concentration will return to about 300 ppm within 800 years and probably even less, based on a natural CO_2 absorption rate of 1.7 ppm per year. This absorption rate is expected to be greater at higher CO_2 levels and decline as atmospheric CO_2 concentrations decline. CO_2 absorption is decreased as temperature rises. Therefore, any future cooling will see enhanced CO_2 absorption. On this basis, if CO_2 is responsible for heating the atmosphere, the time period during which it will have an effect on global temperatures will be determined by how quickly other energy sources are developed or how long carbon dioxide will reside in the air or be absorbed. Basing long term future climate models, beyond 200 years after present, on elevated CO_2 scenarios is therefore not realistic as CO_2 production will decrease in the future and CO_2 absorption will continue, tracking temperature changes which some claim may cool over the next 30 years. CO_2 will not be produced in the same volumes in the future and the dominant natural climate drivers will again control the climate in several hundred years in the system as we now understand it. This is a window in time when CO_2 produced by humans is out of equilibrium with planetary temperature and it will return to an equilibrium state in time, as suggested in Figure 22.



http://www.roperld.com/science/energy.htm

Figure 21: Potential future hydrocarbon energy mix to 2300.



d

lines.ca/energy.htm

Figure 22: Peaks of fossil fuel CO_2 emissions till 2100.

2.2.5 Solar Variation

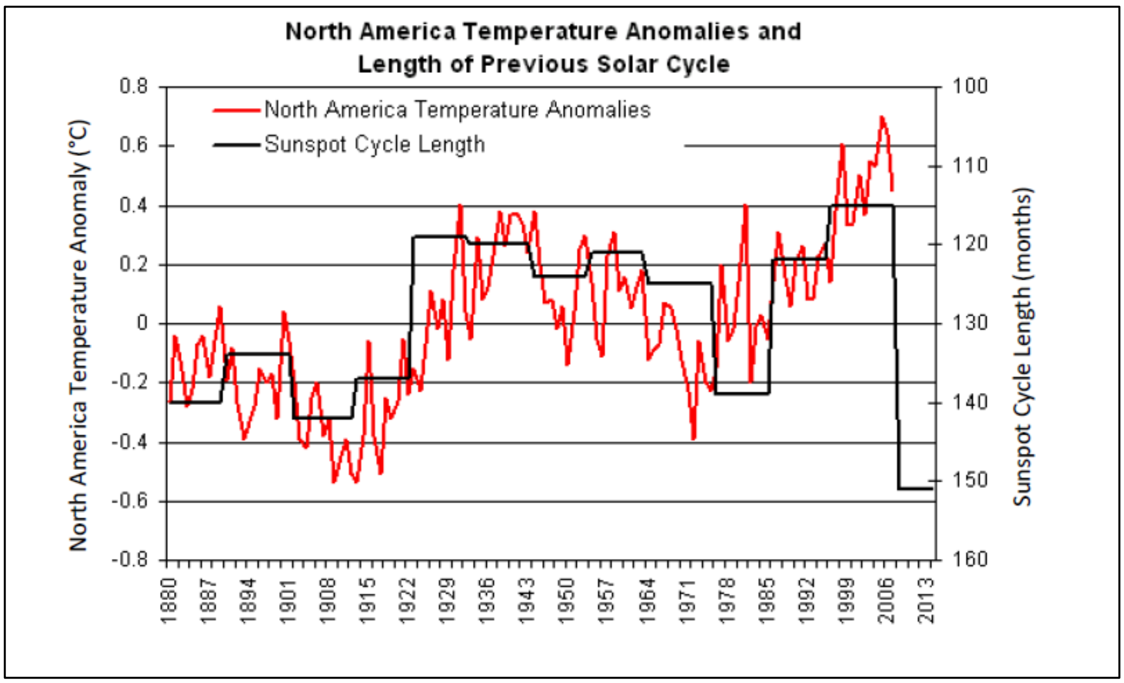
One of the key concerns relating to the methodologies used in the climate models is the strength of and sensitivity to solar radiation. The IPCC reports consider incoming solar radiation to be a natural forcing mechanism (Figure 12), but one with limited influence on temperature (IPCC, 2007; Scafetta, 2010). Studies have shown that the IPCC models do underestimate the influence of the solar contribution and that the climate models do not have the sensitivity that the earth is revealing (Stott et al, 2003; Scafetta, 2010; Krivova et al, 2010), but solar irradiance as measured does not account for the temperature that is experienced on earth. The models that have been evaluated also confirm that the second part of the 20th Century showed a linkage between temperature and CO_2 concentration. Bear in mind however, as noted in the concern described above in Future Energy, that as temperature increases, the ocean's capacity to hold gas is reduced, suggesting that the CO_2 may be responding to the temperature and not causing the increase. Many studies have identified a link between solar variations and the earth's temperature (Glassman, 2010; D'Aleo, 2010; Beradelli, 2010; Courtillot et al., 2006; Le Mouel et al, 2009; Hoffman, 2010; Svalgaard, 2007, 2008, 2009; Sharp, 2010; Shindell et al., 2001; Schmitt, 2010), however, until recently, a possible causal relationship has been elusive. Solar input variation to the earth can be can be achieved by:

- Orbital variations as identified by Milankovitch (described later in this report)
- Variations in the emissions from the sun (also described later in this report)
- Variations in the location of the earth in relation to the solar system spiral arms
- Variations in the earth's magnetic field
- Reflection from volcanic dust and clouds
- Astronomical origins.

These aspects are explored below as part of a brief review of recent literature relating to the relationship between solar activity and earth temperature.

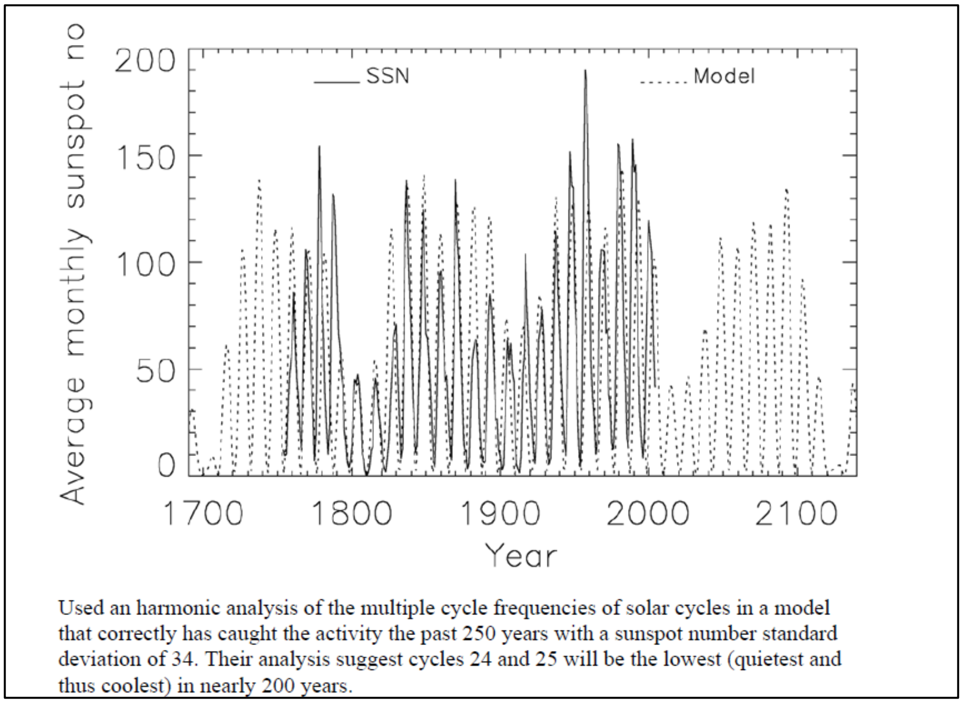
There has been a general increase in the earth's temperature from the latter part of the 19th Century and through the 20th Century, a time during which the strength of the solar cycle based on the number of sunspots was also increasing (Whitehouse, 2010). Some insist that this was not a thermal maximum, while others claim that up to 60% of the global warming identified could be attributed to astronomical causes (Scafetta, 2010). In the second half of the 20th Century, four out of five of the most intense solar cycles that have been recorded occurred. Included in this set of four is the one which occurred in the 1950's, the strongest yet recorded. It is notable that these strong cycles occurred at the time that the earth experienced its greatest warming from CO_2 based on the IPCC reports. This coincidence is fuelling much research into the linkage between solar output variations and the earth's temperature, partly driven by trying to understand what drives solar variation (Sharp, 2009; D'Aleo, 2010, Gray et al, 2010).

Looking back in history, Whitehouse (2010) also notes that if the cycle length is important as an indicator of future solar activity, then past events matching the current activity may give an indicator of the future. Cycle 22 was unusually short (9.7 years) which is on par with cycles 2 and 3, which occurred just prior to the Dalton Minimum. The Dalton Minimum was a period when temperatures are reported to have dropped over a twenty year period and crop failures due to cold were reported for eastern Canada, the USA and Europe. The last solar cycle (23) lasted 12.6 years, which is on par with cycles 4 (13.7 years) and 5 (12.6 years). During these cycles, Whitehouse notes, "the sunspot numbers declined at the start of the period, the solar cycle became more symmetrical and cycle rise and fall times converged at about 6 years," conditions similar to what are currently expected for cycle 24 and some are suggesting will occur in solar cycle 25, as well (Duhau and De Jager, 2010; De Jager and Duhau, 2011; Rawls, 2011; Livingston and Penn, 2008). Therefore, there appears to be a link between the previous cycle's length and the temperature experienced on earth during the next cycles (Rawls, 2011). Rawls quotes Strum, of Frontier Weather Inc., who has calculated that a drop in temperature of 0.6°C to 1.8°C will occur over the next 10 to 12 years (Figure 23). D'Aleo (2010) has also prepared a review that notes this drop in solar activity and quotes Cliverd et al, (2006) to show the future predictions of the solar cycles to 2100 and beyond (Figure 23 to Figure 25)(Sharp 2009).



Source: http://wattsupwiththat.com/2011/01/02/do-solar-scientists-still-think-that-recent-warming-is-too-large-to-explain-by-solar-activity/

Figure 23: Link between future temperature anomalies and previous solar cycle length.



Source D'Aleo, 2010

Figure 24: Prediction of future solar cycles.

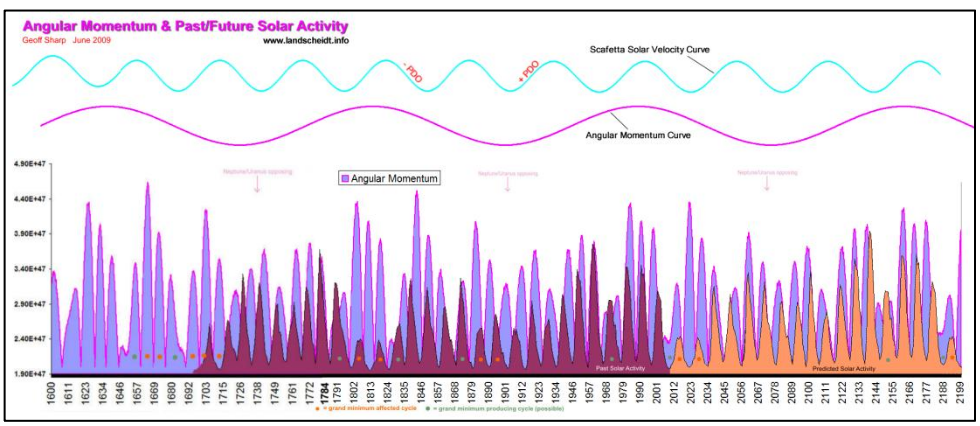
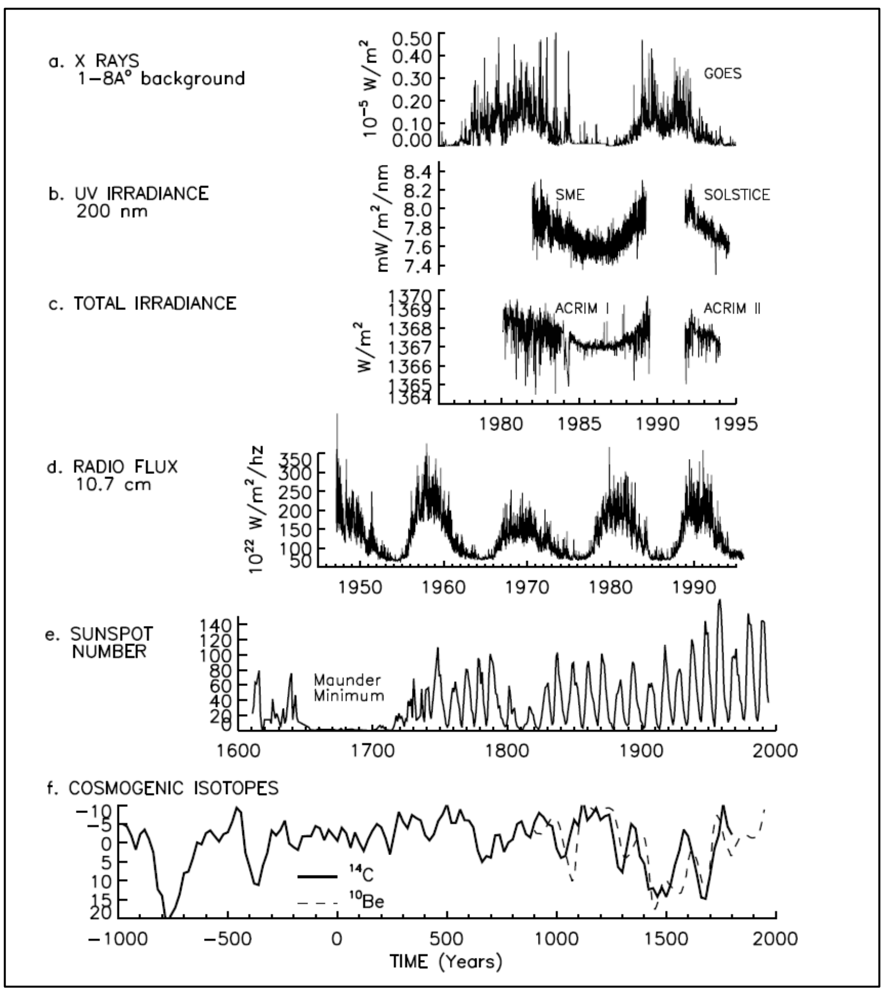


Figure 25: Future solar cycles based on Landscheidt theory (Sharp, 2010).

One of the key concerns with the IPCC report of 2007 relates to the IPCC only considering solar irradiance and its variation. The IPCC uses data that shows very little variation between 1978 and 2000 for Total Solar Irradiance (TSI). This is strongly contested by various groups who have demonstrated from measured data that TSI has increased during this time and over the Holocene (D'Aleo, 2010; Solanki et al, 2004; Solanki and Schuessler, 2004; Eddy, 1977; Krivova, 2010). This simple choice of selecting a particular dataset has allowed the IPCC to claim that solar irradiance was of little significance and, therefore, that heating was primarily based on CO_2 concentration increase.

A further issue with only considering TSI is that several other forms of radiation are not considered. The sun emits radiation at specific frequencies, which individually can alter process in the atmosphere and on the earth's surface. For example, UV radiation alters ozone (a greenhouse gas); UV causes warming in the stratosphere, which warms the troposphere in low and mid-latitudes during winter; visible light stimulates photosynthesis, which feeds back into biosphere systems; and then the Galactic Cosmic Ray (GCR) flux, which modulates clouds that in turn alter the albedo (Figure 26) (Scafetta, 2010; Erlykin et al, 2009; D'Aleo, 2010; Lean, 1993; Hodges and Elsner, 2010, Palles et al 2006; Lamb, 2010; Corbyn, 2010; Svensmark, 1999; Frohlich, 2009). None of these components are considered in the IPCC models and the full extent of their influence is still being determined. Some suggest the feedback mechanism may be stronger than the initial signal from the sun (Rind, 2002).



Source: Lean, 1997.

Figure 26: Variations in specific parts of the solar emission spectrum.

Considering the GCR aspect further, it has been suggested that the GCR flux causes low cloud cover extent to vary. When solar magnetic activity increases, cosmic ray flux decreases and less ionisation occurs in the earth's atmosphere, resulting in less condensation nuclei being available for cloud formation. Fewer clouds result in a decreased albedo and more solar irradiance reaches the earth's surface, resulting in warming. In Scafetta's 2011 paper, studies are reported that show just a 5% modulation of the low cloud cover by the sun could have the same radiative forcing impact as net anthropogenic forcing since 1750. The key linkages identified in the work reported by Sacfetta and Fluteau et al. (2006) are:

- Solar magnetic flux increase during the 20th Century correlating with the increased average global surface temperature during the last century.
- GCR flux decrease from the 1970s to the 1990s correlating with the increased TSI activity and possible earth magnetic field changes (as noted in the TSI dataset rejected by the IPCC due to increasing trend) and with the global warming observed from 1970 to 2000.
- Global low cloud cover decrease from 1984 to 2000 linking with the observed warming during this period (data from ISCCP infrared data) and TSI increase.
- It is also suggested that an increase in TSI would warm water vapour molecules reducing the likelihood of their condensation to form cloud droplets.

From this it is inferred that if TSI decreases and GCR increases, as predicted to occur for solar cycle 24, more clouds can be expected, possibly more precipitation will occur and temperatures are likely to decrease as the albedo increases due to the extra cloud and a larger area covered by snow.

2.3 Implications of Concerns

Although the models created for the IPCC by various organisations have contributed enormously to the understanding of the earth's climate system, they are repeatedly being shown to be making inaccurate predictions and generally overestimating the future temperature. The review presented in this section has pointed to some of the shortcomings, which range from:

- Historical temperature data set integrity issues.
- Temperature measurement accuracy and instrument error levels being as great as the warming identified.
- Overstatement of the effect of CO_2 and an incomplete inclusion of the climate mechanisms associated with CO_2.
- The models limited capacity to include the cyclicity which is being observed in real weather.
- Using energy scenarios which are not regarded as being realistic in the long-term.
- Underestimating the role of the sun, which has for many years been shown to be linked to earth's temperature and recently studies have started to unravel the causal mechanisms.

The literature that has been cited in this section has been selected to show the concerns with linking CO_2 to warming and the inability of the models to predict the current levelling off, if not slight cooling of the global temperature. Any approach used for future climate prediction will inevitably have strengths and weaknesses as there are gaps in our knowledge. By resolving these over time, greater certainty will be achieved. At this time, it would appear that the models have not been able to model climate at a level of accuracy required to substantiate the claims of increasing temperature over the past 10 years. The last 10 years of temperature stabilisation and slight falls at the regional and global scale are not accounted for in most models. If they are unable to reliably model in the near-term, it is unlikely that the long-term monitoring will be reliable at all, at any scale. This review suggests that an alternative mechanism not based on modelling, but rather on an understanding of the climate mechanisms and matching current situations to historical situations can add value to the process for determining a possible future climate scenario for AREVA Resources Canada. This approach can only be as good as the paleo data and cannot predict temperatures, precipitation or other variables which define weather and will also not give the levels of certainty that are required. By providing an alternative approach, the level of certainty or the range of uncertainty can be better defined. This document is not intended to replace the IPCC modelling, nor be pitched against the modelling at a local scale in Canada, but is intended to be read alongside that information in a complimentary manner, so that a better understanding can be achieved. With this in mind, the information presented in this document attempts to create a scenario not based on modelling, but on an understanding of physical processes.

3 Climate Change Cycles

3.1 Climate Cycle Timeframes and Data Types

To understand climate change, it is important to appreciate what weather and climate are and to be aware that there are variations on different time scales. This section has been prepared to show the variability and the timescales involved as well as the source of the data. It is by no means exhaustive but it creates a framework for understanding short term weather against long term climate trends. Indeed, it is possible to see a cyclical nature appearing in the data at the longer time scales which suggests there are some key driving or forcing mechanisms. This section draws on materials from various sources, but extensively from the NOAA Paleoclimatology and Climate Prediction Center, http://www.ncdc.noaa.gov/paleo/ctl/now.html#. This is an excellent summary of the climate cycles within different timeframes. The materials presented below are a concise summary of the various information sources and are fundamental to understanding climate change. The scenario that is developed in this document is based on some of the cyclic trends identified in this section.

3.1.1 Diurnal Cycles (1 Day)

The earth's weather is largely driven by the rotation the earth on its axis and the incoming solar radiation from the sun. A combination of the two we see as day and night or the diurnal cycle. Typically there is a delay between the incoming solar radiation (insolation) on the earth surface and the increase of temperature through the day. The delay is known as the thermal response. Depending on the season and the latitude, the lag can be as long as three or four hours. As an example, the hottest time of day during a typical summer afternoon would be in the mid afternoon, not at solar noon. The suns energy is also needed to drive evaporation which leads to cloud formation and rain. This forms the underlying driver for the daily weather we experience. It is not possible to describe climate variability based on any single day taken in isolation.

In Figure 27 below from the NOAA Climate Prediction Center global and ultraviolet (UV) radiation on a mostly clear day and the variation of surface temperature for the same time period is shown.

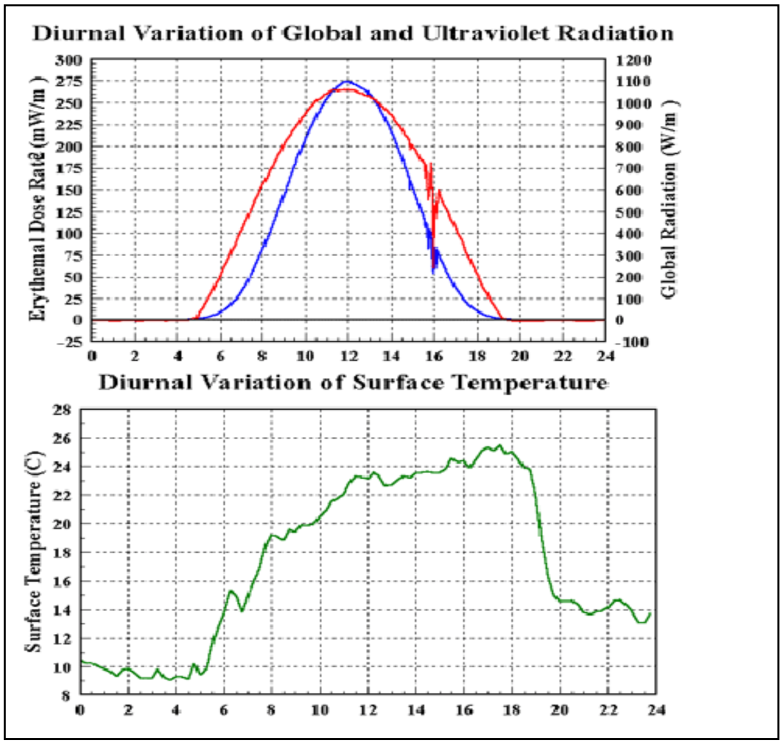


Figure 27: The diurnal cycle for ultraviolet radiation and temperature.

Measures

Measures of weather and diurnal cycles that are frequently used include:

- Weather stations
- Thermometers
- Rain gauges
- Stream gauges
- Tidal gauges.

Proxies

Information about the weather can be stored through processes such as tress rings and can be used to infer the weather that may have occurred in the past and are known as proxies. For diurnal and annual data these are:

- Tree rings
- Coral
- Ice caps and glaciers (Can provide indication of precipitation and extreme events such as fires and volcanic activity. These extreme events can be accurately dated against historic records and are used to aligning data from different sources).

3.2 Annual Cycles (1 Year)

The annual cycle is a complete orbit of the earth around the sun in which there are four seasons caused by the tilt of the Earth's axis, currently at 23.5 degrees. The seasons are caused by the tilt which alters the angle at which solar radiation reaches the surface of the earth and thus the energy available to drive weather systems (Figure 28) (NOAA Climate Prediction Center).

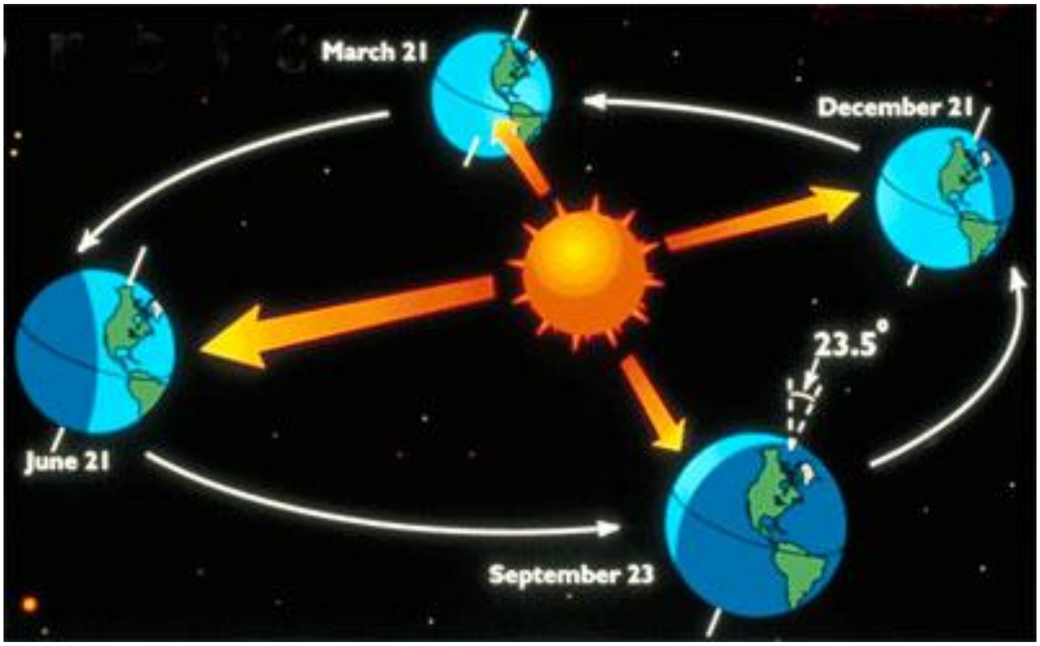


Figure 28: The axis of earth rotation and affects on insolation.

The orientation of the axis remains fixed in space as the earth completes an annual rotation around the sun, producing changes in the distribution of insolation. The earth on an annual basis remains roughly the same distance from the sun. The weather in the seasons is manifest through more extreme seasonal changes generally occurring at high latitudes, and less variation towards the equator. It is easy to discern weather changes by season over a year but difficult to see climate variability within an annual cycle. Climatic variability would require multiple years' worth of seasonal comparisons to see a climatic trend, though this will still not describe climate adequately.

Measures

Measures of weather and annual cycles that are frequently used include:

- Weather stations
- Thermometers
- Rain gauges
- Stream gauges
- Tidal gauges.

Proxies

Information about the weather can be stored through processes such as tress rings and can be used to infer the weather that may have occurred in the past and are known as proxies. For annual data these are:

- Tree rings
- Coral
- Ice caps and glaciers (Can provide indication of precipitation and extreme events such as fires and volcanic activity. These extreme events can be accurately dated against historic records and are used to aligning data from different sources).

3.3 Decadal Cycles (10 year)

Over a decade it becomes possible to get a perspective of climate variability as multiple seasonal data can be compared. Decadal cycles and patterns of climatic variability that are starting to be revealed include those related to:

- Sunspots
- El Niño-Southern Oscillation (ENSO)
- Pacific Decadal Oscillation (PDO)
- North Atlantic Oscillation (NAO).

In addition, research of Crowley (2000), suggests that between 40-65% of decadal-scale temperature variations during the past 1,000 years prior to 1850 were caused by changes in solar irradiance and volcanism. While individual volcanoes usually only impact climate for a year or so, clustered eruptions can perturb the climate system for longer periods of time. The four bulleted points above are described in more detail below, though it should be noted that earth based changes such as volcanism can impact climate on this time scale.

3.3.1 Sunspots

Sunspots, although only more recently measured with exacting scientific instruments are now known to follow a roughly11 year cycle. This is based on a historical record of observations spanning hundreds of years. There are now a growing number of scientists who believe the sunspot cycles may play a role in climate processes as they introduce variability into the amount of solar radiation emitted from the sun.

The information in this section is mostly drawn from:

http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

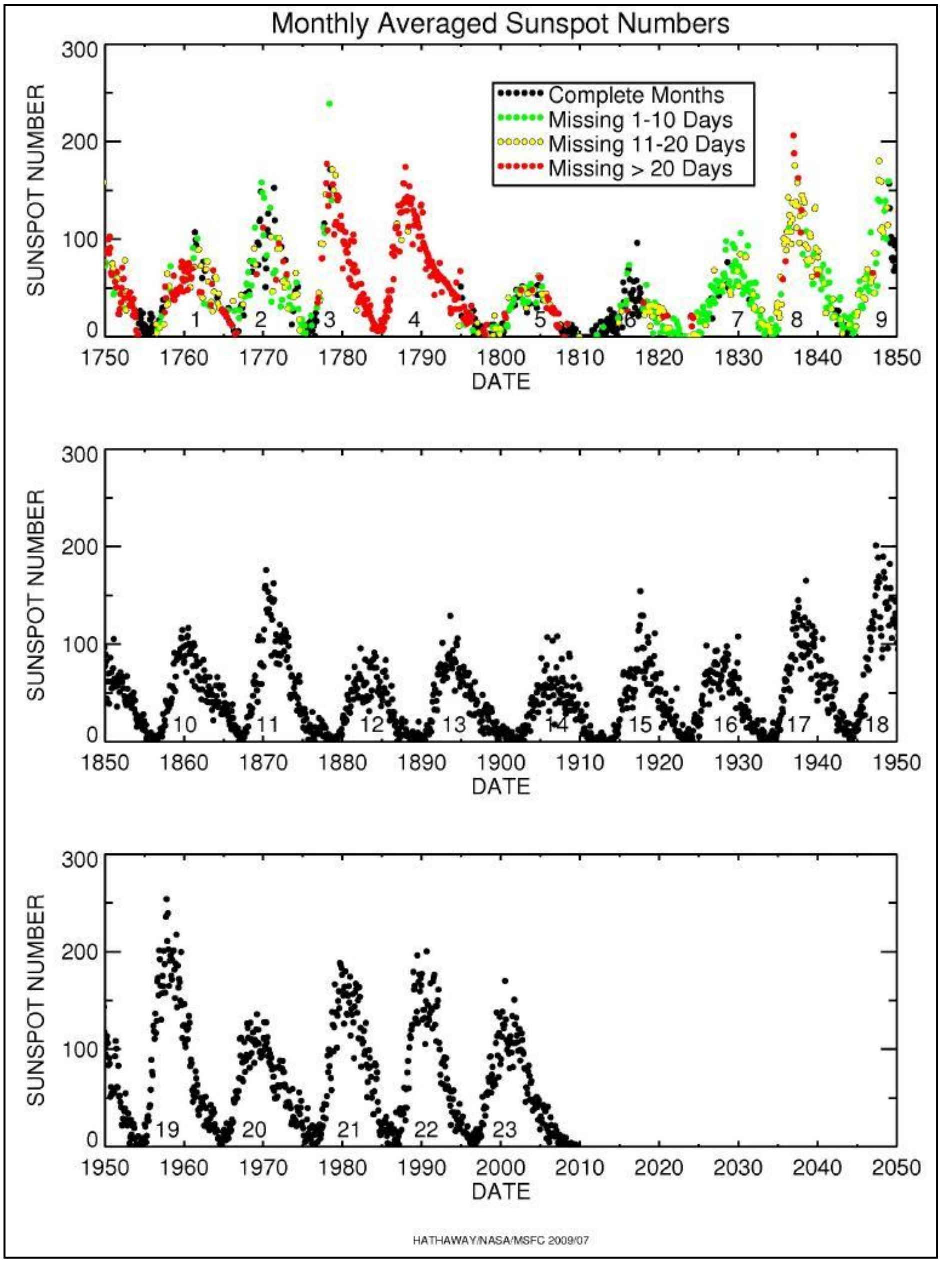


Figure 29: Sunspot data from 1750 to 2009 displaying an 11 year cycle (after Hathaway 2009).

Early records of sunspots indicate that the Sun went through a period of inactivity in the late 17th century. Very few sunspots were seen on the Sun from about 1645 to 1715. Although the observations were not as extensive as in later years, the Sun was in fact well observed during this time and this lack of sunspots is well documented. This period of solar inactivity also corresponds to a climatic period called the "Little Ice Age" when rivers that are normally ice-free, froze and snow fields remained year-round at lower altitudes. There is evidence that the Sun has had similar periods of inactivity in the more distant past. The connection between solar activity and terrestrial climate is an area of on-going research.

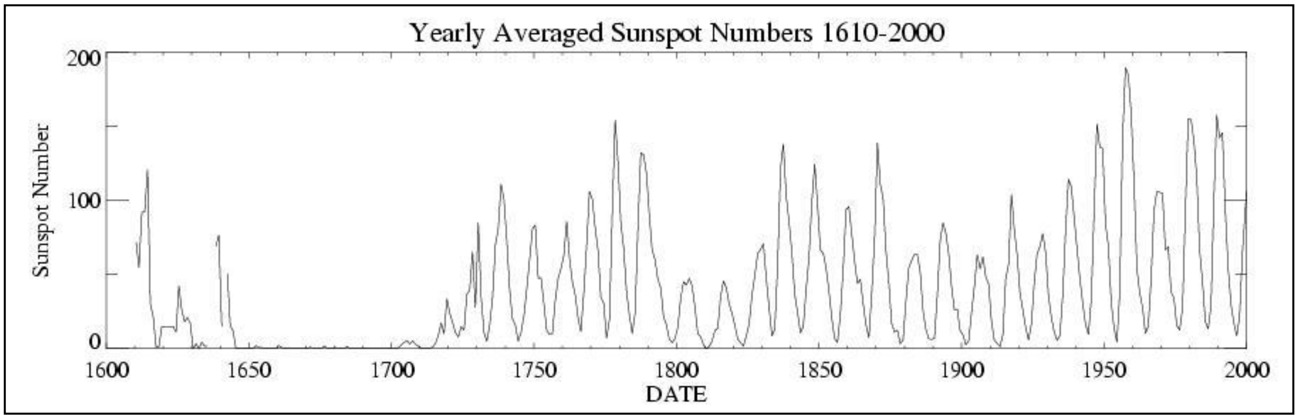


Figure 30: Yearly averaged sunspot numbers 1610-2000.

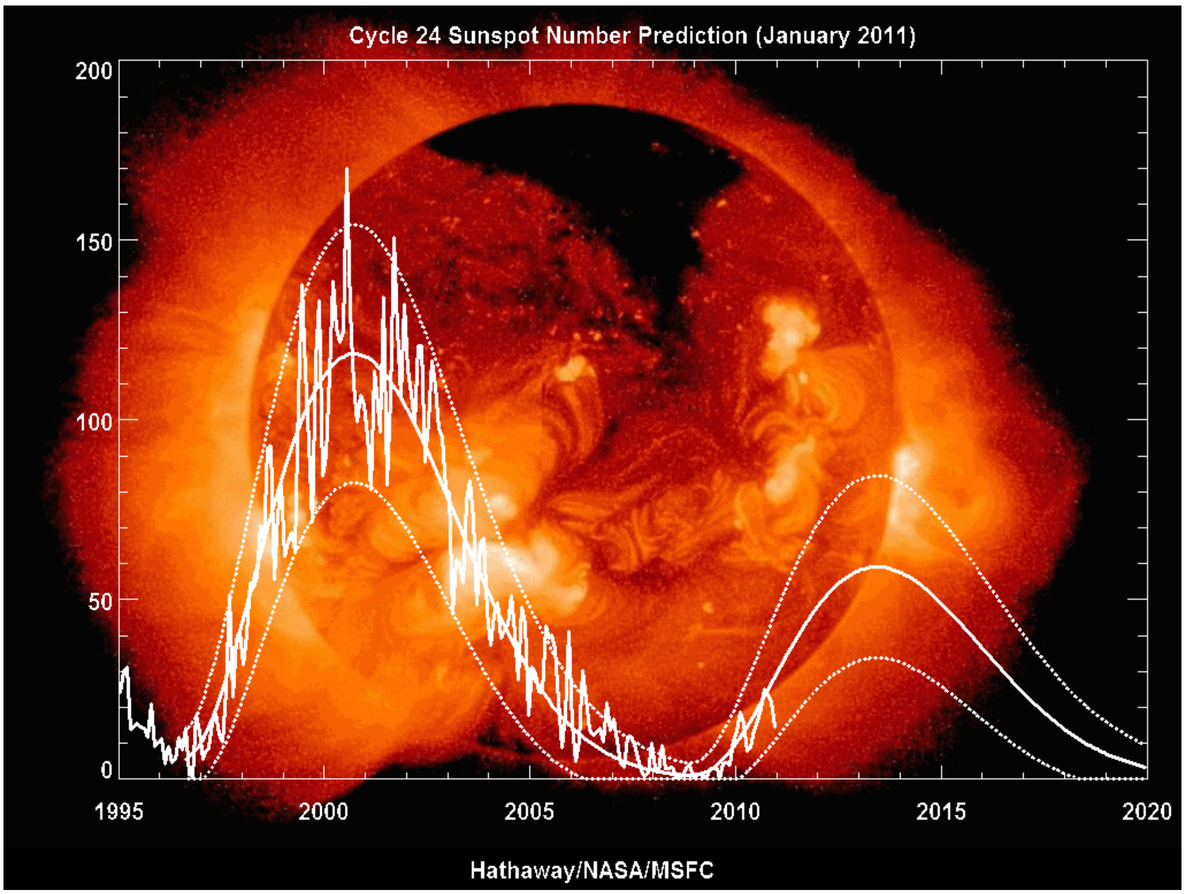


Figure 31: Sunspot number predictions Till 2020 (Updated 2011).

3.3.2 ENSO

The ENSO climatic pattern is between the one and ten year time scales and is now known to have a significant impact on interannual climate variability around the world. ENSO is an interannual variation of atmospheric and oceanic conditions in the Equatorial Pacific.

Importantly, climate occurring between one and ten year periods is only starting to be understood as the science is still relatively new. To help build this understanding paleo records are overlapped with instrumental records for patterns such as ENSO. This reveals an ENSO-like climate signature in paleo records going back thousands of years. is an image drawn from NOAA's Paleoclimatology Program showing the variability within an ENSO cycle and the repeating nature or pattern of the phenomenon. The repeatability of the signature as well as recognising which phase it is in allows it to be used to describe potential future climate.

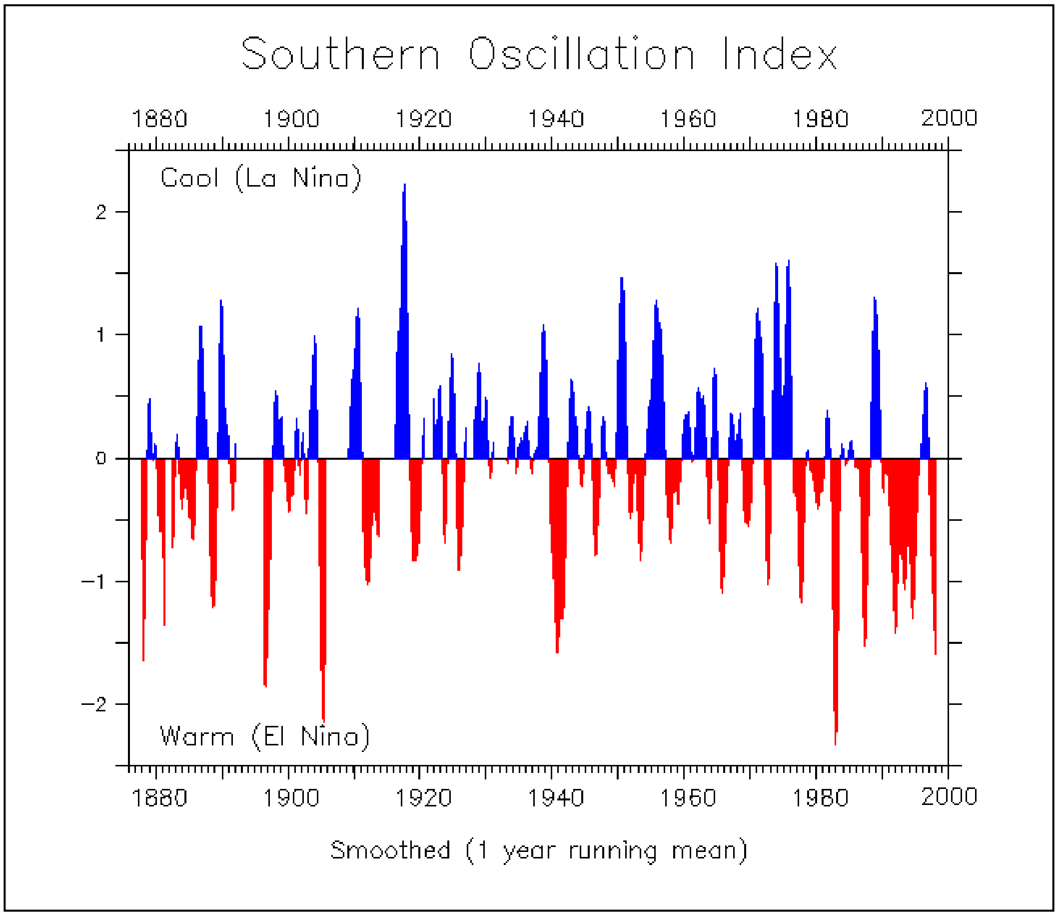


Figure 32: ENSO variability on the decadal scale and pattern on centenial scale.

3.3.3 Pacific Decadal Oscillation

Scientists examining sea surface temperatures (SST) for patterns in the heating and cooling of the ocean systems have identified variability that influence climate and fisheries. One, centered in the north Pacific and most commonly called the Pacific Decadal Oscillation or PDO, seems to have return periods of 15 to 25 years, and of 50 to 70 years. The other, the North Atlantic Oscillation (NAO), has a dominant period of 12 years (Deser, 1993), and as its name implies, it is centered in the North Atlantic.

Similar to and interacting with inter-annual phenomena such as ENSO, these decadal-scale processes appear to play a major role in regional and global climate dynamics.

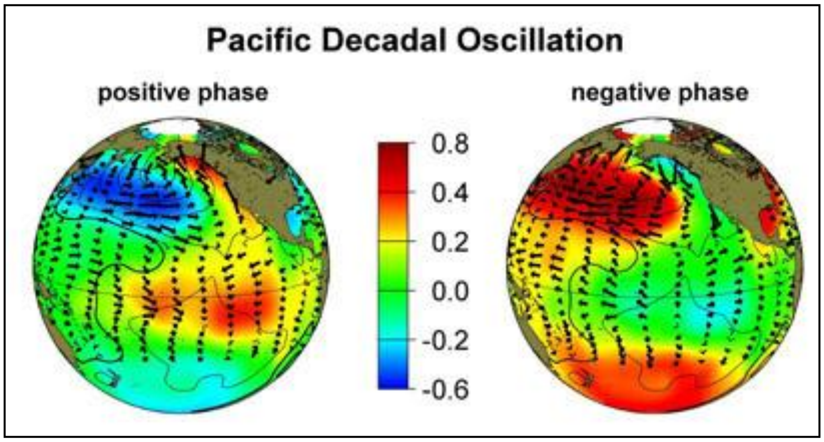


Figure 33: Pacific Decadal Oscillation phase variations.

The term PDO refers to an oscillation marked by a positive phase period when a large pool of colder than average sea surface water in the central north Pacific appears along a narrow band of warmer sea surface temperatures along the west coast of North America. During the negative phase of the PDO, the opposite is observed: a warm pool of sea surface waters in the central north Pacific and cold SSTs along the west coast. The most recent warm phase began in 1977 and may have finished in 1999. In theory, ENSO overlays the PDO's longer pulse.

Not all scientists are convinced PDO is actually an oscillating feature since research on the phenomena is less than a decade old. It has also been suggested by some researchers that PDO may be part of other features such as ENSO, or define the structure of the dynamic differently.

3.3.4 North Atlantic Oscillation - NAO

The North Atlantic Oscillation or NAO has been studied by the Lamont-Doherty Earth Observatory and other researchers for a number of years. Researchers have identified a dynamic process that has particularly important impact on European climate.

NAO varies from year to year (interannual variability) but has a roughly decadal pattern with a dominant period of 12 years (Deser, 1993).

During its positive phase, the NAO shows a stronger than normal subtropical high pressure center around the Azores and a deeper than normal Icelandic low, with increased pressure generating more and stronger winter storms crossing the Atlantic Ocean on a more northerly track. Europe tends towards warm and wet winters while northern Canada and Greenland will usually have winters are cold and dry, with the eastern United States generally experiencing mild, wet winter conditions.

During its negative index phase, NAO is characterized by weak subtropical highs and weak Icelandic lows, with fewer and weaker winter storms that cross on a more west-east pathway, bringing cold air and snowy weather conditions to the U.S. east coast during the winter months, cold air in northern Europe, and moist air to the Mediterranean.

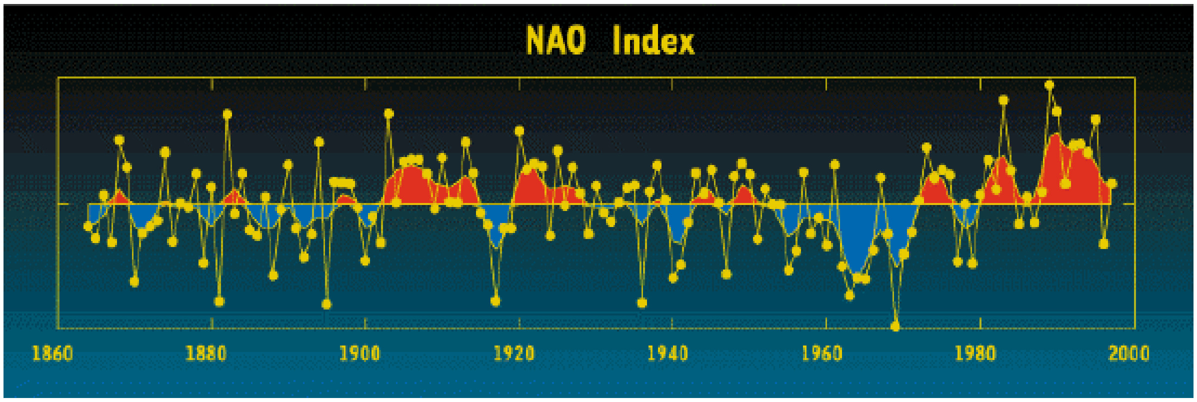


Figure 34: The North Atlantic Oscillation Index.

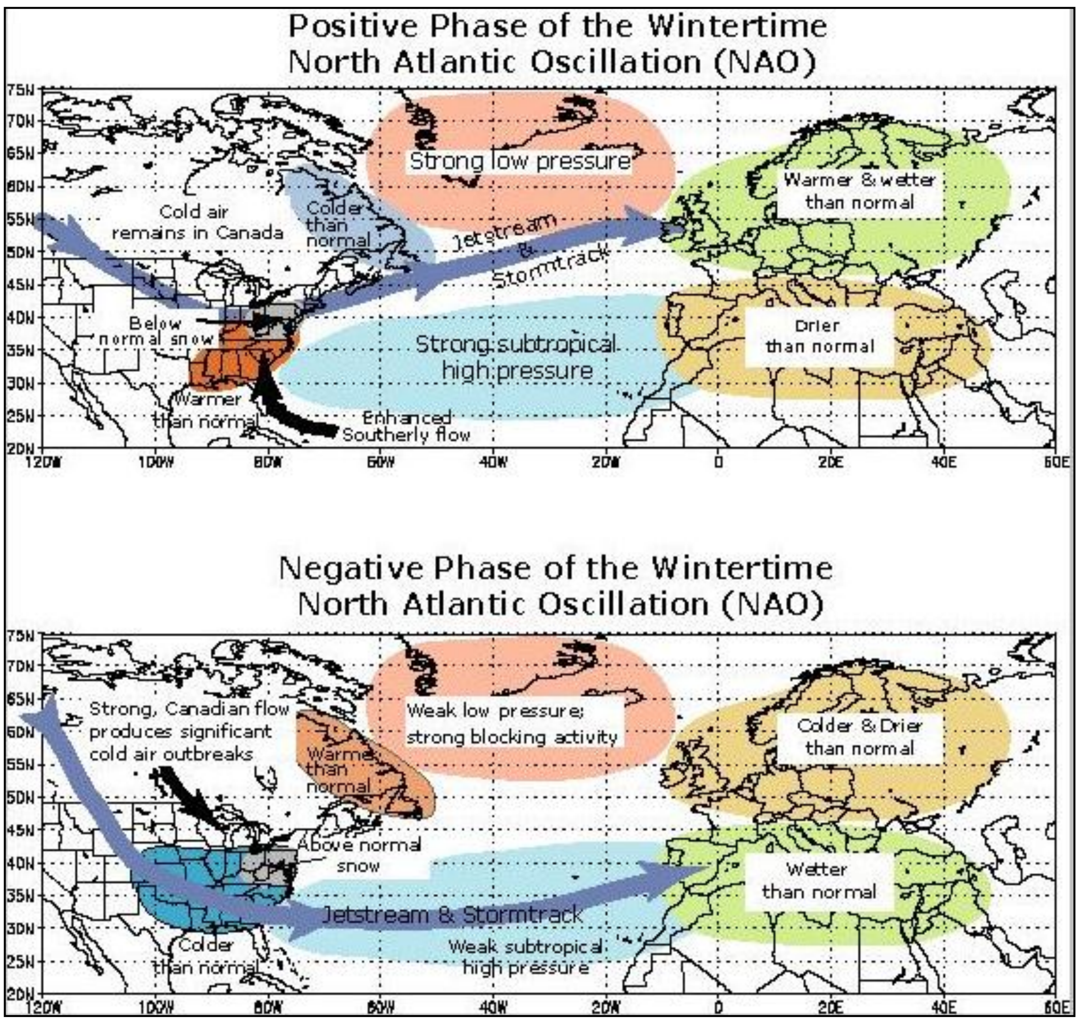


Figure 35: Possible global weather impacts of the North Atlantic Oscillation.

Measures

Instruments used to track decadal variability and climate patterns include:

- Weather Stations
- Thermometer
- Rain gauges
- Stream gauges
- Sea Surface Temperature (SST) is particularly important in tracking ENSO and other ocean oscillations
- Sunspot activity.

Proxies

An ENSO-like signature in some paleo records, including:

- Tree cores
- Corals
- Lake sediments.

3.4 Centennial Cycles (100 year)

Patterns that occur between the decadal and centennial (10-100 year) scales include:

- Greenhouse gases
- Solar cycles.

3.4.1 Greenhouse Gases and Temperature

The past 100 years have seen dramatic climate events and a significant growth in human population, increasing from approximately 1.6 billion to over 6 billion. This rapid growth of the human population has been suggested by many scientists to be an increasingly important factor to consider when assessing climate change. One component of this human factor is greenhouse gas release. One of the greenhouse gases is carbon dioxide which over the past century has seen levels rise from 290 parts per million (ppm) to nearly 370 ppm. The combustion of fossil fuels has been identified as a major factor in the increase of this important greenhouse gases potentially linked to a warming of the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) has been responsible for much of the research conducted in this field. They have used climate models to predict future climate up to 2100. This work is widely criticised for a variety reasons, however there are a large number of scientists who have contributed to this work which is continually being refined and it is becoming more robust under scrutiny. To determine if the models are reliable they have been tested against paleo data and there appears to be generally good correlation with model output. The models are complex and try to incorporate as many variables as possible while still functioning with realistic computing times.

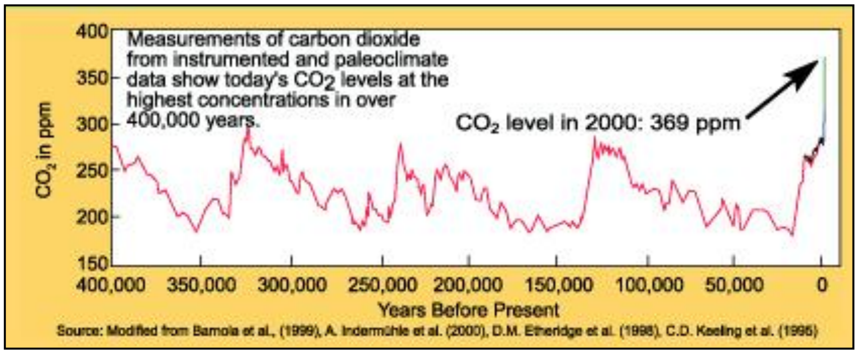


Figure 36: Atmospheric CO_2 concentrations for the past 400,000 years.

To get a flavour of this complexity that needs to be considered in the models: There has been increased cloud cover (cooling), particularly in the Northern Hemisphere during the past century, while water vapour is the most abundant greenhouse gas(warming), low clouds also shade and cool the surface (cooling). During this time carbon dioxide (CO_2) and methane (CH_4) levels have also risen (warming) and the earth is reported by the IPCC to have warmed by 0.6°C over the past 100 years. In addition, sunspot activity peaked during this period (warming) and is now in decline (cooling). It is also important to note that the correlation between solar activity and temperature ended around 1975, temperatures rose while solar activity did not, suggesting that inputs or the extent of amplification may also be changing and that greenhouse gases may be having more influence. All these different variables make for difficult modelling as they need accurate weighting to be realistic.

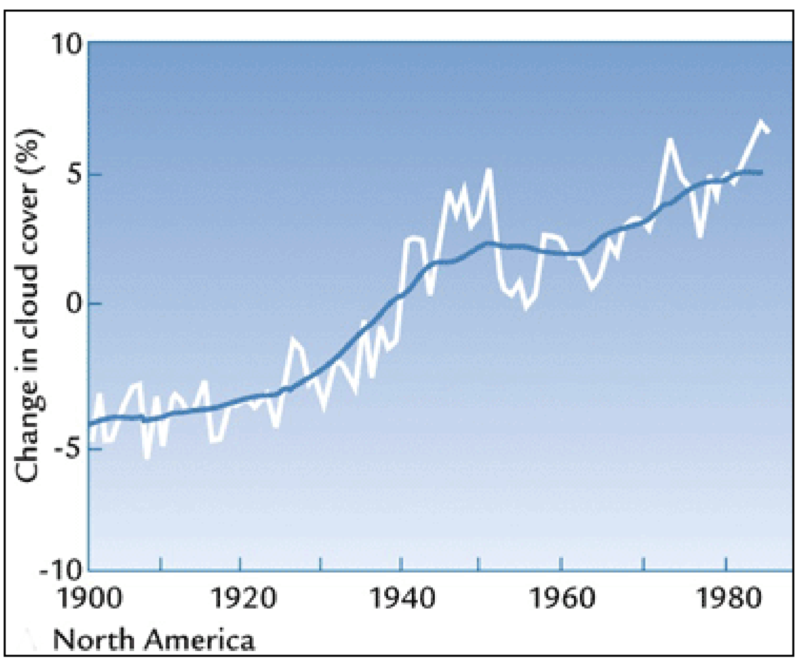


Figure 37: Increased North American cloud cover over the past 100 years.

3.4.2 Temperature and Trends

In the 20th century warming counters a millennial-scale cooling trend caused by long-term astronomical forcing. Simply stated when the key solar input forcing mechanism is weakening, or suggesting a return to cooler temperatures, earth is instead experiencing a slight warming as noted by the IPCC. Figure 38 below, based on data from the National Climatic Data Center, shows observed temperature changes as well as what would be expected from climate forcing mechanisms. CO_2 and other greenhouse gases as well as the vastly increased human population and all the changes they are bringing about in the surface of the earth are all factors that may be influencing temperature. Some scientists believe however, that mans impacts are minor by comparison to the larger forcing mechanisms in operation and hence the controversy in the climate change community.

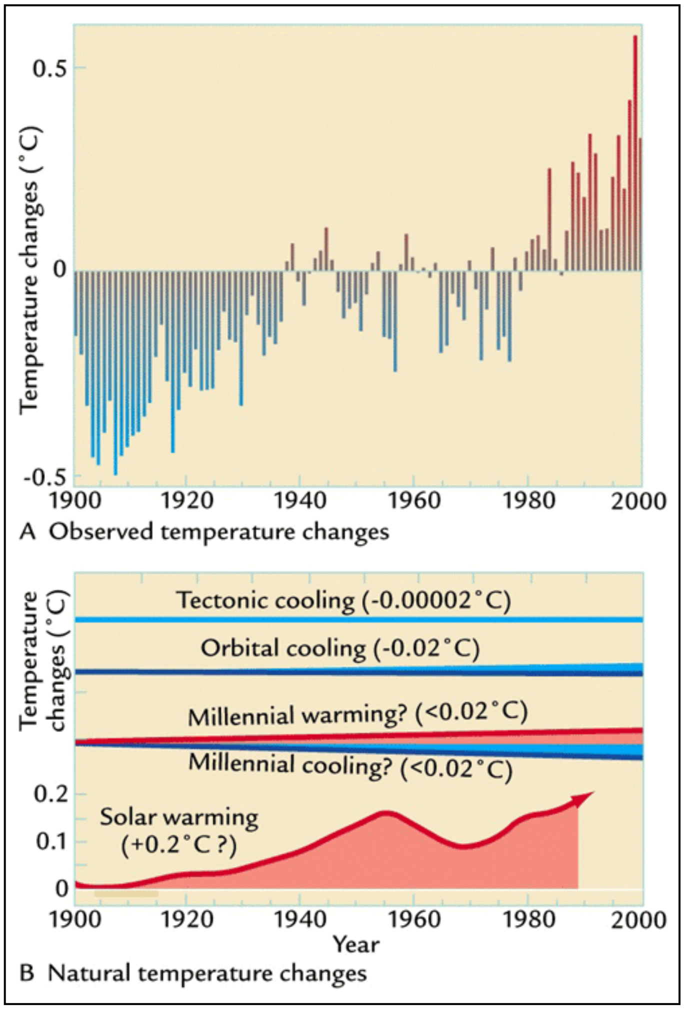


Figure 38: Observed and natural forcing mechanism temperature changes for the past 100 years.

The short term changes, when it is now known that there are long-term mechanisms at play requires that this data be viewed against much longer term records (Millennial and longer cycles) to provide a context. In this context the earth is warmer now than it has been for the past 1,200 years, but is this unprecedented. The dust bowl in the USA for example was a severe drought, but data suggests that it was minor by comparison to droughts that had occurred before and that droughts appear to be returning on a routine and regular basis. This suggests that variations even over a century can be large and that there are larger driving mechanisms at work.

In Figure 39, a comparison between different Northern Hemisphere temperature reconstructions and instrument records are shown. This clearly shows that the temperatures being experienced today are within the range of uncertainty associated with different data sets and that what we are experiencing is not necessarily unprecedented and may have occurred in the past.

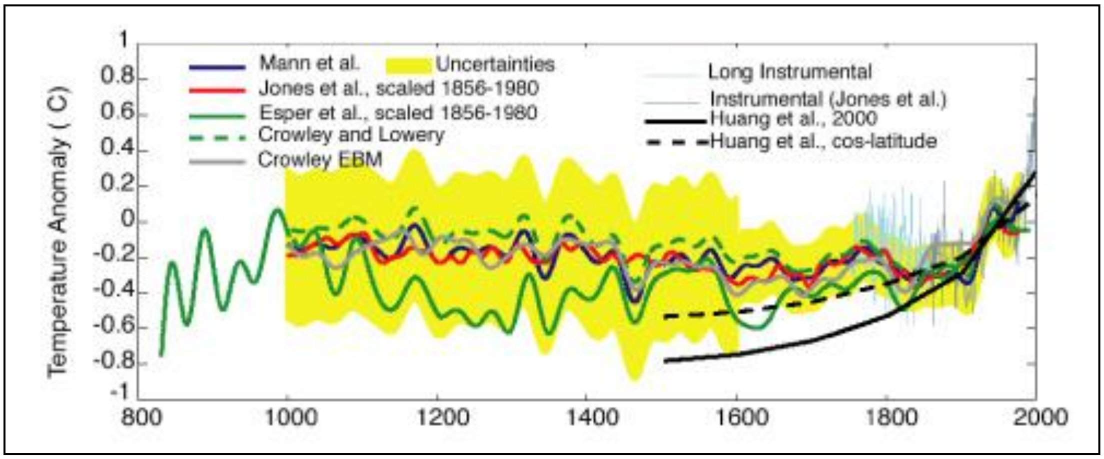


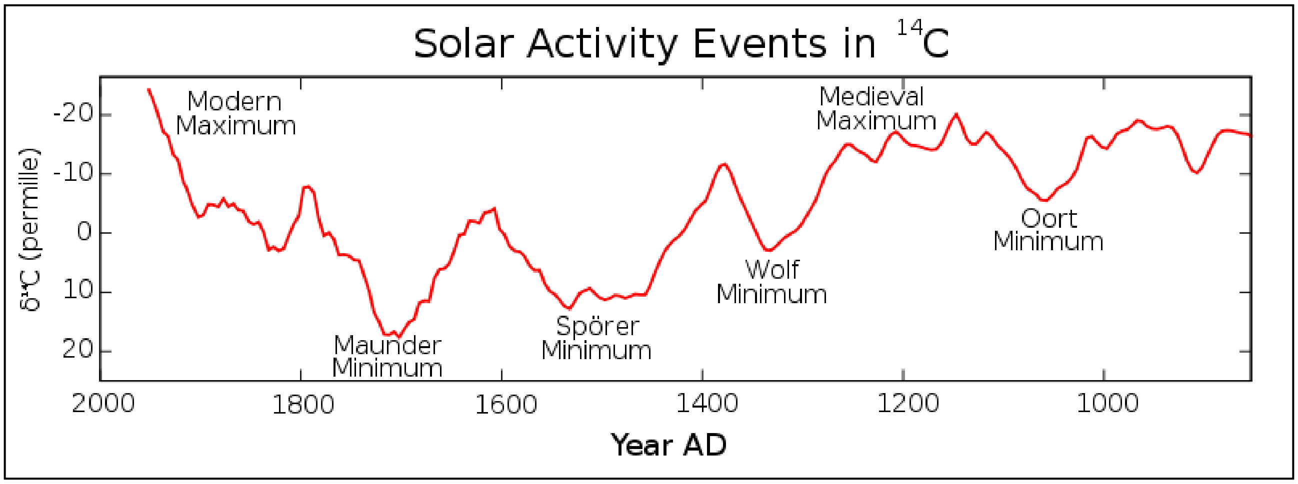
Figure 39: Temperature changes for the 1,200 years suggests we are warmer today than during this period, but within limits defined by uncertainty for past records (after Mann, M. E., Rutherford, S., et. al., 2003).

3.4.3 Solar Variation

The following solar cycles are evident and they do appear to have a connection with the climate that is experienced on the earth, though the exact mechanisms and linkages are not clear. Sunspot activity and changes in the suns magnetic field are thought to play a role. Sunspot cycles are described in the section concerning Decadal Cycles above and are not repeated here. The various solar cycles that are claimed to exist are presented below:

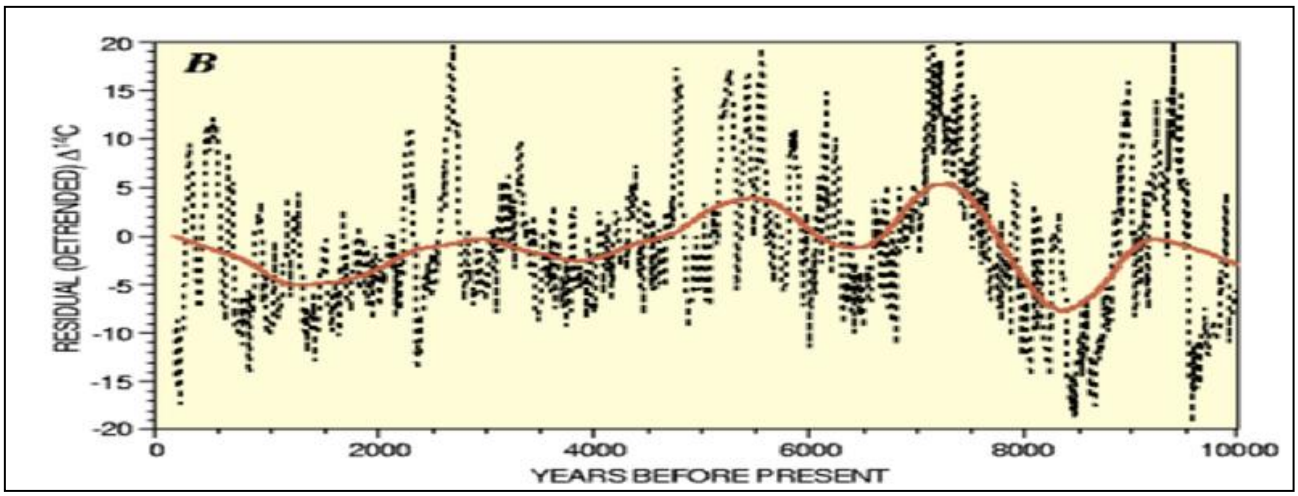
- 22 years: Hale cycle. The magnetic field of the Sun reverses during each cycle
- 87 years (70–100 years): An amplitude modulation of the 11-year Cycle
- 210 years: Suess cycle or de Vries cycle (Figure 40)
- 2,300 years: Hallstatt cycle (Figure 41).

The 200-year solar cycle (Suess or de Vries cycle) is commonly believed to be one of the most intense solar cycles, was a dominant cycle during the Holocene and is associated with the deep Maunder, Spörer and Wolf solar minima (Raspopov 2008).



(Source: http://www.radiocarbon.org/IntCal04%20files/intcal04.14c)

Figure 40: Red curve shows c.210 year solar de Vries cycles.



Source: http://pubs.usgs.gov/fs/fs-0095-00/)

Figure 41: Red curve shows c.2,300 year Hallstatt cycle.

Measures

Instruments used to track centennial variability and climate patterns include:

- Weather Stations
- Thermometer
- Rain gauges
- Stream gauges
- Sea Surface Temperature (SST) is particularly important in tracking ENSO and other ocean oscillations
- Sunspot activity.

Proxies

An ENSO-like signature in some paleo records, including:

- Tree cores
- Corals
- Lake sediments.

3.5 Millennial Cycles (1,000 Years)

http://www.ncdc.noaa.gov/paleo/ctl/cliihis1000a.html

In looking for climate processes and the forces that influence them at periods ranging from 100 to 1,000 years, scientists use weather instrument data with calibrated proxy data from tree rings, ice cores, marine and lake sediments layers, and corals etc as evidence. Climate patterns with possible millennial cycles have been identified though not all of them may remain operational today. It is evident though from paleoclimatic research that there are cycles operating, however the data is sporadic, uncertainty high, resolution low, from various different locations and it is not always possible to date it accurately. For this reason scientists studying climate need to bear in mind the unknowns and uncertainties involved with the data, particularly when attempting to match up records from different types of proxies or different regions.

3.5.1 Insolation

The figure below (Figure 42) is based on a model of solar output, and it shows how these outputs are matched up with actual know climatic events. It is clear that there are millennial scale cyclic patterns occurring and the forcing mechanism appears to be solar output, which reasonably makes sense as the climate system is driven by energy.

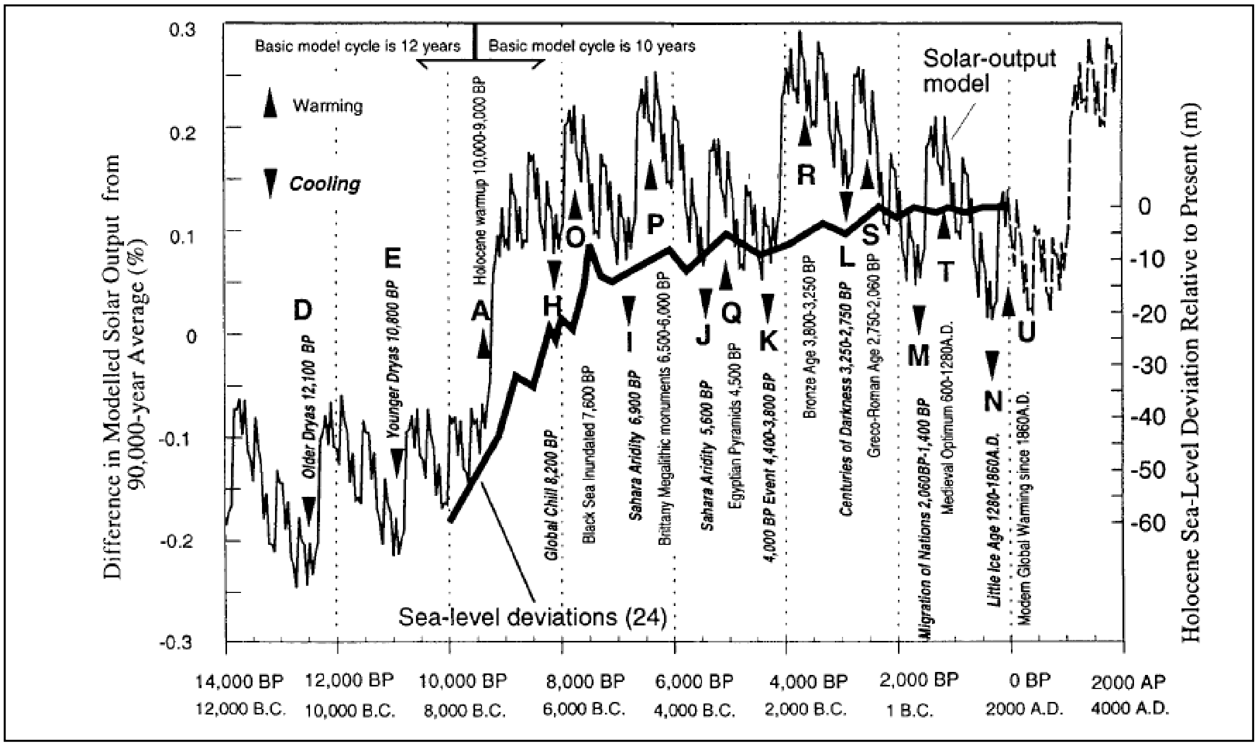


Figure 42: Solar-output model from 14,000 YBP to 2,000 YAP compared with sea-level deviations (24) and selected events (After Perry and Hsu, 2000).

Measures

There are no instrumental records stretching beyond 100's of years. Reliance now moves to proxy data.

Proxies

Proxy records such as

- Tree rings
- Sediment layers
- Ice layers.

In looking for climate processes and the forces that influence them at periods ranging from 100 to 1,000 years, paleoclimatologists splice instrumented data with calibrated proxy data such from tree rings, cores from icecaps, glaciers, marine and lake sediments layers, and corals, and evidence of vegetation change found in pollen samples and packrat middens. These proxies can provide an array of information including temperature, precipitation, chemical composition of air or water, biomass or vegetation, volcanic eruptions and solar activity with varying degrees of accuracy and detail.

3.6 10,000 Year Cycles

To identify long-term cycles of 1,000 years or longer a variety of paleo proxies such as tree rings, ice cores and cored from sediment layers from the ocean or lakes are used. In these data sets it is often possible to see abrupt shifts of less than a decade. Figure 43 shows the amount of ice melting from an ice cap in northern Canada. The graph is indicative of the ice loss which is a proxy for warming that has occurred since the last ice age. The extent of the variability, despite the trend, is significant and indicates that short term changes can be counter to a long term trend and that the changes can happen very quickly. This is particularly evident between 8,500 and 8,000 years before Present (BP) and again in the last 100 years. In the last 100 years has been greater than for almost any period in the last 5,000 years (Dashed line in Figure 43).

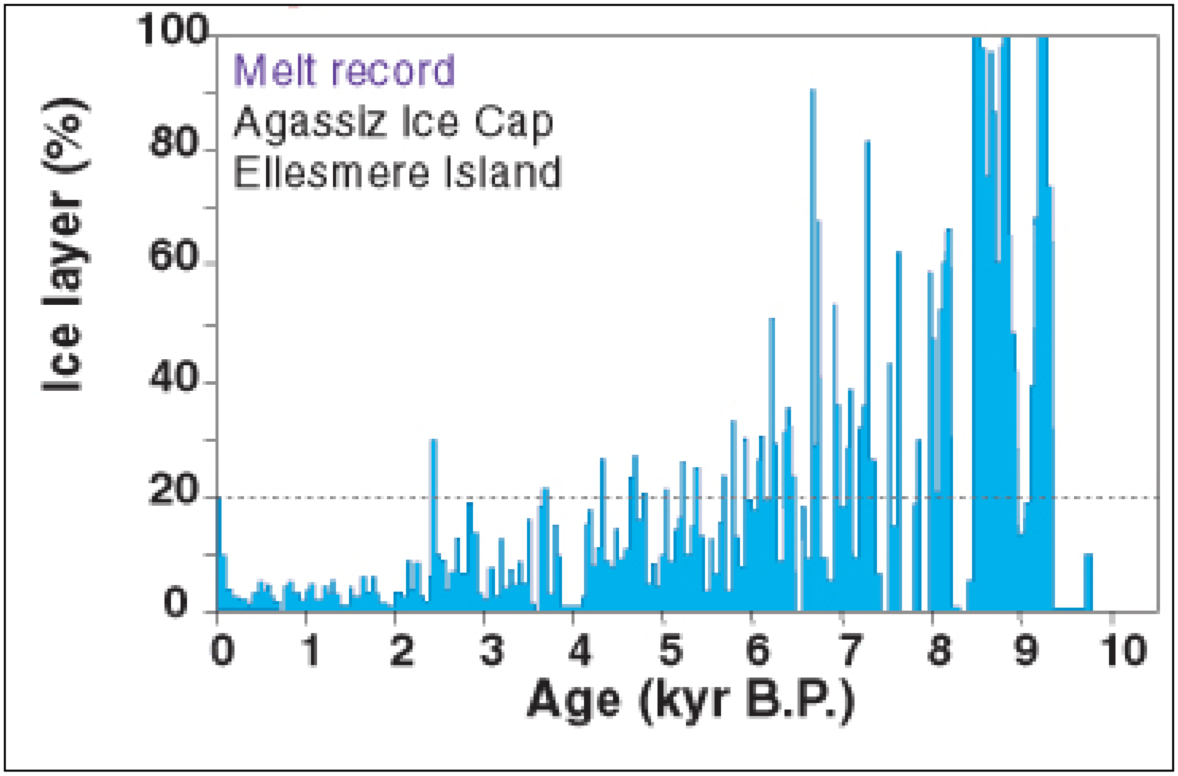
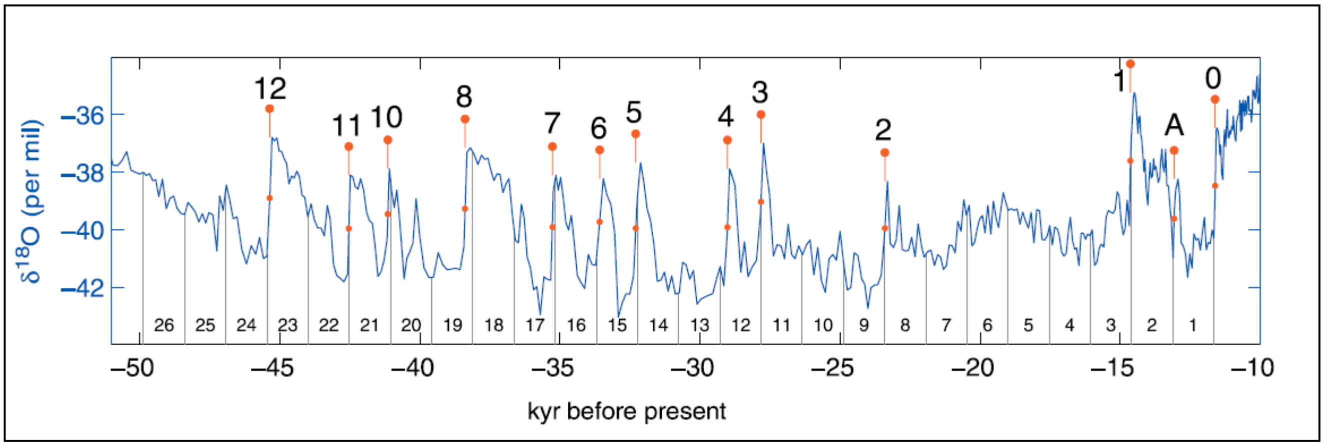


Figure 43: Northern Canadian ice cap melting for the past 10,000 years (CCSP, 2009).

3.6.1 Dansgaard-Oeschger Events

Dansgaard-Oeschger events see a rapid warming of temperature, followed by a cool period lasting a few hundred years (Bond et al, 1999). This cold period sees an expansion of the polar front, with ice floating further south across the North Atlantic Ocean (Bond et al, 1999). Dansgaard-Oeschger events as indicated by ice core $\delta\ ^{18}O$ analysis indicate return periods of close to 1,500 years in length (Ruddiman, 2001). A well described event occurred about 11,500 years ago when average annual Greenland icepack temperatures warmed by about 8°C over 40 years (though temperatures of about 5°C appear more typical. The little ice age of c.400 to 200 years before present has been interpreted as the cold part of a D-O cycle, suggesting we are now in a period of warming climate (Bond et al, 1999). The events are linked to changes in the North Atlantic Ocean circulation, possibly triggered by an influx of fresh water (Bond et al., 1999). The events may be caused by an amplification of solar forcings, cyclic changes in deep ocean currents or "binge-purge" cycles when ice sheets accumulate too much mass and become unstable and collapse.

The solar trigger for this is of important note, as it suggests insolation is key to understanding cyclical nature of climate change. Pronounced solar cycles of 87 and 210 years are known, but a 1,470-year solar cycle has not been detected. However, Braun et al, (2005), using a an intermediate-complexity climate model with glacial climate conditions have simulates rapid climate shifts similar to the Dansgaard–Oeschger events with a spacing of 1,470 years. The basis for the simulation was periodic freshwater input into the North Atlantic Ocean in cycles of 87 and 210 years. They attribute the robust 1,470-year response time to the superposition of the two shorter cycles, together with strongly nonlinear dynamics and the long characteristic timescale of the thermohaline circulation. They conclude that the glacial 1,470-year climate cycles could have been triggered by solar forcing despite the absence of a 1,470-year solar cycle.



After Rahmstorf, 2003.

Figure 44: The GISP2 Climate record for the second half of the last glacial. Dansgaard-Oeschger warming events are labelled with red flags. The grey vertical lines show 1,470-year spacing, small numbers at the bottom count the number of 1,470-year periods from DO event 0.

3.6.2 Heinrich Events

Ice rafting during very short intense cold periods are known as Heinrich Events, and are associated with cold (3-6 degrees lower than normal glacial temperatures) and arid conditions (Adams et al.). During warm periods, debris from rocks are carried by rafts of ice into the North Atlantic, which then melt and deposit the debris in ocean sediments. During colder periods, debris is absent in sediments allowing warm and cold periods to be identified. The Heinrich events have an abrupt onset and last for about 750 years. By comparing the $\delta^{18}O$ ice core record with analysis of sediment cores from the North Atlantic, repeated cycles of slowly developing glacial conditions followed by abrupt shifts back to warmer conditions are evident. The repeating cyclic nature of these events is important as it suggests a forcing mechanism that is linked to insolation. Heinrich events only occur in the cold spells immediately preceding Dansgaard-Oeschger events, leading to suggestions that they are linked (Bond & Lotti 1995).

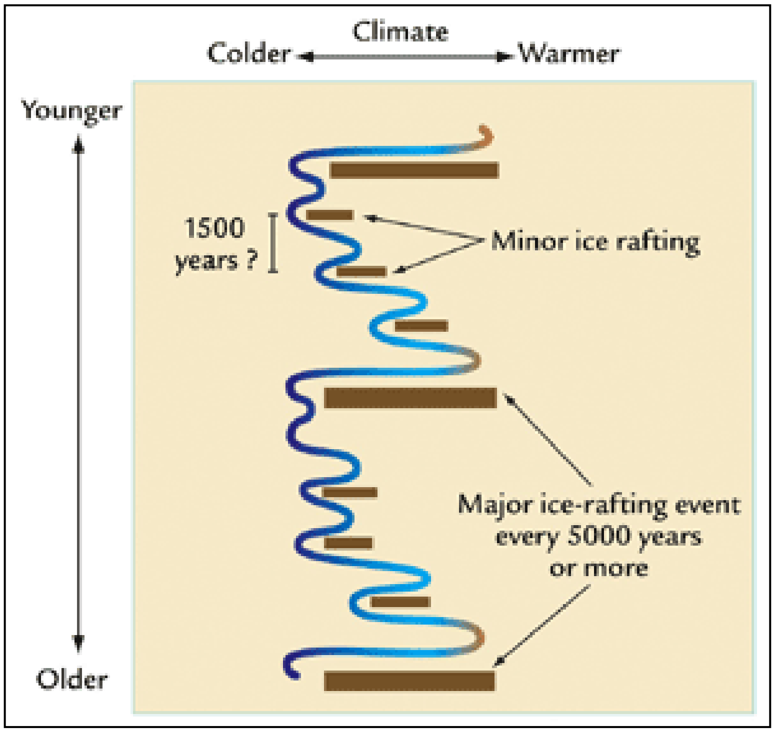


Image from Ruddiman, Earth's Climate: past and future; 2001

Figure 45: Major and minor ice rafting events in the North Atlantic (After Ruddiman; 2001).

3.6.3 Sporadic Events

An influx of freshwater into the Atlantic 8,200 years ago from large lakes in northern Canada may have triggered the coldest climate event for the past 10,000 years Baldini (2002); Von Grafenstein (1998). It is thought this 400 year period of cooling was started by two gigantic glacial lakes in Canada's Hudson Bay region broke some 8,200 years ago when an ice dam from a remnant of the Laurentide Ice Sheet collapsed (Barber, et. al.1999). The flow of cold fresh lake water rushing through the Hudson Strait and into the Labrador Sea is estimated to have been about 15 times greater than the current discharge of the Amazon River. This would have altered the thermohaline circulations of the ocean and altered temperatures warmed by normal currents. These events are also found in the proxy record and can lead to obscuring of the cycles, making for difficult long term trend tracking and use in prediction.

3.6.4 Orbital Forcing

In the mid Holocene, approximately 7,000 to 5,000 years ago, temperatures appear to have been warmer than today. Specifically, temperatures were generally warmer, only in the northern hemisphere summer and are linked to changes in the Earth's orbit. This suggests that there are changes in the amount of solar radiation reaching each latitudinal band of the Earth during each month. Long term cyclical orbital changes can be calculated, and what they indicate is that the northern hemisphere summer would have been warmer and winters cooler than present. Again the key influence of the sun is evident.

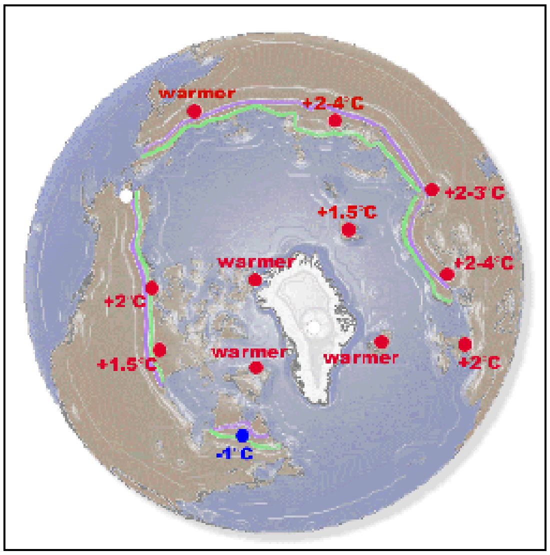


Figure 46: Northern hemisphere summer temperature changes during the Mid-Holocene.

Measures

There are no instrumental records stretching beyond 100's of years. Reliance is on proxy data.

Proxies

Scientists examining climate variability of 1,000 years or more have come to rely on studying the δO^{18} values taken from ice cores and the shells of planktonic foraminifera from marine sediments. The sediments also reveal lithics (rock particles) and dust that offer additional clues of the climate variations thousands of years ago.

3.7 100,000 Year Cycles

Although going beyond the period of interest in this study, it is important to understand that there are cycles happening at the 100,000 year time scale and beyond. Scientists have resolved multi-millennial scale orbital cycles of precession, eccentricity, and obliquity (Described in detail in Section 3) which can play an important role in the rise and fall of ice ages and were first described in detail by Milankovitch. These orbital forces include the 22,000 year cycle of precession, 100,000 and 400,000 cycles of eccentricity, and 41,000-year cycles of Earth's obliquity or axial tilt.

Due to variations in the Earth's orbit, the planet has experienced a series of Ice Ages over the past 2.6 million years. The most recent cycle ended in the Last Glacial Maximum some 18,000 years ago. The northern hemisphere in particular had large tracts covered by ice, nearly 32% of the Earth's land area was covered by ice and sea level was about 120 meters lower than it is today (Ruddiman, 2001). The ice ages are primarily caused by orbital fluctuations that result in a few percent change in the sunlight received yet this now appears to have a significant impact on climate systems.

3.7.1 Insolation and Global Temperature and Sea Levels

Sea level and temperature provides useful proxies of the variations in insolation cycles as determined by orbital variations. Indeed variations in these proxies match the cycles that Milankovitch suggested would be apparent based on orbital variation.

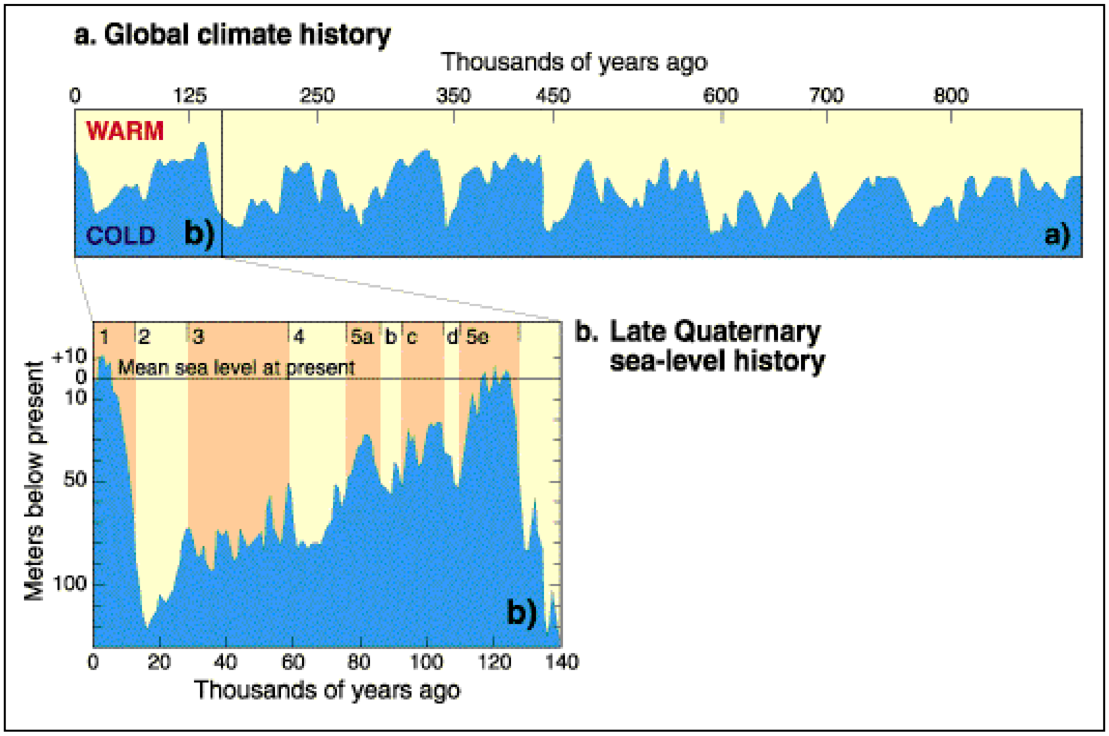


Figure 47: Relative temperature over the past million years and sea level change over the past 140,000 years.

3.7.2 Insolation and Global Ice Volume

When the data for solar insolation and global ice volume over the past 400,000 years are analysed, it is apparent that they fluctuate at the same major frequencies of the:

- Precession cycle of 23,000 and 19,000 years
- Obliquity cycle of 41,000 years
- Eccentricity cycle of 100,000 years
- Eccentricity cycle at 400,000 years cannot be confirmed as data does not extend back far enough.

Importantly, the Milankovitch theory predicts that changes in eccentricity have a smaller effect on climate than variations in precession and obliquity even though climatic records from across the globe suggest that ice sheets have advanced and retreated to a 100,000 cycle. Within this context significant climate changes can be expected to occur on the smaller cycles and this is what was evident in Figure 48and Figure 49 .

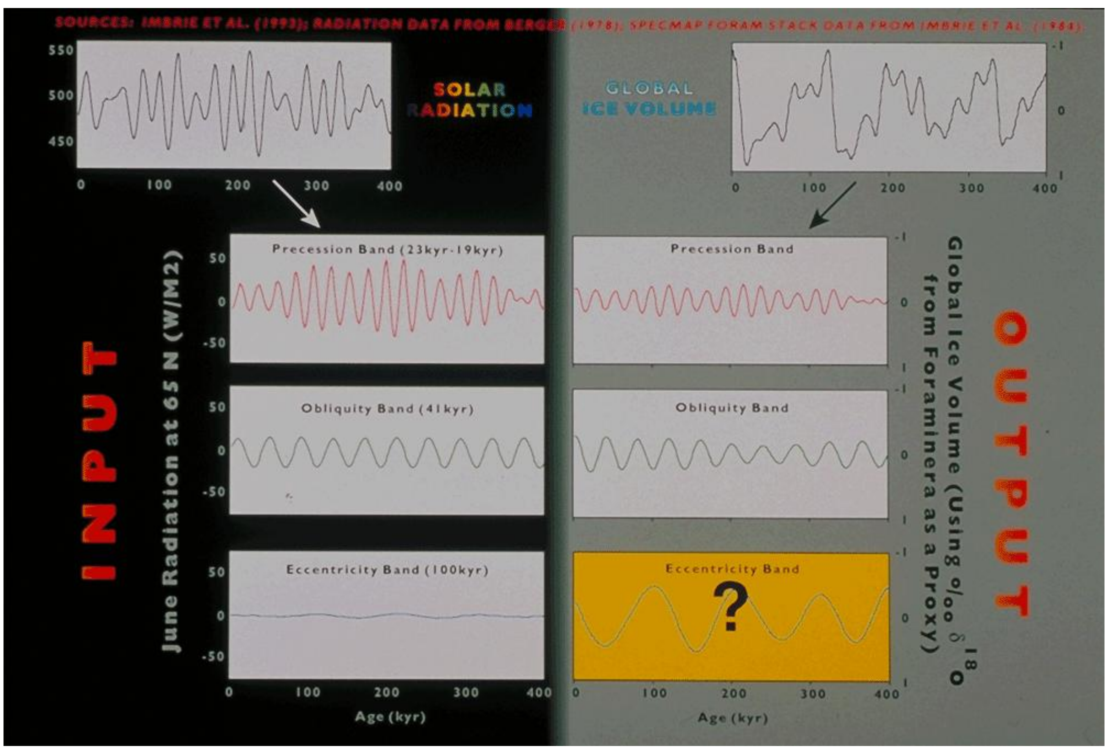


Figure 48: Solar Insolation and Global Ice Volume over the Past 400,000 Years.

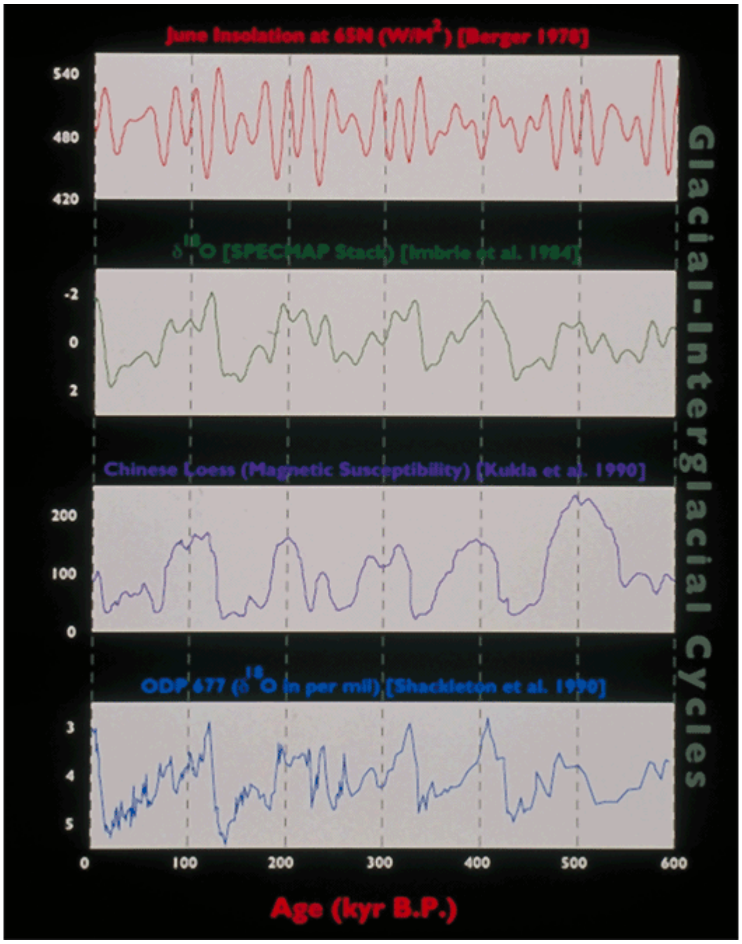


Figure 49: Insolation and Quaternary Climatic records reveal Milankovitch Cycles.

Measures

Proxies from marine sediments, geomorphic features and astronomical observations and calculations provide the means of reconstructing past climate variability at 100,000 year and longer time scales.

4 Forcing and Amplification Mechanisms

Based on the previous section it is apparent that there are a range of mechanisms that can be held responsible for the determination of the climate that is experienced on earth. If the cyclical nature of these events is understood it is possible to determine how future climate will respond to these influences. Some of these forcing mechanisms are external to the planet, like the sun, and some are a result of earth based phenomena such as volcanoes. Of all of these the most important forcing mechanism for our climate appears to be the sun. Indirectly the earth's orbit causes variations in the energy received from the sun and the sun itself shows cyclical variations in its output. Factors that can affect the amount of solar radiation reaching the earth include:

- Atmospheric Trace Gases: Greenhouse gases such as carbon dioxide and methane which absorb infrared radiation resulting in greenhouse gas warming
- Orbital Variations: 22,000 year cycle of precession, 100,000 and 400,000 cycles of eccentricity, and 41,000-year cycles of Earth's obliquity or axial tilt
- Solar Variability: The energy output from the sun varies over time with a clear cyclical pattern evident. Lower energy output from the sun means lower energy receipt on earth
- Volcanic Aerosols: Increase the earth's albedo (reflectivity) and cool the climate
- Tropospheric Aerosols: Affect the formation of clouds, increase the albedo and cool the climate.

The first three key factors are discussed in more detail below.

4.1 Greenhouse Gases

Although "greenhouse gases" are frequently held responsible for "global warming", this is somewhat misleading as they on their own cannot create energy to change climate, but only trap energy in the system. In this sense increasing greenhouse gas concentration is seen as an amplifier of the major forcing mechanism which in all likelihood is insolation derived from orbital variation or solar output variation. As an amplification mechanism, a small increase in the input (insolation) or the amount of amplifier (greenhouse gases) could translate to relatively significant increases in the temperatures experienced on earth. Similarly, a small drop in insolation on a strongly amplified signal could lead to a relatively abrupt and steep drop off in the temperature. As amplification of these input variations is considerable, the significant role of greenhouse gases should therefore not be underestimated.

Managing of greenhouse gases and the finding of mechanisms to produce clean energy is a key assumption in this report. It is assumed that greenhouse gases will be managed and that they will have a reduced influence on future climate and that the other forcing mechanisms are therefore likely to play a more dominant role in a future climate scenario. Indeed several scientists have started to speculate that it may be possible to moderate potential future climate cooling by releasing, in particular, carbon dioxide in the future. IPCC predictions for the next 100 years are largely based on greenhouse gas influence in global circulation models. The importance of managing fuel use, energy consumption and emissions remains a priority as it is the basis of good stewardship at a time when it is evident that climate change is occurring and there is not absolute certainty how all the various forcing mechanisms are working together.

4.2 Milankovitch Cycles

4.2.1 Precession of the Earth's Orbit (22,000 Year Cycle)

The earth's orbit wobbles so that over the 22,000 to 23,000 years of a precessional cycle, the North Pole traces a circle in space. This wobble causes the precession of the equinoxes. Precession changes the date at which the earth reaches its perihelion the point in the wobble when the earth is closest to the sun and in so doing serving to amplify or dampen seasonal climatic variability. If the perihelion is reached in the middle of winter then the winters will be mild and if it occurs in the middle of summer then the summers will be hotter. The earth currently reaches its perihelion on January 3, close to the Northern Hemisphere's winter solstice reducing seasonal differences in insolation and creating relatively warmer winters. This means the earth is further away from the sun and relatively cooler during the Northern Hemisphere's summer, reaching its aphelion on July 5. However, 11,000 years ago, the reverse was true: the earth reached its perihelion during the northern summer, increasing the seasonal variability of earth's climate. Since this time the earth has gone through the Holocene warmup as the wobble has brought the perihelion to coincide with winter. It can be inferred that we are therefore now starting on a cooling trend towards another ice age where the summers will be warmer and the winters colder and the seasonal variation in insolation greater. Under these circumstances the winter ice will grow thicker and last longer into the summer and potentially start to build up if there is enough albedo effect to offset the warmer summers. This would be a slower process than the warming and melting of the ice caps as we are witnessing currently and would fit in well with the observed slow glacial formation and abrupt warming saw tooth graphs presented in the previous section. The information in this section is largely adapted from Pisias and Imbrie (1986/1987).

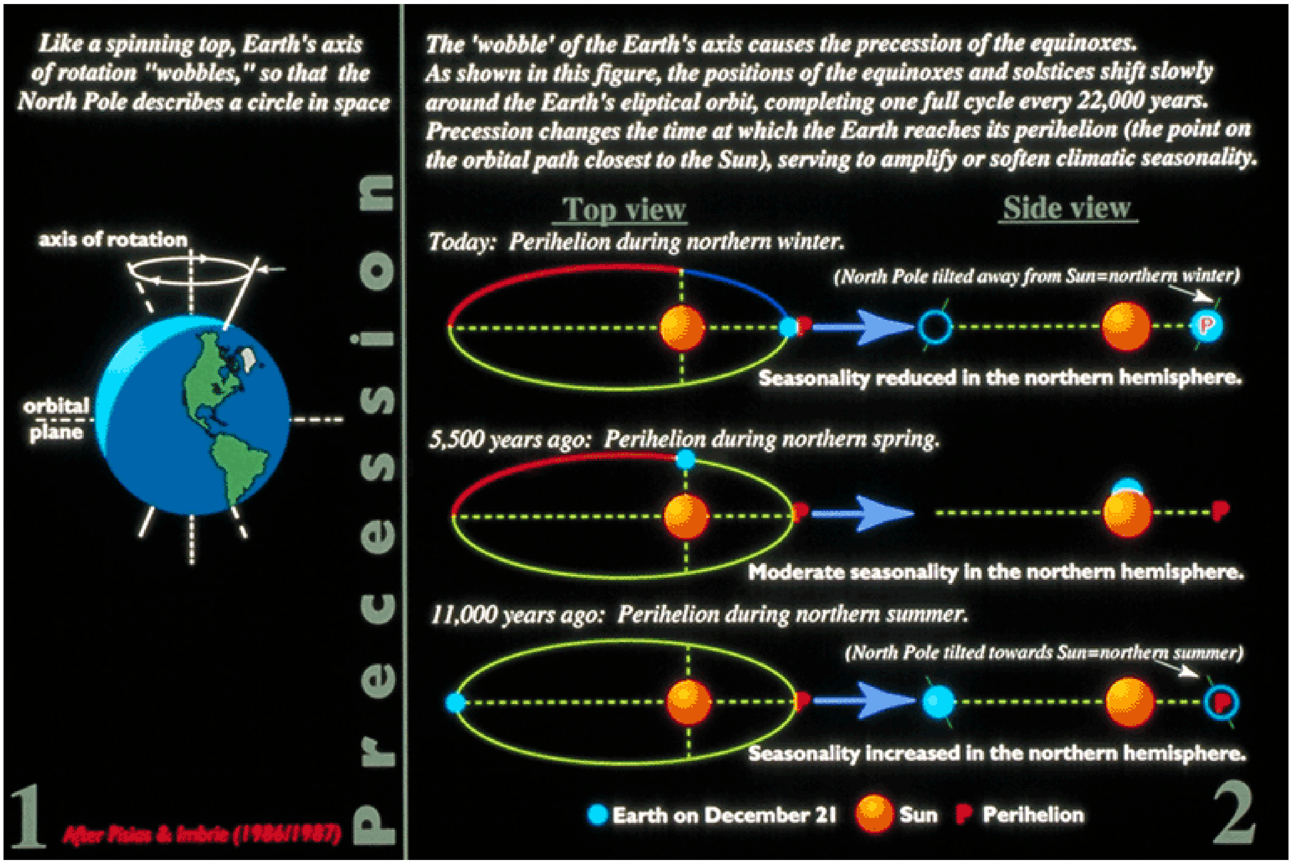


Figure 50: The earth's precession cycle of 22,000 years (After Pisias and Imbrie 1986/1987).

4.2.2 Earth's Axial Tilt (41,000 Year Cycle)

Adapted from Pisias and Imbrie [1986/1987]

The obliquity of earth's axis varies over the course of a 41,000-year cycle during which the earth's axial tilt varies from 24.5 degrees to 22.1 degrees. Changes in axial tilt affect the distribution of insolation received at the earth's surface. When the angle of tilt is low, polar regions receive less insolation and when high they receive more insolation during the course of a year. This in effect influences the relative strength of the seasons and are particularly pronounced in the high latitudes where the great ice ages began.

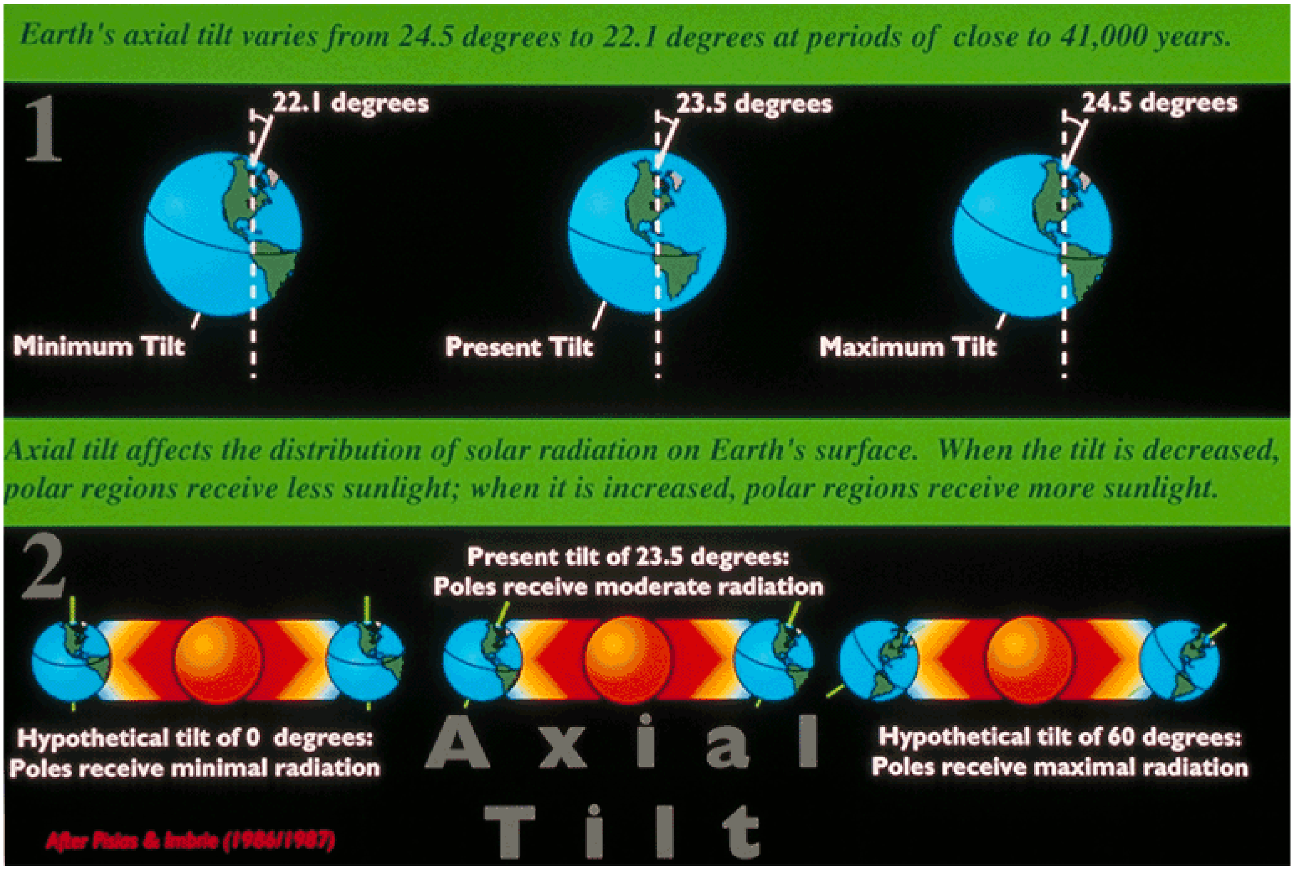


Figure 51: The earth's axial tilt or obliquity cycle of 41,000 years (After Pisias and Imbrie 1986/1987).

4.2.3 Earth's Eccentricity (100,000 and 400,000 Year Cycle)

Adapted from Pisias and Imbrie [1986/1987].

The shape of earth's orbit changes slowly but consistently over time from nearly circular (eccentricity approaching 0.00) to more elliptical (eccentricity=0.06). These variations occur at a frequency of 100,000 years and 400,000 years. Variations in orbital eccentricity have a small impact on insolation at the top of earth's atmosphere roughly 0.1%. Eccentricity and precession can work together either to enhance or modulate insolation. During periods of high eccentricity (elliptical orbit), the effect of precession on the seasonal cycle is strong, whereas when eccentricity is low (more circular), the effect of precession on the seasonal cycle is weak as all points on the orbit are the same distance from the sun.

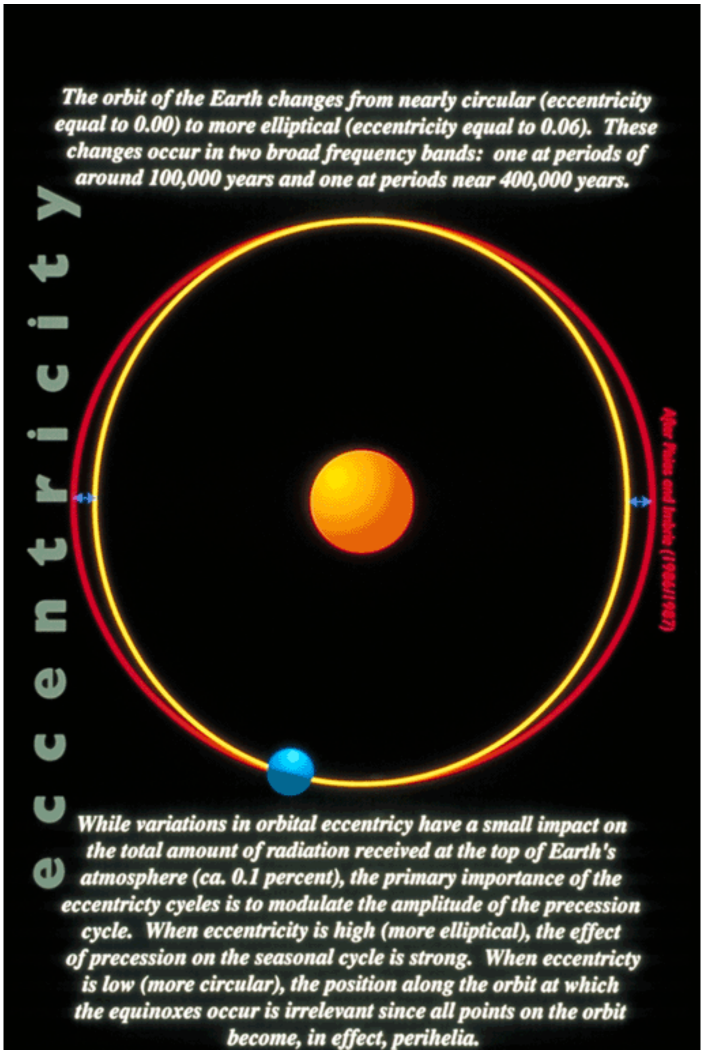


Figure 52: The earth's eccentricity cycle of 100,000 and 400,000 years (After Pisias and Imbrie 1986/1987).

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.

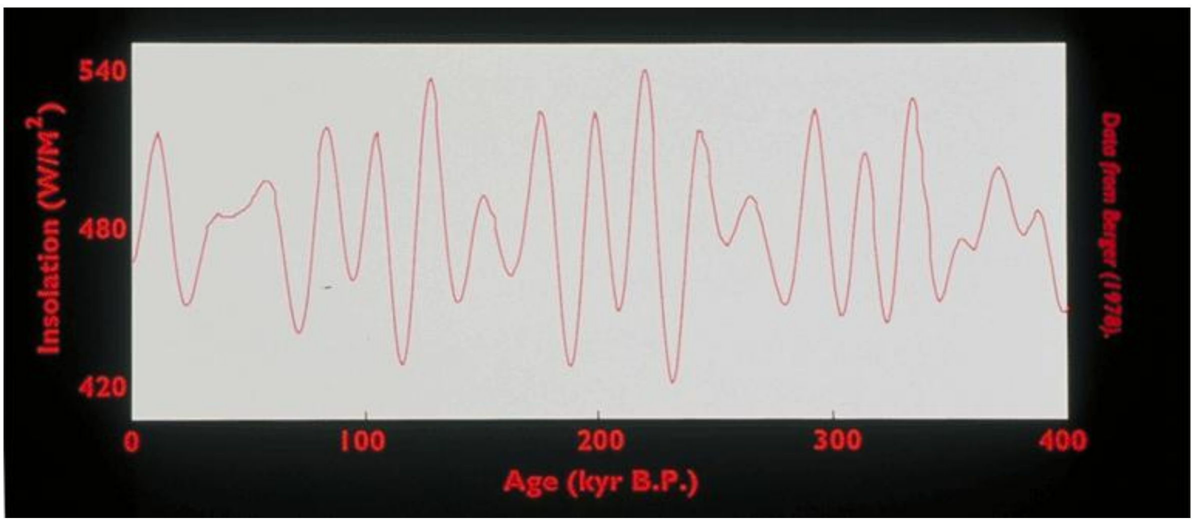


Figure 53: Summer insolation curve for 65°N demonstrates how variations in precession, eccentricity and tilt have affected the amount of solar radiation reaching the surface of the earth.

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).

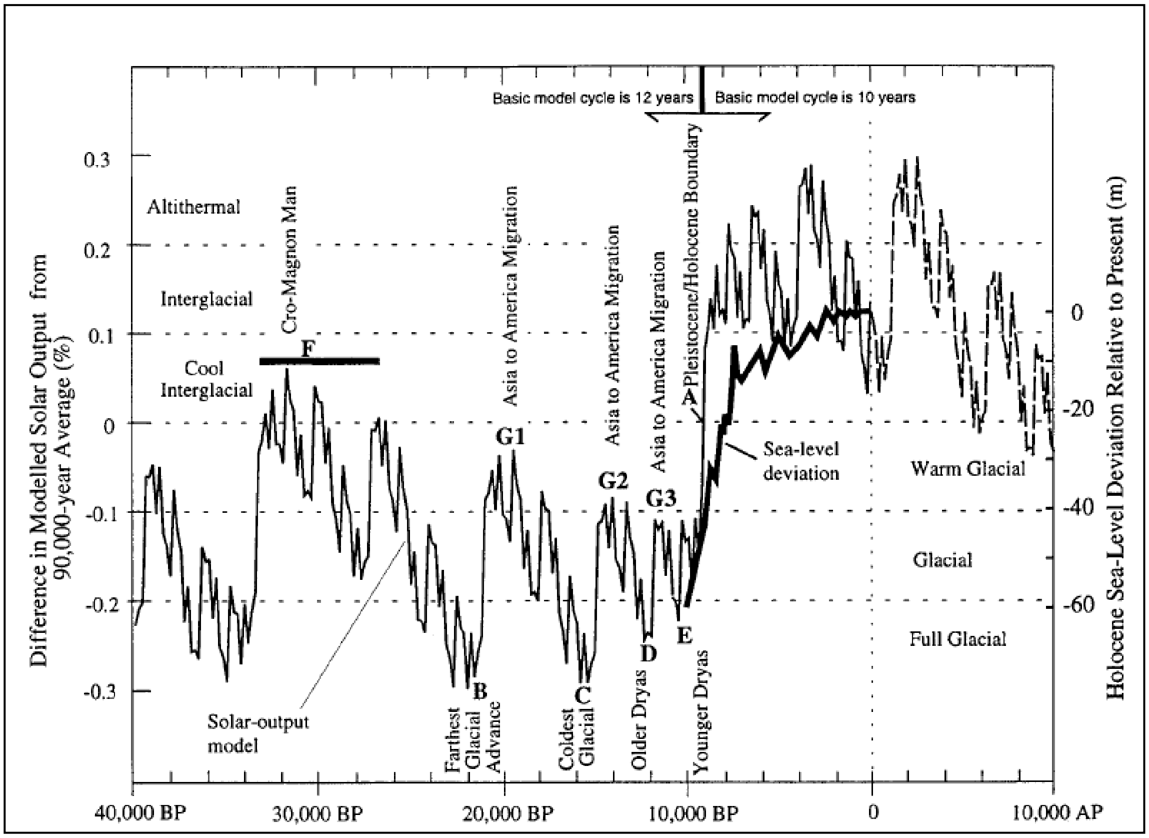


Figure 54: Modeled solar output (Luminosity) from 40,000 YBP to 10,000 Y AP compared with glacial, sea-Level-deviation (24), and archaeological information during the Late Pleistocene and Holocene (after Perry and Hsu, 2000).

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.

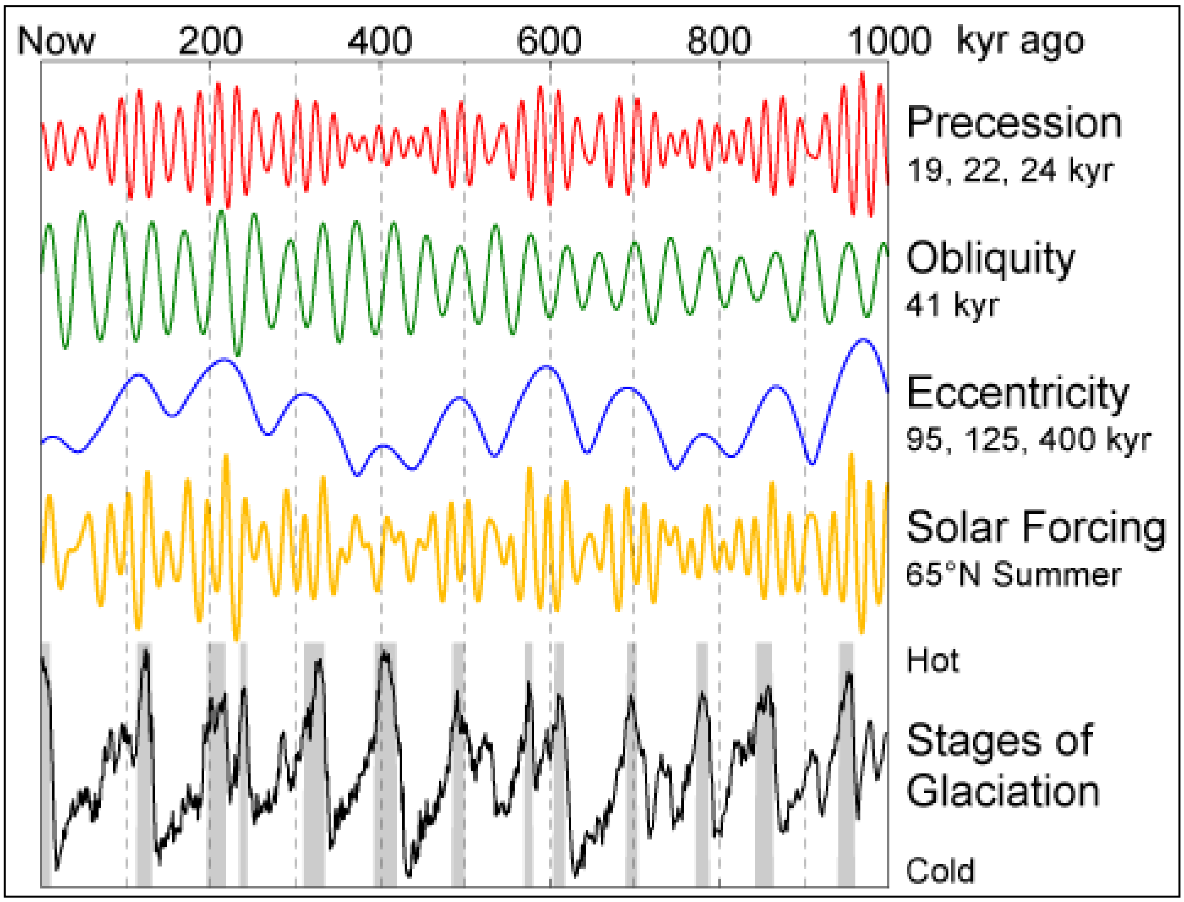


Figure 55: Variations in earth's orbit, the resulting changes in solar energy flux at high latitude, and the observed glacial cycles (Global Warming Art, 2006).

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.

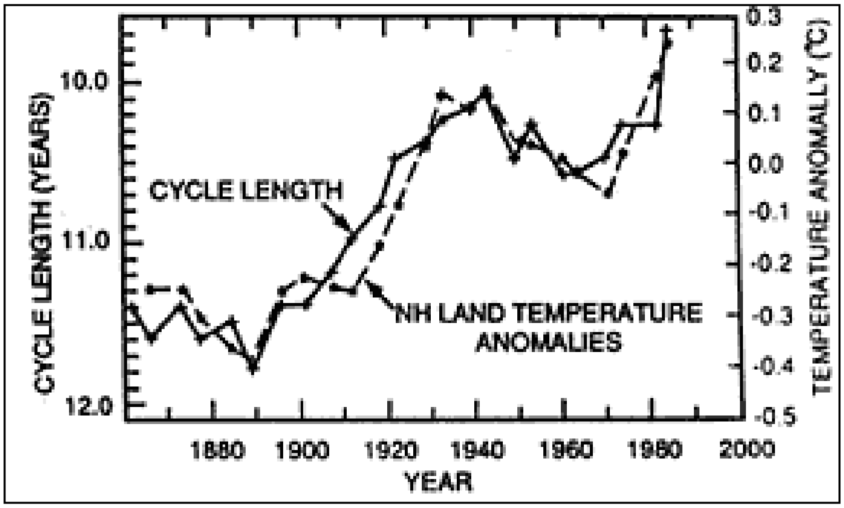


Figure 57: Comparisons of globally averaged temperature and solar activity the northern hemisphere land temperatures are plotted with the solar cycle length (Friss-Christensen and Lassen; 1991) (After NOAA SEC).

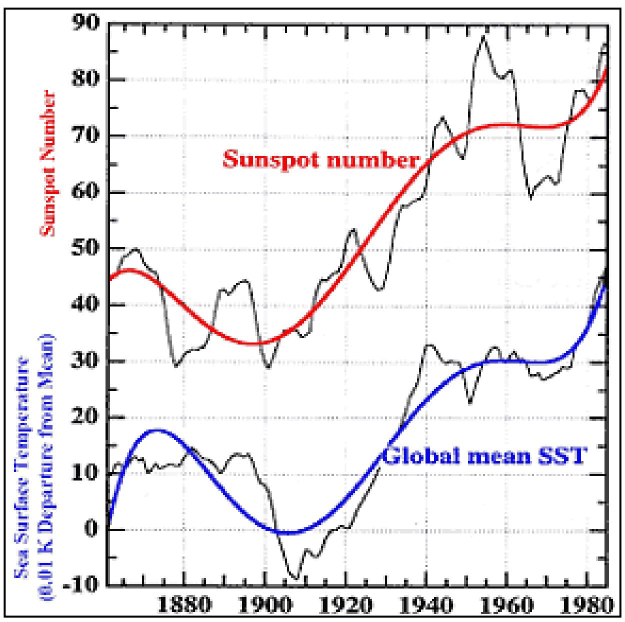


Figure 58: The globally averaged sea surface temperatures are plotted with the sunspot numbers (Reid; 1999) (After NOAA SEC).

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.

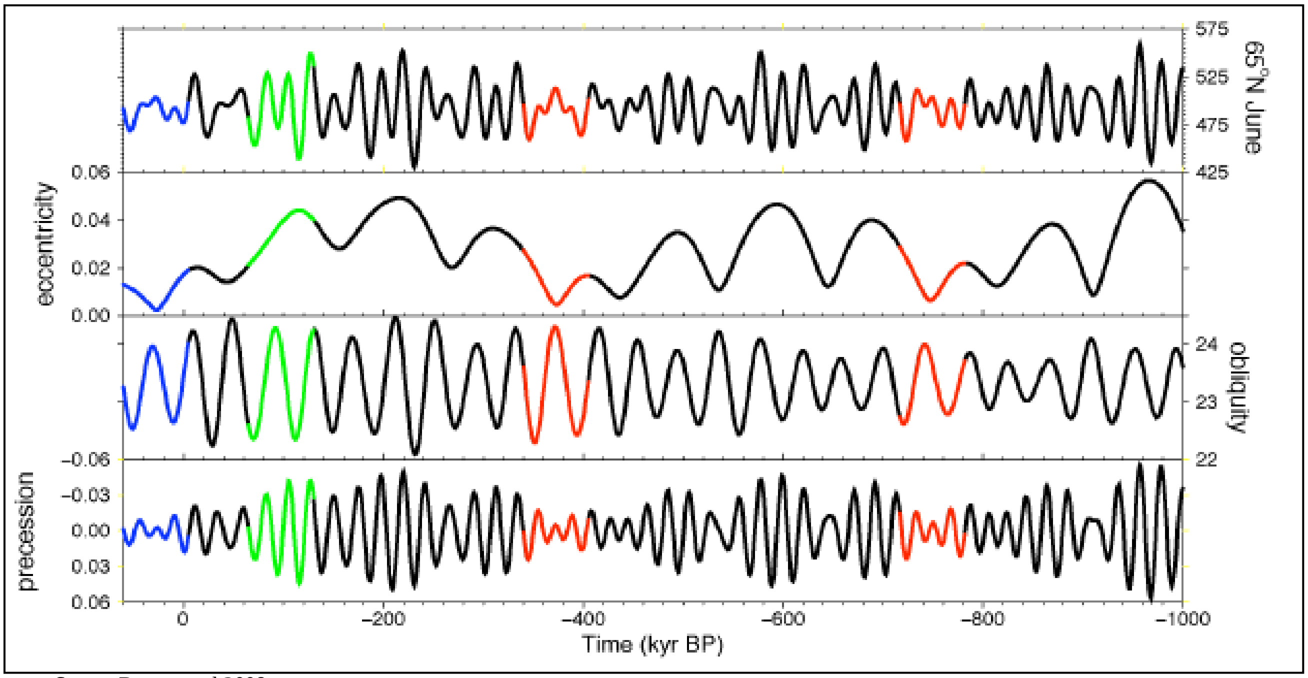
5.2 Predictions from Models and Monitoring Groups

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

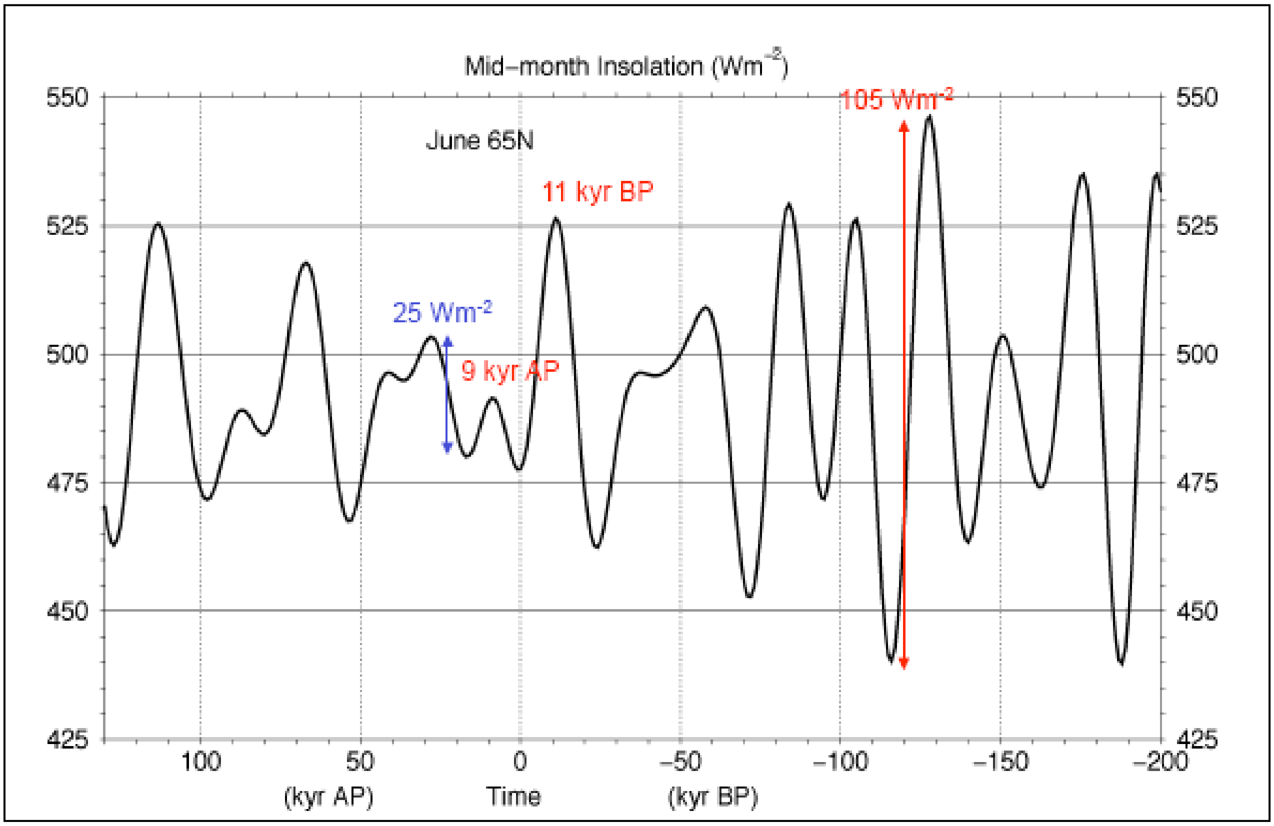
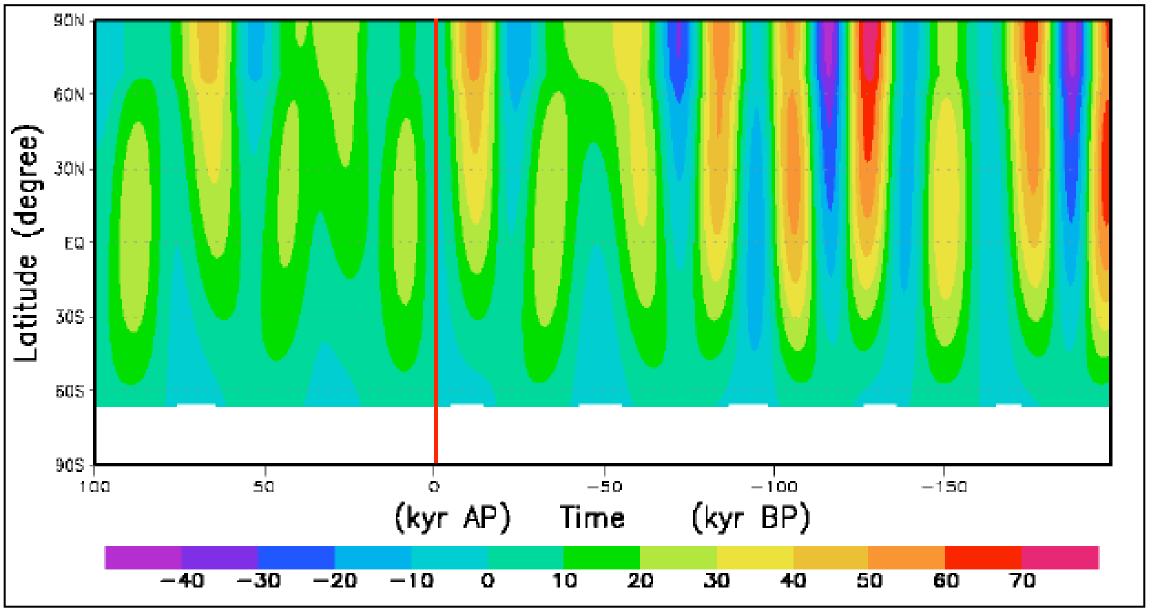


Figure 60: Monthly insolation predictions for 65°N.

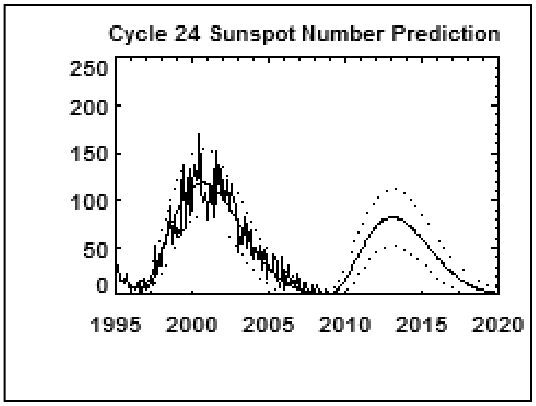


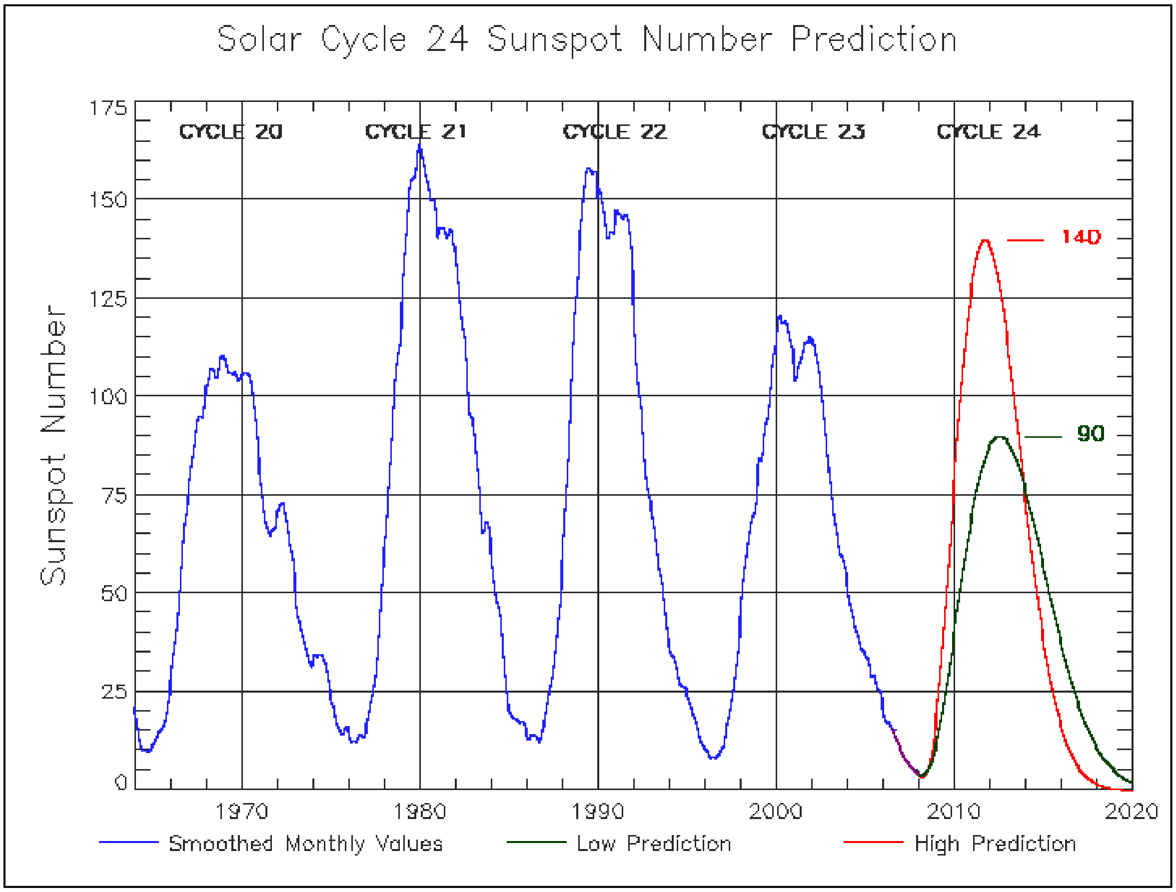
Source Berger et al 2008

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

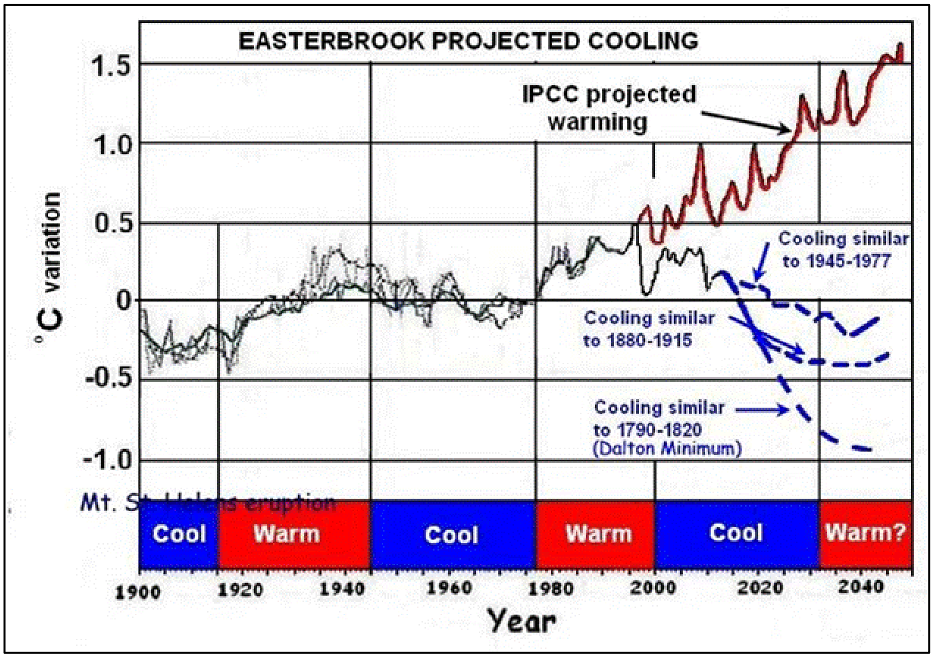
Analysis of the past (1931-1999) PDO shows that warm phase winters tend to be associated with warmer and drier conditions than average, while cool phase winters tend to be cooler and wetter than average. PDO's typically last between 20 -30 years. The largest differences occur in the fall, winter and 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.

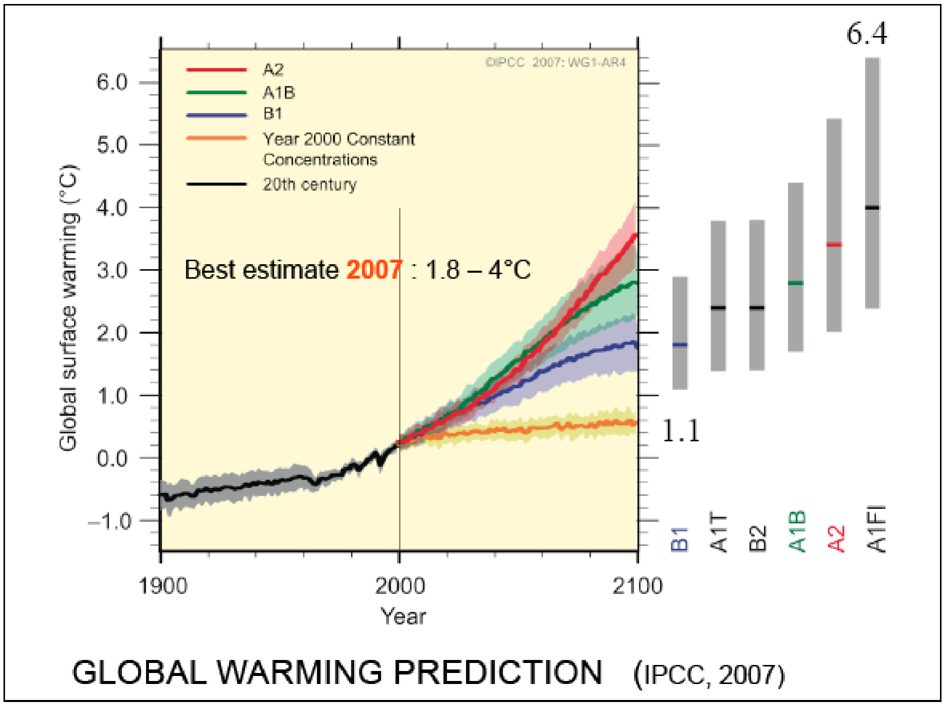


Figure 64: IPCC global warming predictions from AR4.

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).

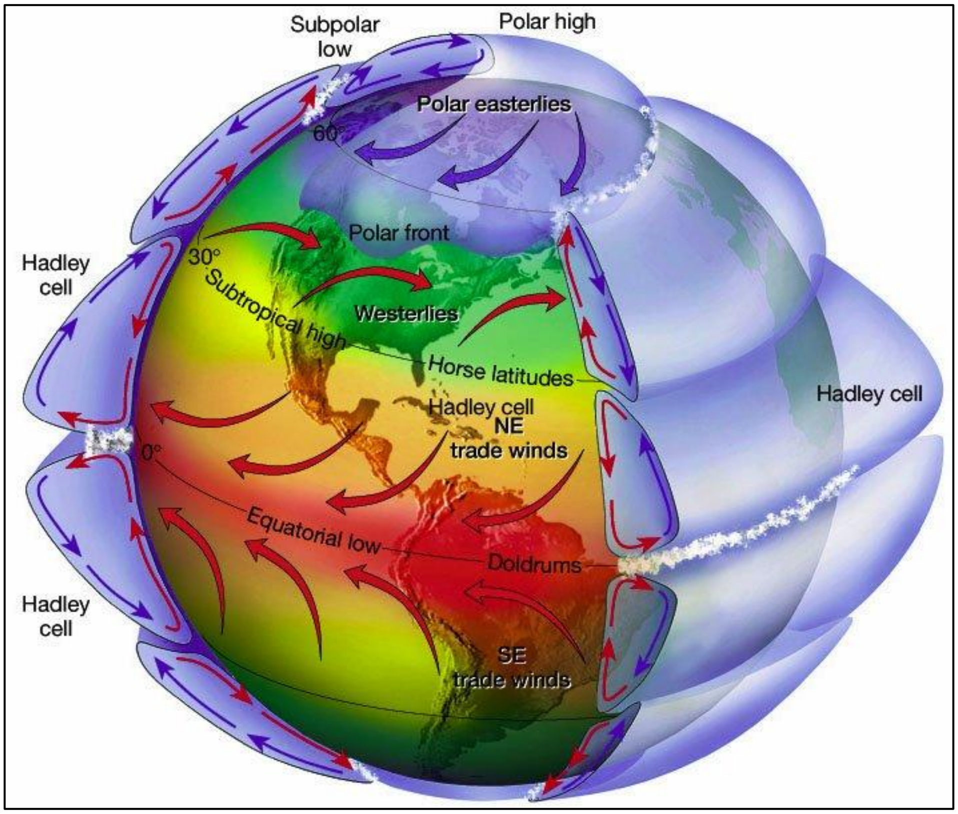


Figure 65: Earths general circulation.

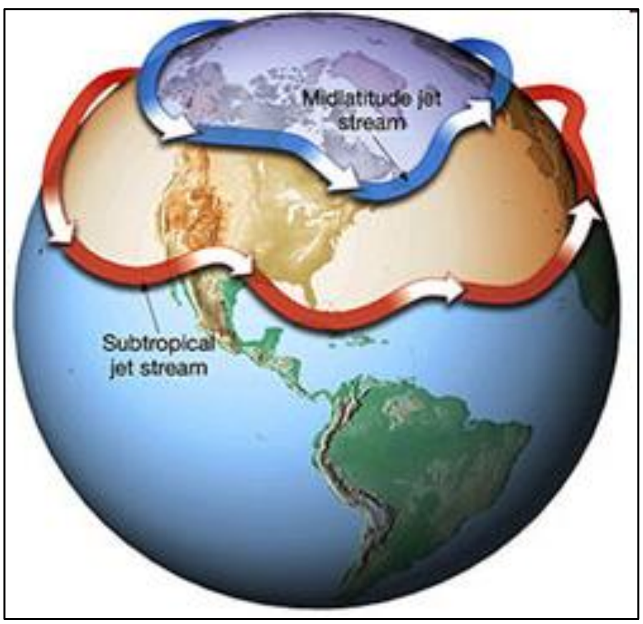


Figure 66: Direction of flow and general position of the mid-latitude jet.

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.

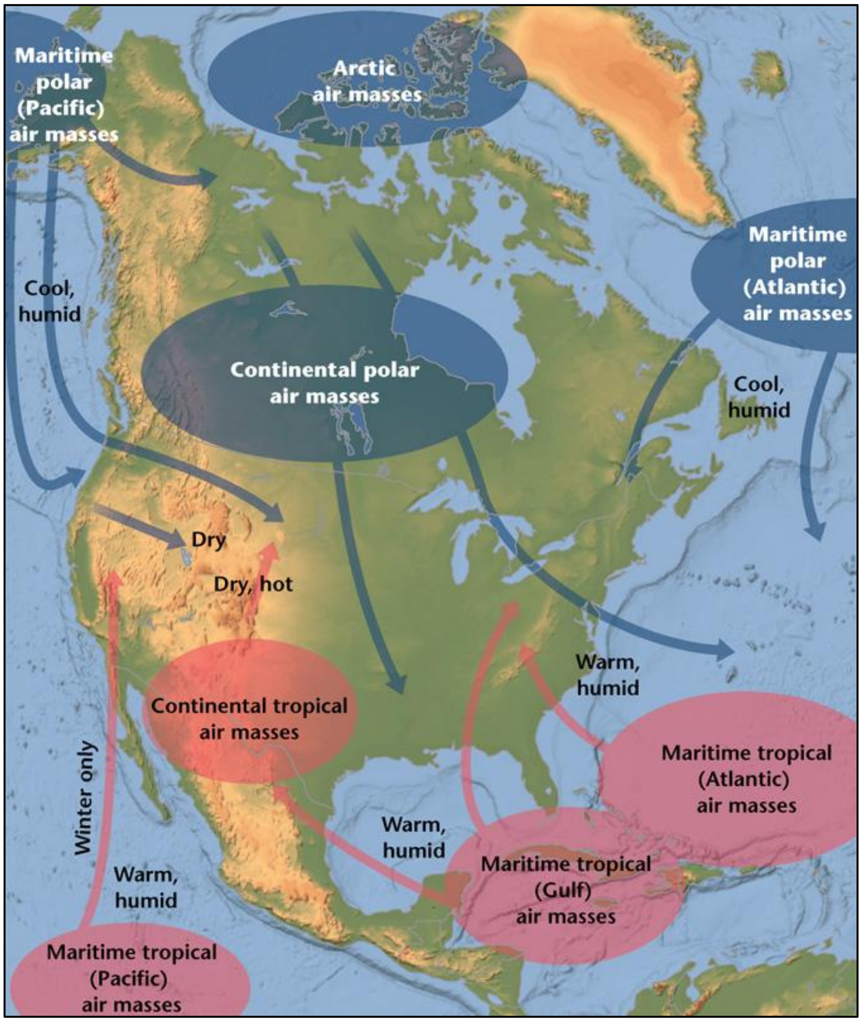


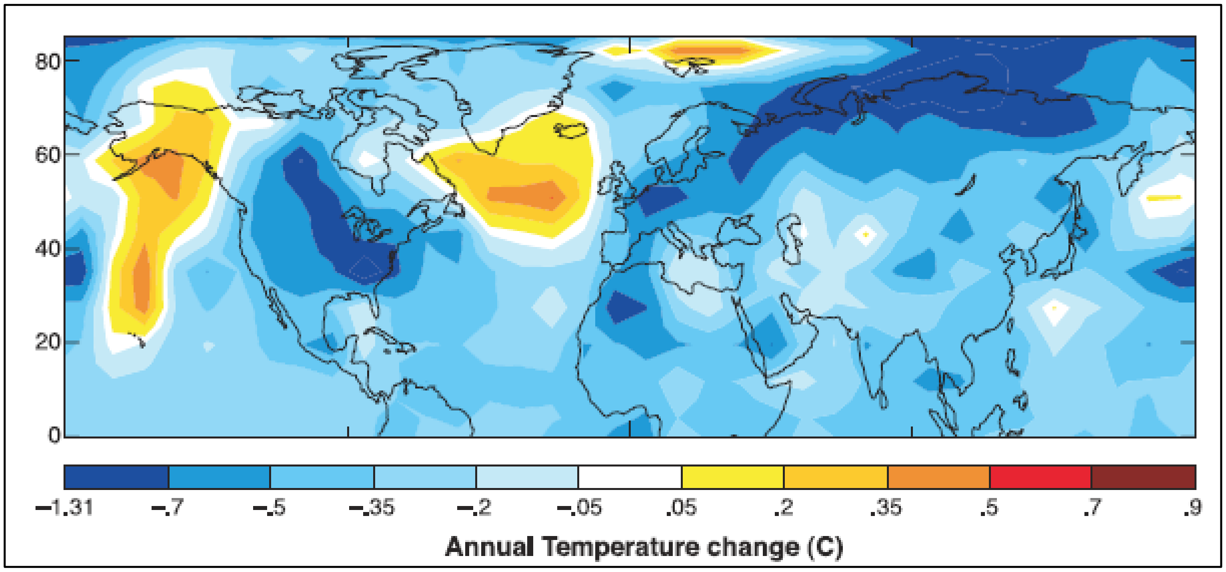
Figure 67: Main air masses affecting weather over Canada.

- 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.

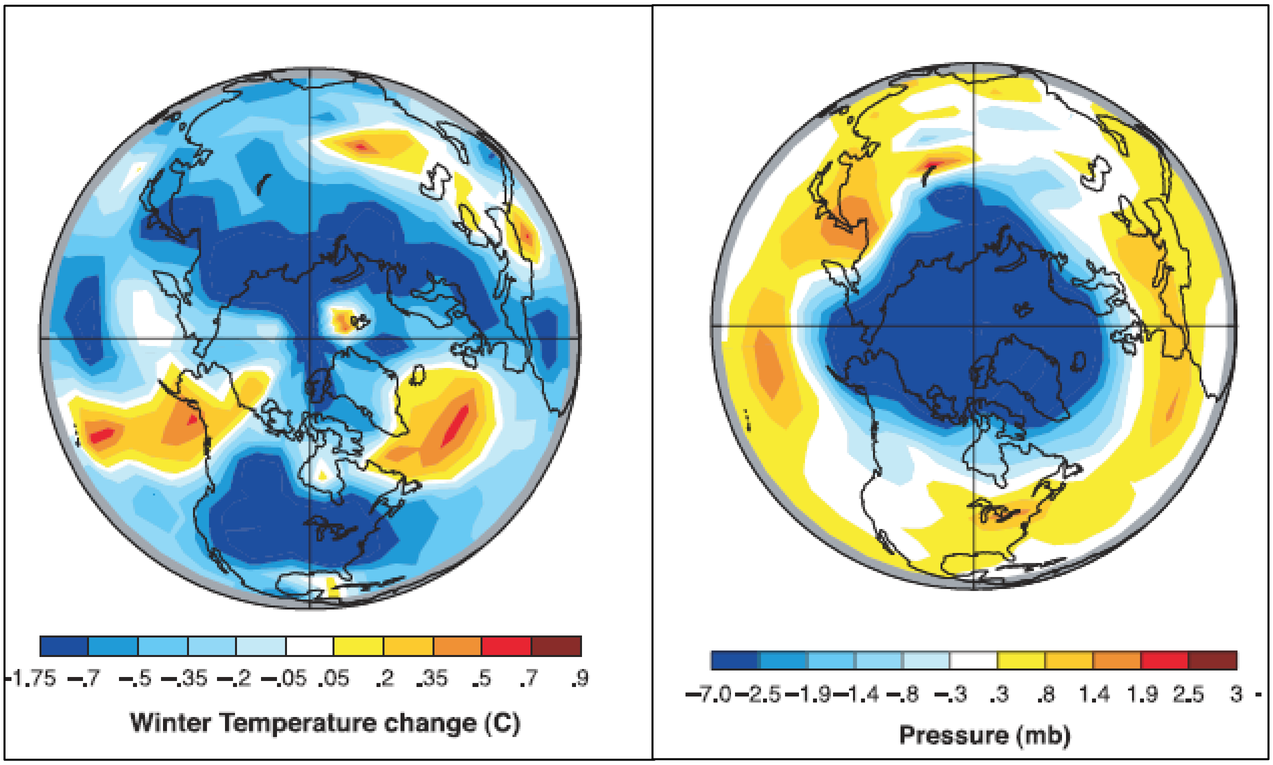
5.6.2 Climatology of the Past

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.

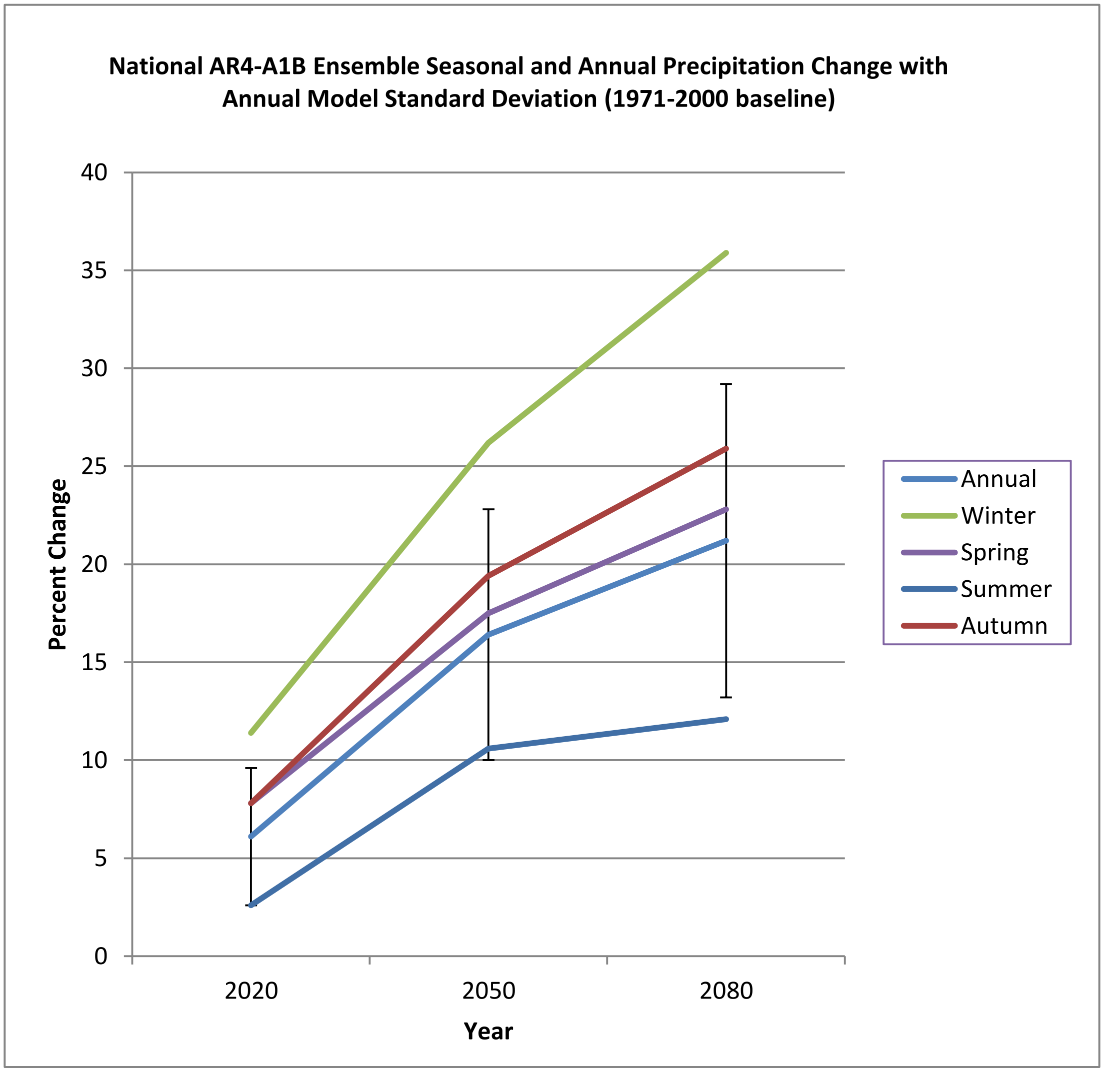


Figure 70: CCCSN AR4-A1B Ensemble Seasonal and Annual Precipitation Change for Canada.

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.

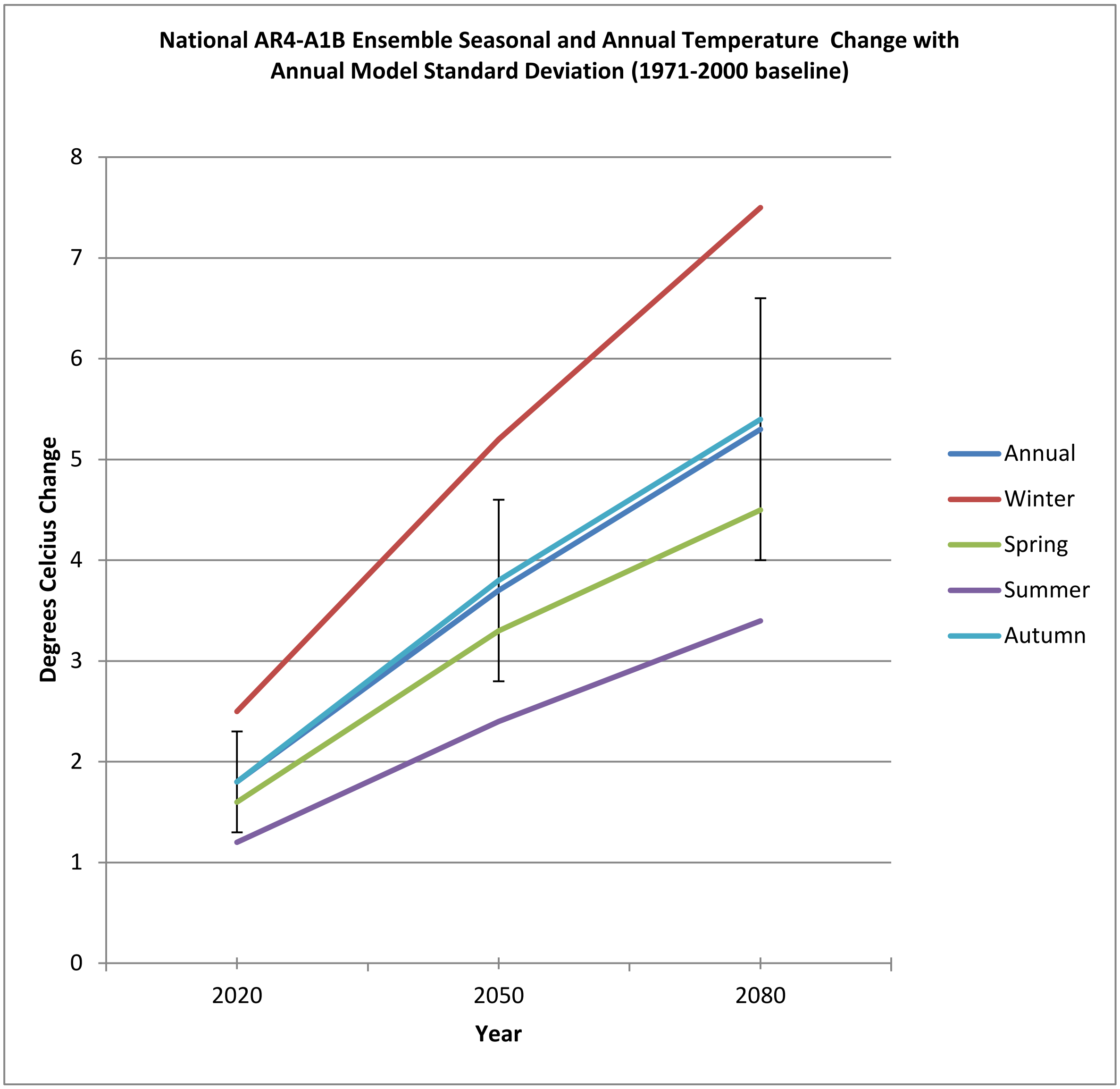


Figure 71: CCCSN AR4-A1B Ensemble Seasonal and Annual Temperature Change for Canada.

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.

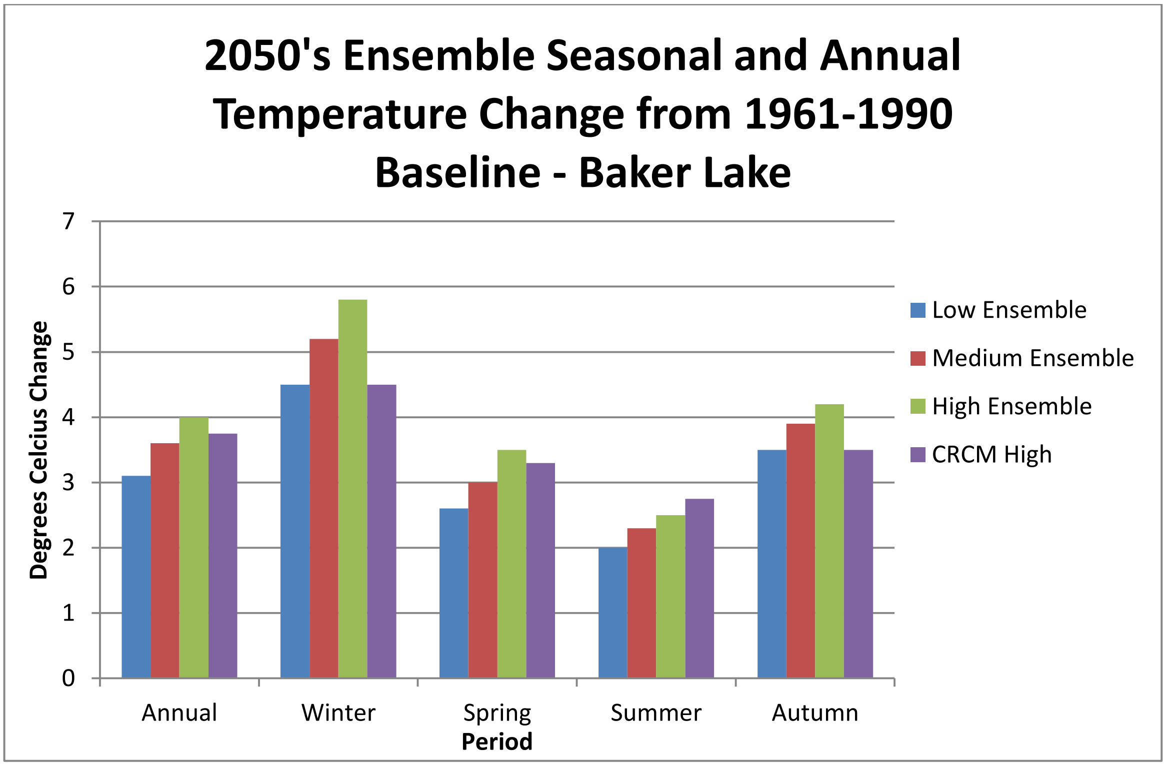


Figure 72: CCSN temperature change predictions for Baker Lake for 2050`s.

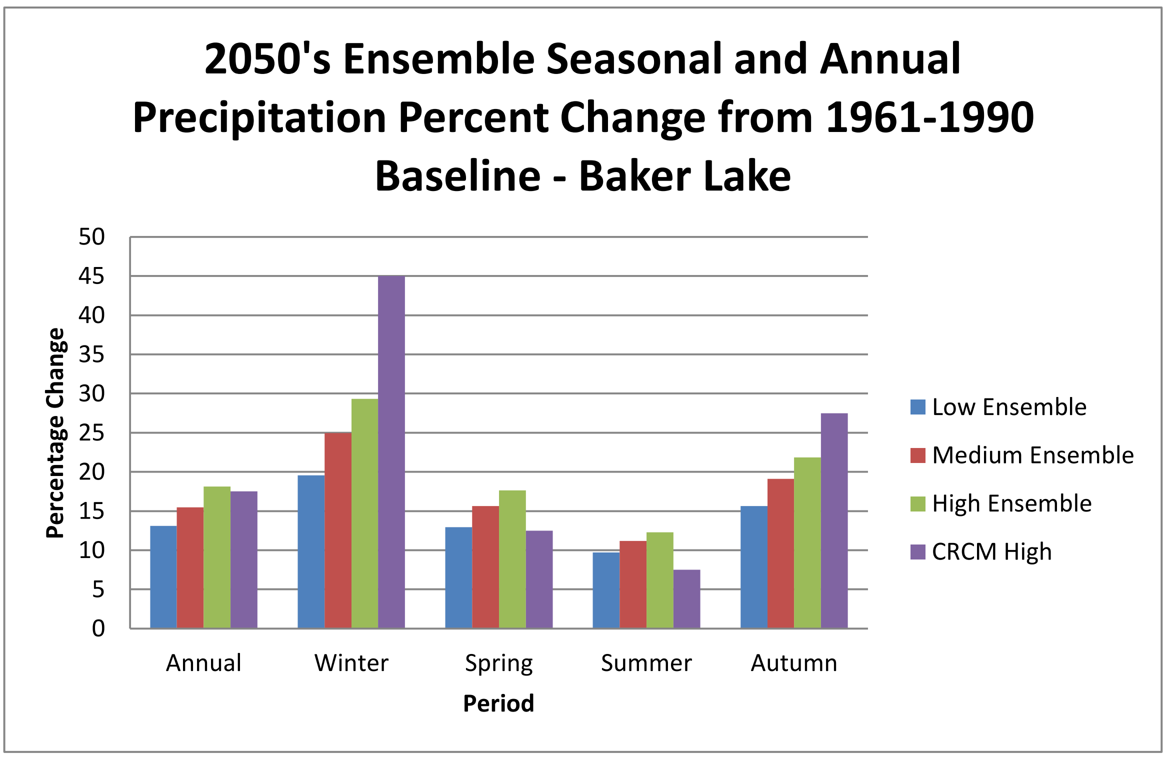


Figure 73: CCSN precipitation change predictions for Baker Lake for 2050`s.

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.

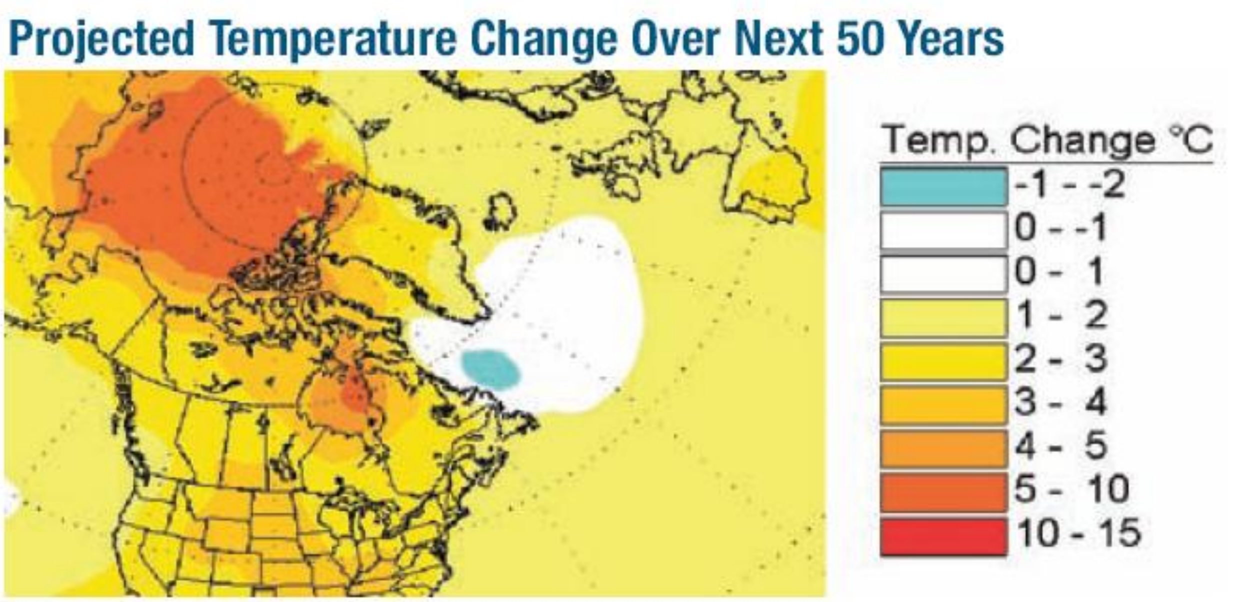
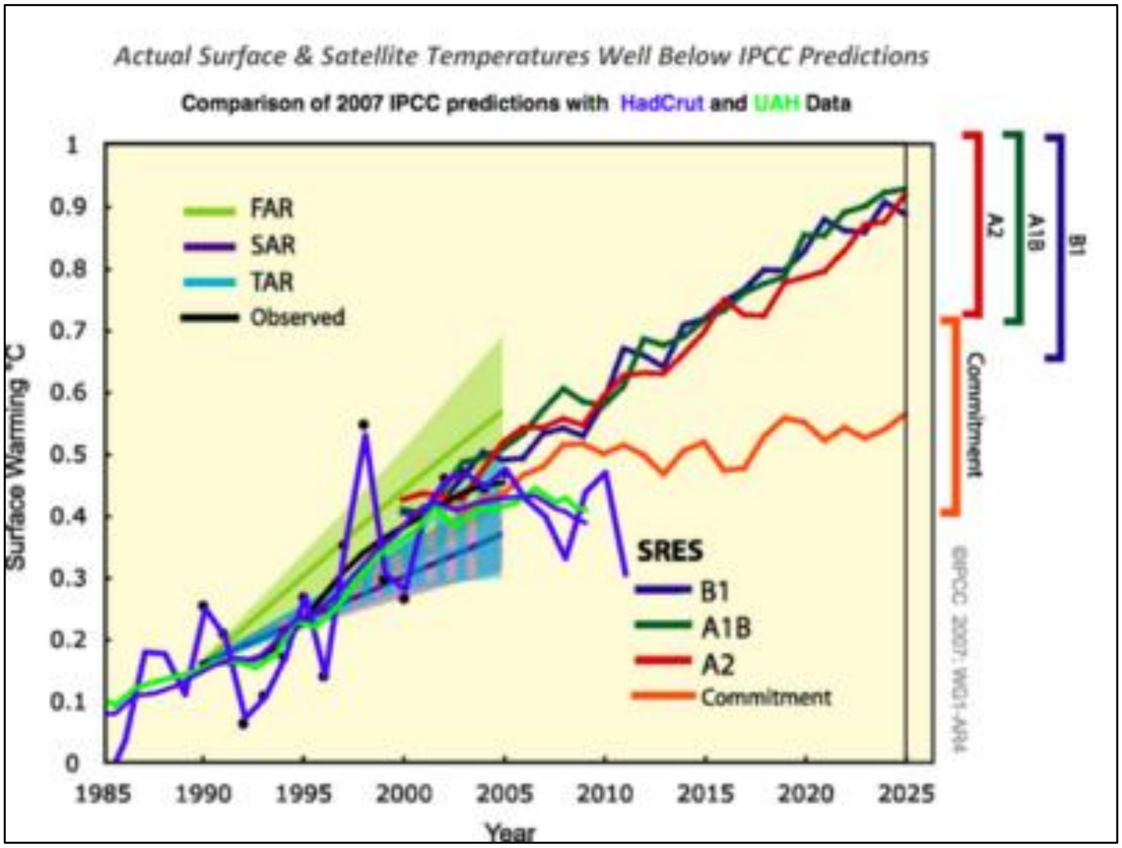


Figure 74: Nunavut Climate Change Strategy projected temperature change over the next 50 years.

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.

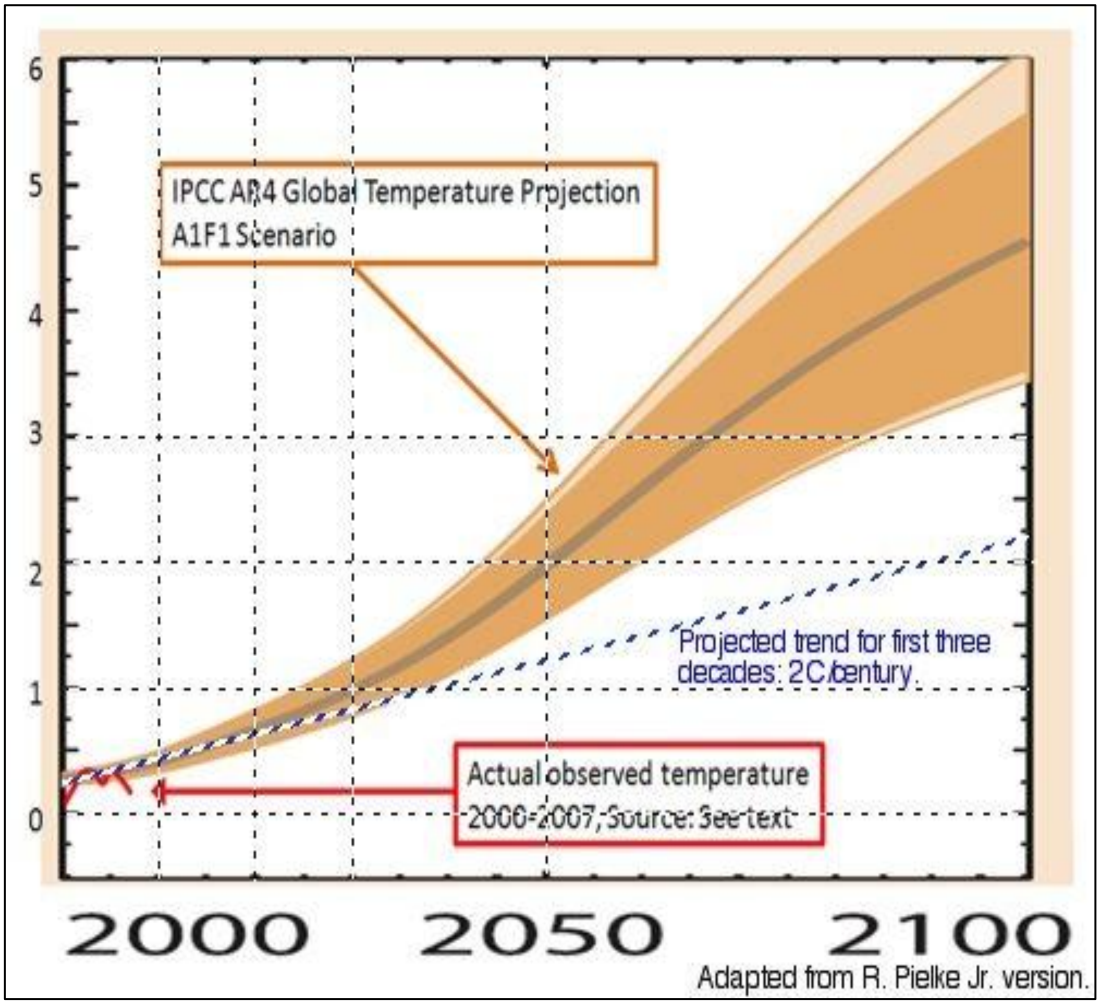


http://c3headlines.typepad.com/.a/6a010536b58035970c01538f6ce0f7970b-400wi

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

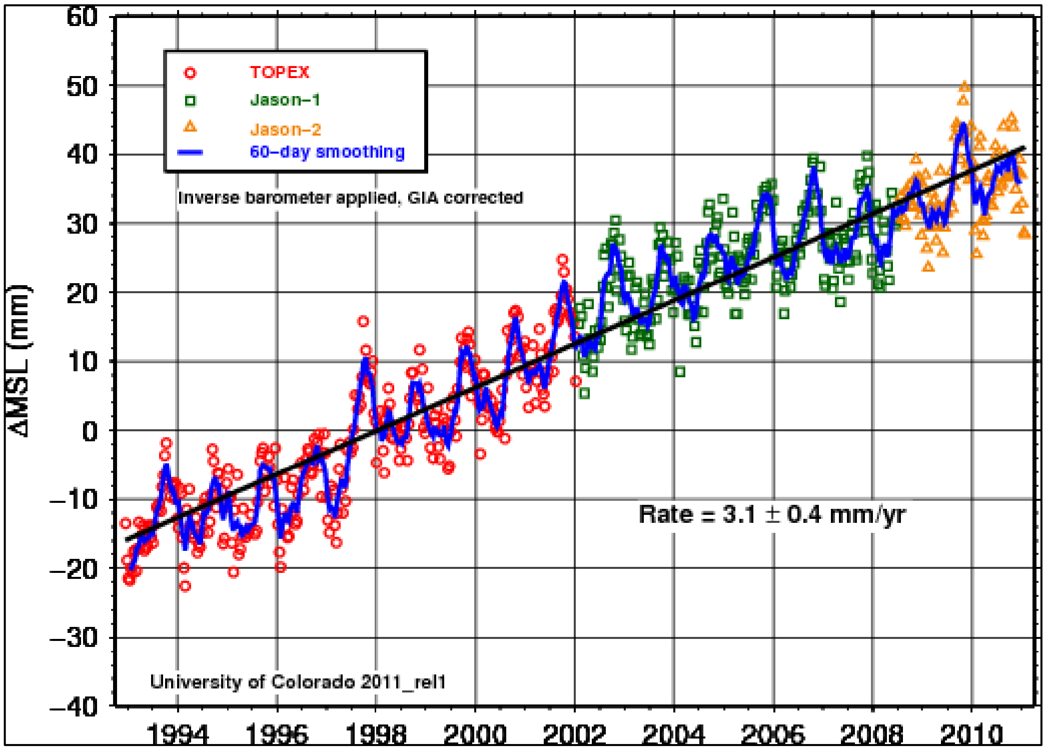
From this graph it is apparent that actual surface and satellite temperatures are below the IPCC predictions in all cases. It is clear that there has been increasing temperature from 1995 till about 2000, but that at that point the predictions and observed temperatures appear to diverge. During this 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.



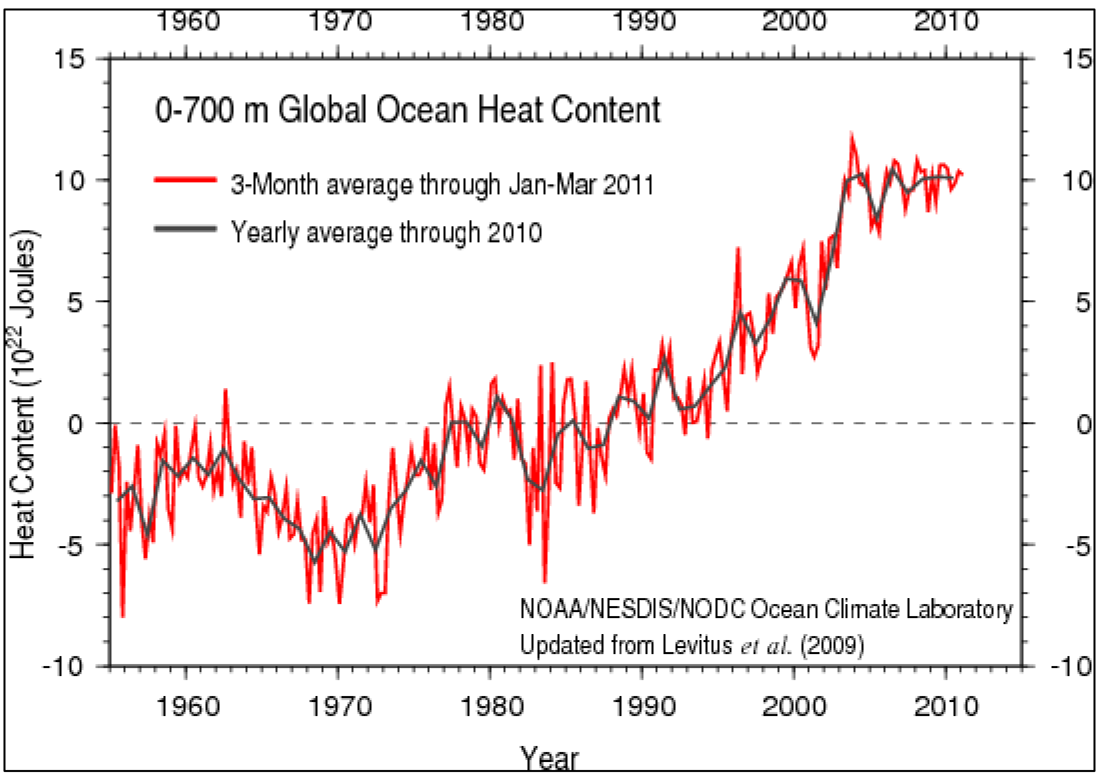
Http://rankexploits.com/musings/2008/what-are-the-ipcc-projections-and-how-not-to-cherry-pick/ipcc-projections/

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/.

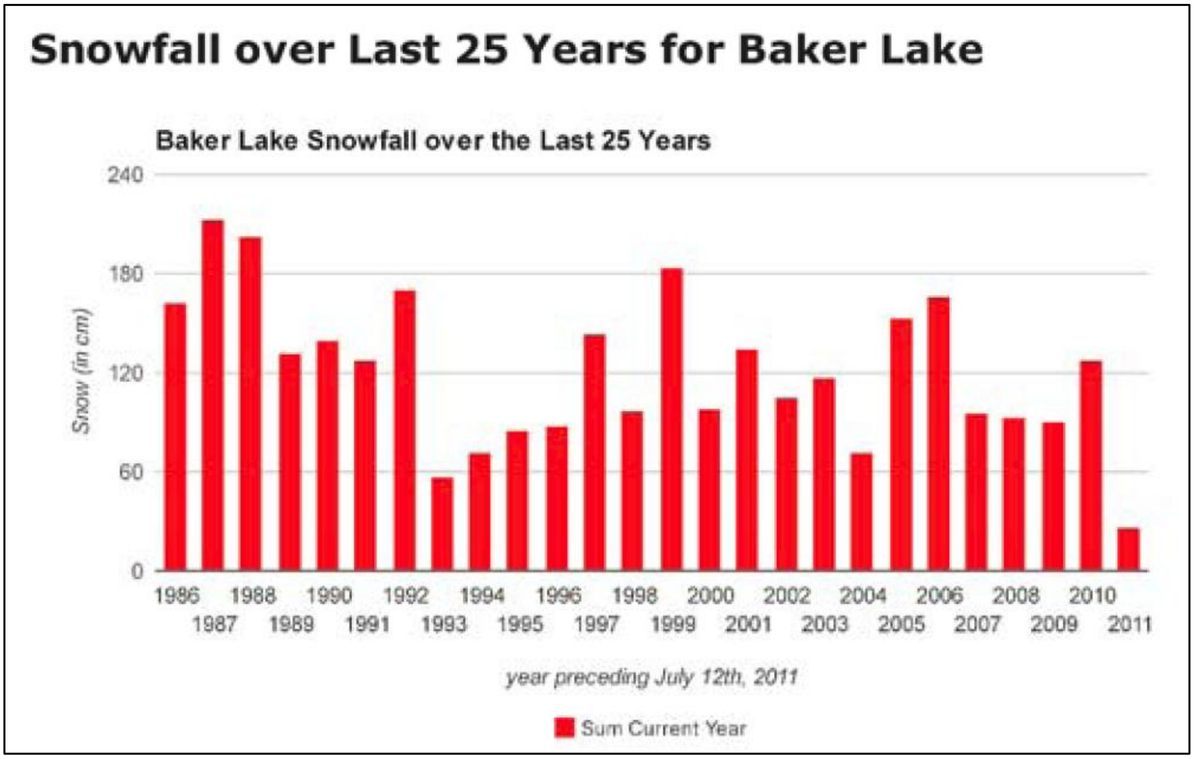


Figure 79: Baker Lake snowfall for the last 25 years.

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.

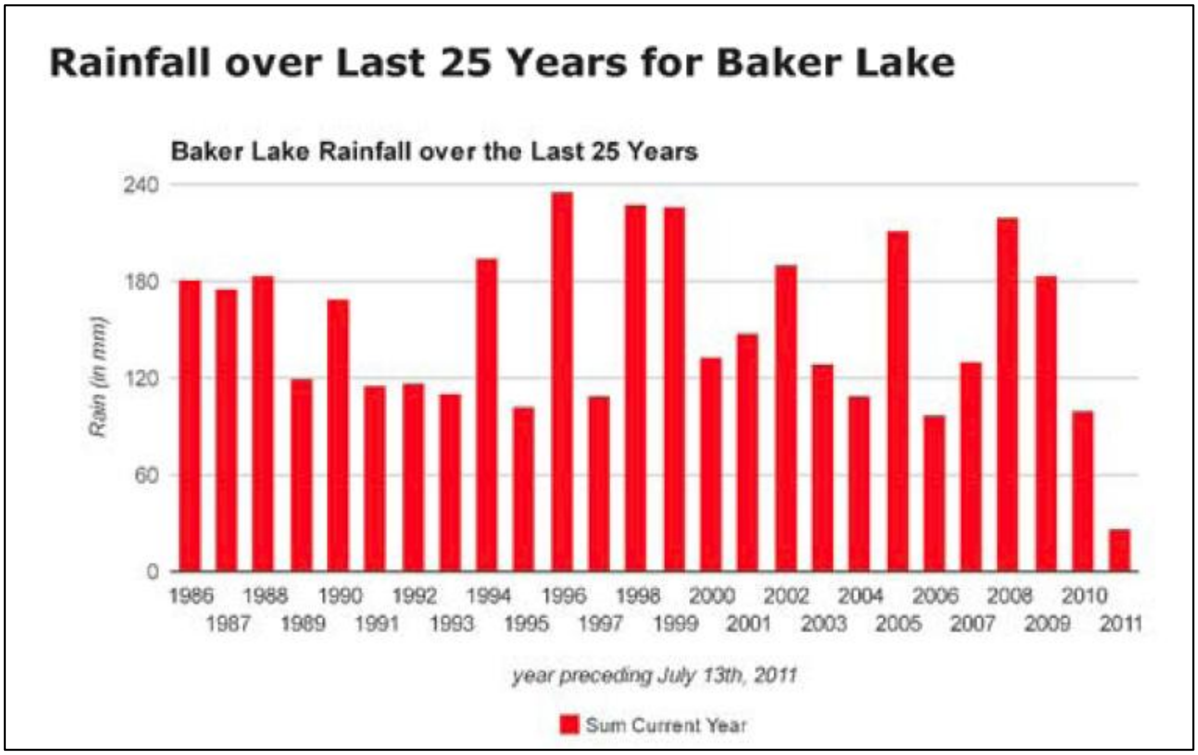


Figure 80: Baker Lake rainfall for the last 25 years.

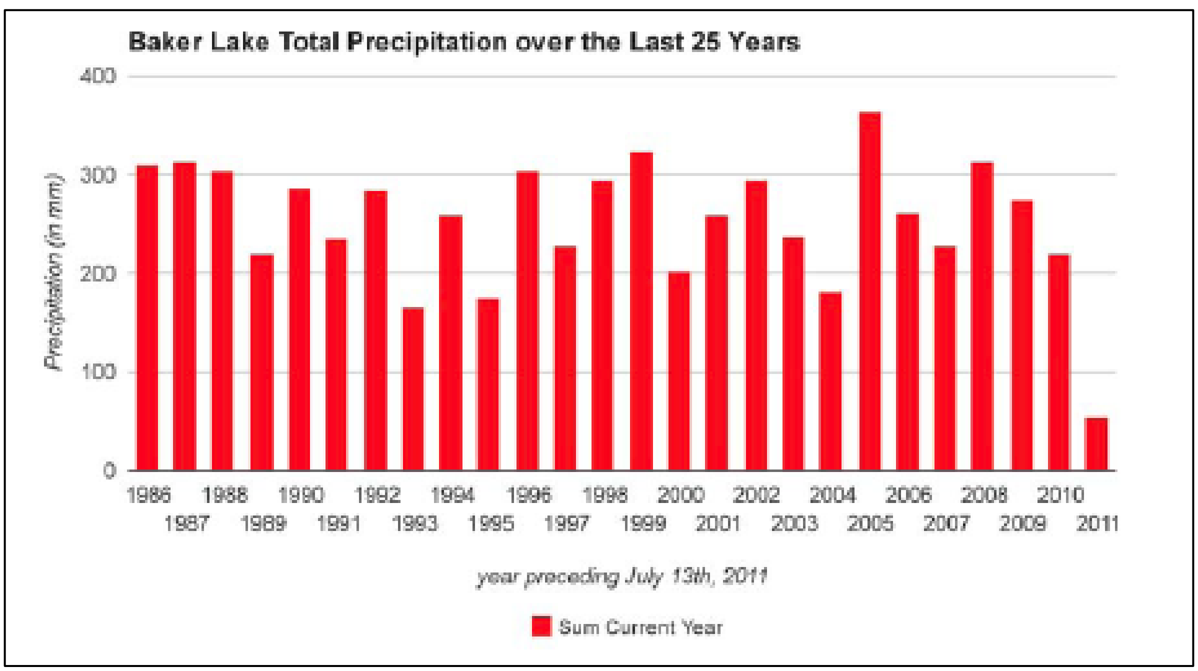


Figure 81: Baker Lake total precipitation for the last 25 years.

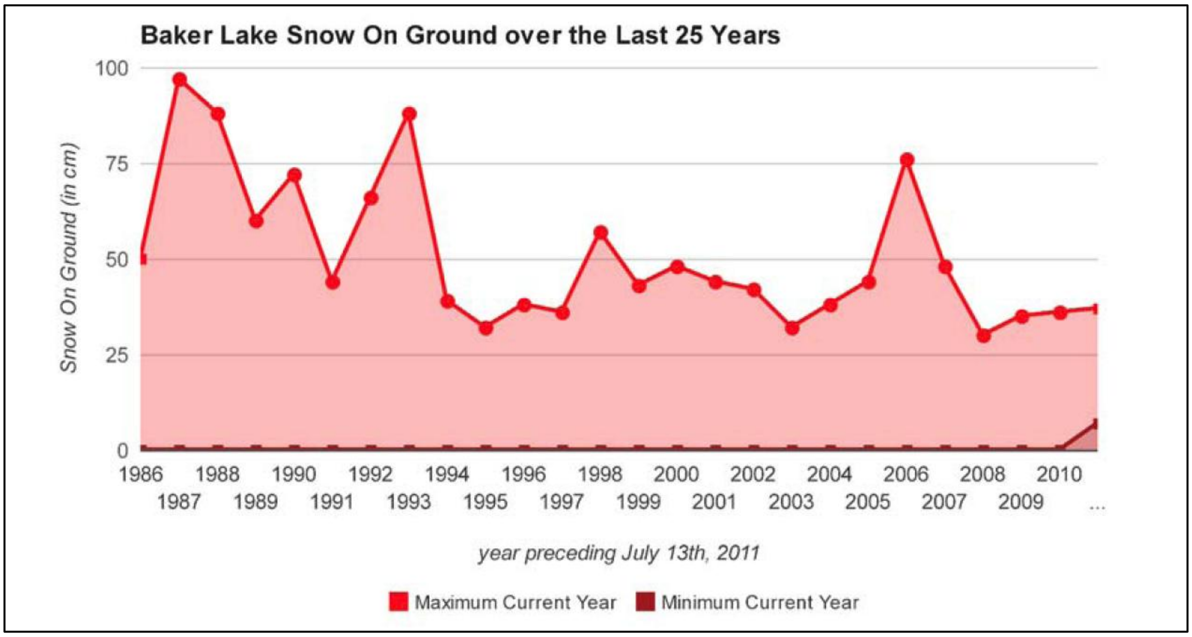


Figure 82: Baker Lake snow on the ground for the last 25 years.

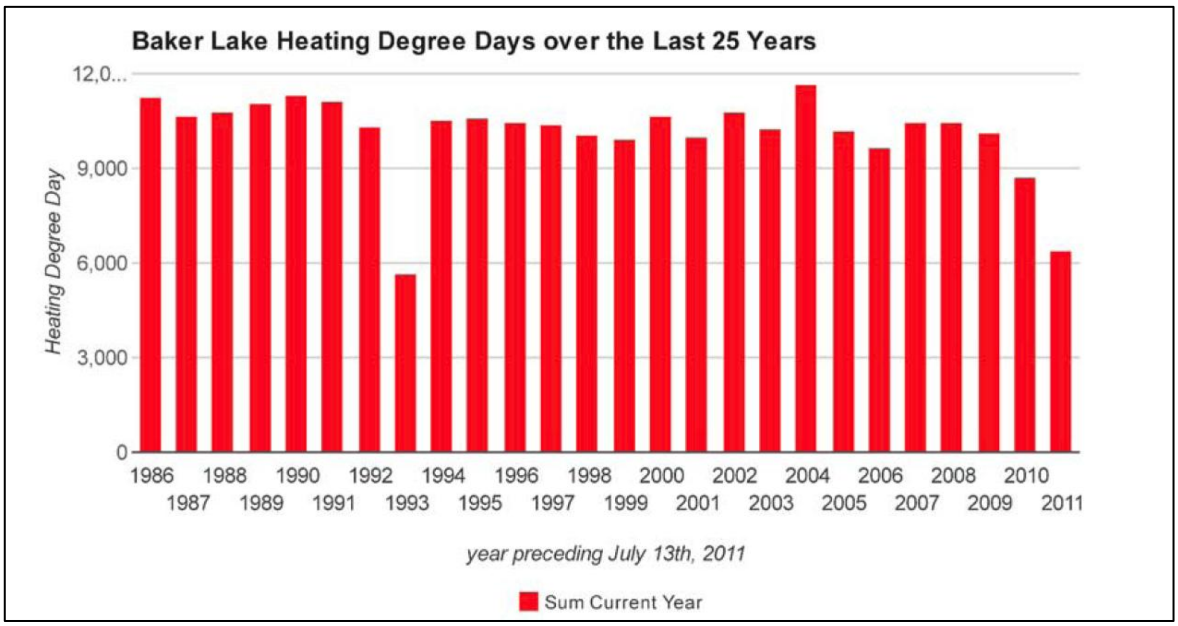


Figure 83: Baker Lake heating degree days for the last 25 years.

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.	

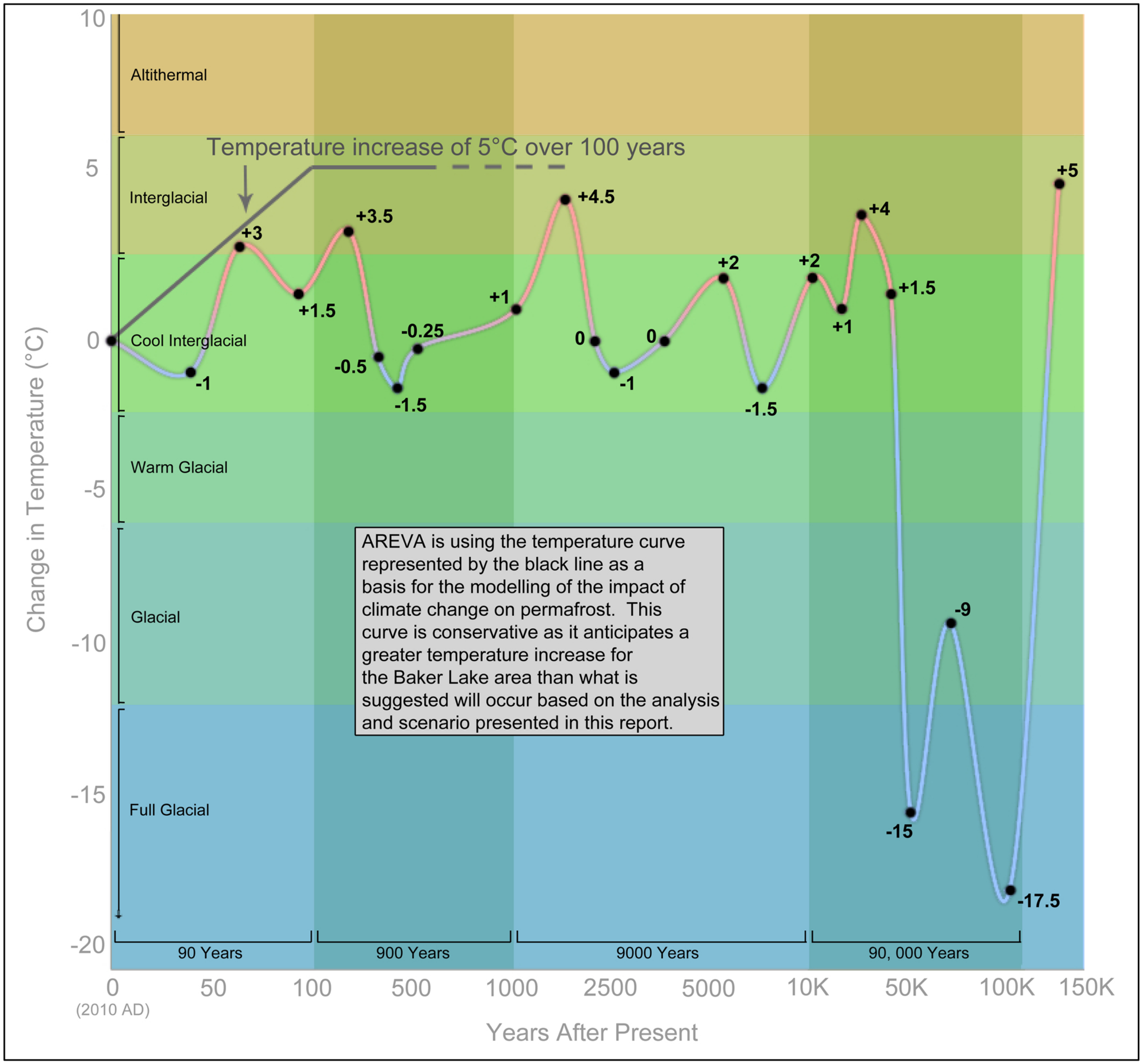


Figure 84: Projected Future Temperature Relative to Current Temperature for the Period 0 (current) to 150,000 Years AP

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

Holocene Palaeo-Climate Review

Periodicity of cycles	Reference	Roman Calendar	Phase	Years Before Present (YBP)	Detailed Period	Precipitation	Humidity/Fire	Temperature	Solar	Glaciers	Other	Circulation	Additional notes	Reference
900 000 year period with approximately 90 000 year cycle for full glaciation and deglaciation. Some authors refer to this as the 100000 year glacial cycle Climate is non linear which is driven by thresholds and feedbacks.	Normani et al, 2009 Bintanja and van de Wal, 2008 Rial et al, 2003 Denton et al, 2010			From 900K		Precipitation controls glacier formation. If lower moisture conditions exist there is lower glaciation.		Once orbital cooling starts, cold periods may be started by an influx of fresh water into the Atlantic slowing warm water movement to the poles. Wind patterns may change expanding the polar front and preventing northward movement of warm air. Warming may be caused by more warm water moving poleward, and liberating CO2 which has a feedback mechanism resulting in more heating and displayed as rapid deglaciation and recovery from ice ages.	Reduced solar about 115000 BP reduces boreal forest, increases tundra and increases albedo and decreases spring and summer temperatures, triggering glaciation over extreme north east of Canada. Appears to be trigger area for Laurentide ice sheet formation if further cooling occurs. Experiment based on current CO2 levels. Orbital and insolation changes shown to be key. GCM Model tests.	Glaciers up to 4 km thick to south of Canada US border. Deglaciation rapid (10000 years), glaciation slower.		ENSO apparent in 130 K years of records.		Cane, 2005. Normani et al, 2009 Gallimore and Kutzbach, 1996. Denton et al, 2010 Funder and Hjort, 1973
			Last Glacial Maximum	25000										
400–500 and 900–1100 and 1500 yr cycle. Glacier advances last 600=900 years. Glacier retreats last 1750 years. strongest advances 200 to 350, 2800 and 5300 BP. Solar possible trigger. Bond cycles peaked around 400, 1,400, 2,800, 4,300, 5,900, 8,100, 9,400, 10,300 and 11,100 BP. Less sea ice than at present existed from 7300 to 3700 cal yr BP.	Viau et al, 2006. Gajewski et al, 2007. Warner and Butikofer, 2008			14000		Beringa precipitation shows 250 mm variation with drying starting since 12000 BP		Ice age. Significant glacier growth requires at least a 10-12C decrease in summer temperature in NWT. (In Beringa Summer temperature 4C lower and January temperature 2C lower than present. Temperature rise begins 16000 BP peaking at 12000BP).					Magnitude of climate variation greater in last and late glacial periods than over last 8000 years	Williams, 1979 Viau et al, 2006 Viau et al, 2008
2500 yr warming and cooling cycle, Saw tooth structure, alternating peaks and troughs: "reconstruction also shows the typical ''saw tooth'' structure found in other Holocene palaeo-climate records, where a more gradual cooling typically follows an abrupt warming". early Holocene shows higher amplitude changes than later Holocene.	Hu et al, 2003		Late Glacial Maximum	13000				3-4C Warming		Deglaciation (2500 yr cycle of building and waning)				Viau et al, 2006 Warner and Butikofer, 2008
At least 10 mini ice ages within Holocene and most have climate change rates and magnitudes greater than what is currently being experienced.	Bluemel et al, 2009.		Holocene Starts	12.9 - 11.6		Dry summers wet winters	High fire incidence, dry summers due to higher solar radiation and dry adiabatic winds from the residual Laurentide Ice Sheet.	Temperature driven by summer insolation increase.	Increasing Solar Radiation. Summer insolation higher than current. Surface temperature responds to solar radiation except lags where Laurentide ice sheet remains. High NH summer insolation from coincidence of precession and obliquity cycles at about 11000 BP.	Deglaciation. Key feature that influences climate of northern Canada for next several thousand years is the melting Laurentide ice sheet.	Prior to 10000 BP water levels lower than today in South west Yukon.			Booth et al, 2005 Kaplan and Wolfe, 2006 Shuman et al, 2002 Anderson et al, 2005
		8000	Pre Boreal	10000					Periods of decreasing insolation from 10000 BP to current. When ice sheets not present insolation appears to be main driver. 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.	Start of 50 000 year interglacial	Water levels rise to 3 to 4 m to below today by 7500BP in South west Yukon.		During the last millennium maxima of volcanic activity happened to coincide with both, low orbitally induced insolation in the Northern Hemisphere and an unusual concentration of solar activity minima (Wolf, Sporer, Maunder, Dalton) which likely led to the lowest temperatures in this area since 8000 years BP. Cosmic rays and magnetic fluctuations also held responsible for decadal to multi-century long climate fluctuations along with reduced Milankovitch orbital forcing, reduced solar, volcanic eruptions, increased sea ice, and reduced deep convection in the north Atlantic. Final component is reduction of sea surface temperature in northern latitudes and strengthening of polar anticyclone particularly in winter.	Kutzbach and Guetter, 1986
9000 YBP considered as a possible analog for today. (radiation cycle)	Kutzbach and Guetter, 1986	7000	Boreal	9000			Low or neutral fire anomaly					ENSO weak in Early Holocene cause d by boreal summer perihelion.		Lorenz et al
		6000	Atlantic	8000	8400 warming 8200 brief cooling		High fire incidence	1 C Warming (ice sheets have minimal influence). Brief cooling period at 8200		Deglaciation. 8200 cooling related to collapse of Laurentide ice sheet.				Gajewski et al, 2007. Booth et al 2005
		5000		7000		From 8000BP to 4000 BP lake levels frequently low.	Decreasing fire incidence	Variable decline			7500 to 5000BP water levels fall to 5-6m below current In south west Yukon		Strong adiabatic dry winds and air-mass instability conducive to frequent lighting associated with the Ice Sheet could have provided ideal conditions for frequent fires prior to 8±7 ka BP.	Carcaillet and Richard, 2000 Anderson et al, 2005 Fritz et al, 2001
6500 BP a surrogate for a future warm climate		4000		6000		Fair winter rain. Moderate lake levels	Humidity starts to increase at about 5800	Warming starts				ENSO weak period ends, possibly increasingly negative North Atlantic Oscillation about 1000 BP	Intermediate water level at 7.0±6.0 ka BP. Laurentide ice remnants too small to significantly affect the atmospheric circulation so Atlantic Maritime Tropical humid air mass moves in over southern Quebec in summer - inhibiting fire occurrence.	Carcaillet and Richard, 2001 Wanner et al, 2008 Fritz et al, 2001 Sundquist et al, 2010
		3000	Sub Boreal 5000 to 2500	5000		Precipitation control by orbital driver of circulation. The middle Holocene was dominated by wet summers. Northwest Canada 200 yrs wet. High latitudes cold and wet (Europe and Siberia) Centennial scale drought in great plains to great lakes.	Fire incidence increases from 5800 to 3000 YBP	Variable warming and cooling. Millennial scale variation becomes apparent on top of long cycle +-0.2C. West Canada 1-2.5 C increase. 6000-2600 seen as optimal temperature period but with millennial scale cycle. Temperature controlled by orbital cycles. Summer temperatures may have dropped.				Anomalies in the atmosphere and SSTs and pressures in the Pacific and Atlantic, allowed the incursion of dry Arctic air masses.	Low lake-levels occurred between 6.2±3.8 ka BP in northern Quebec caused by drier warmer climate. Lakes drier for longer moving west and south.	Ali et al, 2009 Diffenbaugh and Sloan, 2004 Viau et al, 2006
				4200				Middle Holocene temperature fluctuations were dampened down.			Water Levels start to drop 4500 Possible volcanism 4.2 - 4.0 water table reaches lowest level. Between 4000 and 2000 water levels rise to above current level in south west Yukon.	Climatic change toward colder conditions probably promoted the southward displacement of the polar jet stream, thus allowing more incursions of dry Arctic air masses into Central and Eastern Canada. Similar to La Nina.		Ali et al 2009 Anderson et al, 2005
		2000		4000	4400 wet 4100 - 4300 dry 4000 wet			Canada possibly cooler. North UK Cool or wet Maximum warmth about 3000 YBP for central North America	Possible reduced Solar radiation - increased GCR Possible amplification Possible Milankovitch slow orbital changes. Milankovitch cycles considered to be the key driver			Steep La Nina type circulation persistent or enhanced, increased warmth in tropical oceans. Stable Atlantic air mass over eastern Canada.	The middle Holocene was dominated by wet summers due to stability of the Atlantic air mass over eastern Canada. Rapid climate changes, dune reactivation, forest fires, long-term changes in forest composition The spatial pattern of wet and dry anomalies resembles that of the mid-latitudinal drought that occurred June 1998 /May 2002. Possibly similar to dust bowl 1930s Possible North Atlantic Cooling. Resembles Maunder Minimum	Booth et al, 2005. Gajewski et al, 2007.
		1000		3000	3900	Colder wetter climate	Fire transition period around 3000 BP. Humidity starts to decrease and level off at current levels. Maximum fires at 3400BP	Abrupt decrease and high variability			Increased sediment from rain. Increased lake levels and water table height. Most northerly extent of tree line in Holocene.	Tree line roughly coincides with Polar Front		Ali et al, 2009 Carcaillet and Richard, 2000 Nichols ?
		0	Subantlantic 2500 to present	2000	2500	Summers begin to become drier	Fire incidence increases from about 2500 BP	Slight slow warming			Water Levels stay below current by 1 to 2m in South West Yukon for 2000 years till current time.	More frequent incursions of dry Cool Pacific or Cold Arctic air masses over eastern Canada conducive to fire weather during late-spring or summer. The Atlantic Maritime Tropical humid air blocked.		Carcaillet and Richard, 2000 Anderson et al, 2005
Millennial scale	Viau e t al, 2006	950	MWP	1050				Warming	Irradiance levels high		Possible high volcanic aerosol period			Bradley, 2000
		1010	MWP	1000										
		1250	MWP	800			Begin in sharp decrease of fires.							Ali et al, 2009
Millennial scale variation	Viau et al, 2006	1510	LIA	500				Long term cooling trend related to orbital cycles or insolation.	Orbital influence reduces insolation by 4Wm2 in July and increase January by 2 Wm2 (High Northern Latitudes)		Decadal and longer variations in the strength of the ENSO cycle within the past 1000 yr; may be due to solar and volcanic variations in solar insolation	Slight equatorward displacement of the sub-tropical high pressure centers		Cane, 2005 Bradley, 2000
		1610	LIA	400										
		1710	LIA	300		Increasing snow depth in winter	Decreasing fire in eastern Canada							Ali et al, 2009
		1810	LIA	200		Increasing precipitation in eastern Canada (c1850) onwards.								
		1910		100										Viau etal 2006
		1920		90										
		1930		80		Drought								
		1940		70				Cooling						Coutillot, 2006 Gascon et al, 2010.
		1950		60		1950-2006 Decrease in Winter and Autumn storm activity and decrease in amount of precipitation.								
		1960		50										
		1970		40										
		1980		30				Warming				1980-2000 Maritime air from Hudson Bay affects Baker Lake Area. At Lupin evaporation range is 220 to 320 mm per year or about 70 to 100% of annual precipitation		Coutillot, 2006 Gibson et al, 1996
Oscillatory modes with the period of approximately 7 to 8 years were detected in monthly time series of sunspot numbers, geomagnetic activity aa index, NAO index and near-surface air temperature from several mid-latitude European locations (Data from 1950 onwards). Statistical evidence for a coupling between solar/geomagnetic activity and climate variability. NAO also displays a 7-8 year period. Phase coherence shown, causality inferred but not shown by Paulus. Courtillot shows possible mechanism and shows primary driver is orbital variation affecting both temperature and CO2. Recent work shows Galactic cosmic rays possibly sed clouds. GCRs affected by geomagnetic fields.	Paulus and Novotna, 2009. Courtillot et al, 2006.	1990		20		Eastern Canada to receive more rainfall under influence of CO2. This contradicts actual findings in some areas.						Increase in moisture probably related to northward displacement of the polar jet stream, favouring the incursion of humid air masses from the Atlantic Tropical zones. Northward displacement induced by a warming of the SST along the North Pacific coast, blocking dry Arctic air masses. Costal sea surface warming induced by a cooling of SSTs in the central Pacific, i.e. a negative PDO.	Ground temperatures within the discontinuous permafrost zone are generally above −3°C, and range down to −15°. Eastern Canada permafrost warming since early 1990s. Rate of permafrost warming greater north of tree line.	Gascon et al, 2010 Wiffen, undated.
		2000		10				Warm peak in Canadian north 2.5C to 3C higher than 1951-80 normal. Temperature not seen as the driver though. A pressure height anomaly over North west Canada appears to have been the controller. (Study includes Baker Lake area). Period seen as untypical and a poor analogue for the future. Several studies cited that show polar amplification of global warming has not materialised.	Peak of solar cycle and some argue of the solar maximum	Retreat or melting	1998 Is amongst warmest of century. Key feature is long melt season. Early start and late finish. Extremes in ground thaw penetration, snow free season, lake ice free season, glacier melt, and duration and extent of marine water.	Synoptic events and preconditioning appear to be vital to warm event. A strong pressure ridge across Northern Canadian Archipelago displaced the polar vortex to the Siberian sector and the Aleutian low intensified and shifted North and West. Result was a strong pressure gradient and subsiding air favouring a strong southerly flow and cloud free conditions resulting in increased temperature. ENSO strongest of 20th century and temperature and circulation consistent with Northern Canada patterns though it is not alone responsible. Similar events in 1962. The Aleutian low allows warm maritime air masses to more frequently penetrate inland. *	Permafrost Thaw - key feature of this period is continuation of warm temperatures in the fall.	Atkinson et al, 2006 Anderson et al, 2005 Wanner et al, 2008 Spooner et al, 2003
		2010		0		Lake effects around the Great Lakes causes an increase in snowfall. Areas around Hudson Bay may also show increased snowfall.		1-2 C Temperature decline due to weak solar cycle	Solar Cycle 23 completes on a high				Projected CO2 increase of 40 ppm to 2030 calculated to increase global atmospheric temperature by 0.04°C. Based on Palaeocene-eocene thermal maximum, CO2 not adequate to describe temperature increase beyond 1=3.5 C despite 5 to 9 C warming and rich CO2 environment. Other mechanisms involved.	Zebee et al, 2009 Archibald, 2009 SSRC, 2010 Burnett et al, 2003
		2020		20		Under CO2 models Arctic to receive more precipitation. Models overestimate spring precipitation but annual average is reasonably accurate.		Anticipated cooling under PDO. CO2 models predict Arctic warming double rest of world at 2.5 to 9C with greatest warming in the fall and winter and smallest in Summer till 2100. Northern hemisphere under NAO/AO likely to show 1 to 2 C drop in winter and global 0.3 to 0.4C drop. Similar to Maunder Minimum.	Solar cycle 24 likely to have 30% of SC 23 sunspots.		Future ENSO strength indeterminate. Entering phase of low PDO therefore La Nina circulation likely to occur more frequently.	CO2 models overestimate Arctic pressure and therefore wind and ice drift. Models overestimate cloud in winter and underestimate it in Summer. AO and NAO likely to be in the negative phase.	Pacific ocean temperature linked to atmospheric CO2 concentration. Warmer oceans hold less gas and CO2 leaves the Oceans. Ocean cooling predicted may slow rate of CO2 increase down if additional emission sources are not added.	SSRC, 2010 Cane, 2005 Hanssen-Bauer, 2004 Bastardi, 2010 Shindell et al, 2001
		2030		30					SC 25 expected to be weak					
		2040		40										
		2050		50					More normal sunspot cycle expected.					
		2060		60				Continuation of long cooling trend from 6000BP	Insolation variation very small					Loutre and Berger, 2000
		2070		70										
		2080		80										
		2090		90										
		2100		100										
		2200		200										
		2300		300										
		2400		400										
		2500		500										
		2750		750										
		3000		1000										
		4000		2000										
		5000		3000										
		6000		4000										
		7000		5000										
		8000		6000										
		9000		7000										
		10000		8000										
				9000										
				10000				Slight warming at 15K						
				20000				Slow cooling from 6000BP continued		Cold Interval at about 25K AP				
				30000										
				40000				Cooling into Glacial period						
				50000						Entry into next Glacial period				Loutre and Berger, 2000
				60000										Loutre and Berger, 2000
				70000				Slight warming		Short interstadial				Loutre and Berger, 2000
				80000				Continued cooling						
				90000										
				100000										
				110000						Peak of Glacial				Loutre and Berger, 2000
				120000						Ice sheet starts to melt rapidly				Loutre and Berger, 2000
				130000						Ice volume minimum				

Viau et al, 2006 "Another potential factor that could affect the final reconstruction was our choice of using only the best analogue, as opposed to the top five or more. We explored this potential factor by comparing our temperature reconstruction at 6000 cal yr BP based on the best analogue with another map prepared using the best 5 analogues [Sawada et al., 2004]. Visual inspection of both temperature reconstructions reveals
"The resulting temporal resolution of our continental scale temperature reconstruction remains difficult to determine but appears to be a function of the sampling interval, age-depth model and especially the spatiotemporal correlation. Nevertheless, the presence of spatial and temporal coherency and reproducibility of spatial patterns ensures that the climate signal is preserved in the composite record.
"In summary, these sensitivity analyses show the robustness of our reconstructed temperature time series in both time and space. This analysis shows the advantage of using a network of sites in palaeo-climate reconstructions [Gajewski, 1993], which results in increased confidence in temperature estimates at least on the continental-scale of North America during the Holocene. The use of a network of sites has the
"Cross-spectral coherency of the North Atlantic IRD marine record and cosmogenic nuclide records (14C and 10Be; proxies for solar variability), at the 400 to 500 and 900 to 1100-year frequency bands during the past 12,000 years [Bond et al., 2001] falls reasonably close to the circa 1150 year periodic component identified in this study."
"Evidence of circa 550 and 1000 year periodicities has been detected in North Atlantic ocean circulation patterns (NADW) during the Holocene [Chapman and Shackleton, 2000]. Hughen et al. [2000] have shown that the Younger Dryas was synchronous with atmospheric 14C production changes interpreted as ocean circulation changes."
"However, during interglacials ice sheets are limited in extent and insolation variations dominate. It has been hypothesized that a weak periodic solar forcing on century to millennial scales may be the dominant forcing during the Holocene when ice sheets are no longer a forcing factor [Haigh, 1996; Shindell et al., 1999; Lean et al., 1992; Crowley, 2000]."

Carcaillet and Richard, 2001 "Fire occurrence however closely matches summer relative humidity inferred from d18O. The differences between fire frequency and lake level history, are due to changes in the seasonality of precipitation and drought frequency. Lake levels are essentially controlled by winter precipitation while summer precipitation controls fire occurrence."

"In most North American forests, fires currently occur during intervals when precipitation is low, and when the surface litter layer is very dry. The litter layer generally becomes very dry after a long sequence of days with either less than 1.5 mm of rain or with relative humidity less than 60%. Strong wind and high summer temperature also contribute to the variance. The abundance of lightning is an additional variable
"Changes in fire status can be reconciled with lake-level records if the main factor triggering change in lake level is the amount of winter precipitation, while fire frequency is controlled by the frequency of late-spring and summer drought events (related to air-mass stability). Winter snow cover prevents fire ignition and spread until early spring during snowmelt. If winter precipitation increases, the water produced by
"Charcoal data-bases world-wide could provide a new global perspective on the Holocene climate useful to test model outputs for past key periods such as 6 ka BP, which is used as surrogate for the future changes."

Ali et al, 2009 "Air mass circulation and geo-potential height anomalies (4500 hPa), and anomalies in sea surface temperatures (SST) or sea level pressures across the Arctic, the Pacific, and the Atlantic oceans. These interactions involving the El Nin˜ o-Southern-Oscillation , the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO) and the Arctic Oscillation , affect air mass circulation and moisture/drought balance

Loutre and Berger, 2000 "Paleo-climatic evidence lead to an estimate of the length of the last three interglacials of about 10 kyr each, although recent analyses tend to conclude that the last interglacial must have been twice as long."

"Saltzman et al. (1993) concluded that if values of CO2 higher than 350 ppmv were to become established, the climate system would be placed into a stable non-oscillating regime characterised by low ice mass and perhaps by a retreat of the Greenland and Antarctic ice sheets." Comment - CO2 not considered to be a significant driver at all times.

Wanner etal "During most of the Holocene, variations in predominantly three natural forcings (orbital, solar and volcanic) can be invoked as influences on global climate. Only during the last millennium, or possibly centuries, has forcing induced by human activities (such as rapid land cover change, increase of greenhouse gases and aerosols, and stratospheric ozone depletion) started to play an increasing role."

Fritz etal, 2001 "Throughout the Americas, the broad millennial scale patterns of climate variation are consistent with insolation-driven forcing. However, at a sub millennial scale, the considerable spatial variability in the pattern and rate of climate change points to the influence of other climatic controls, as well as the differing response times of individual systems to climate."
"Although the Holocene limnological and climatic variability is smaller in magnitude than Pleistocene changes, the data indicate extremes more severe and persistent than observation- and instrument-based records of the last 150 years (Laird et al., 1996b; Overpeck, 1996; Dean, 1997)."

Sundquist et al, 2010 We also find that the available proxy records have a large over-representation towards summer temperatures, whereas only rather few represent annual mean temperature, winter temperature, annual precipitation and winter precipitation.

*Spooner et al, 2003. "The AL (Aleutian Low)dominates the winter climate of the North Pacific and beginning about mid-October intensifies and migrates south-eastward to a location centred over the Gulf of Alaska. Winter surface winds blow in a counter clockwise circulation around the AL. To the south, winds blow in a clockwise circulation around a semi permanent centre of high pressure (Pacific High, PH) that intensifies in the

Appendix 2

Review Comments and Short Responses

Review Comments From Golder Associates

1. Additional climatic parameters will be necessary for effectively modeling groundwater transport at the Kiggavik site. We suggest that additional climatic parameters, such as precipitation, evaporation, seasonal temperature trends and permafrost conditions also be examined. The University of Victoria's Canadian Institute for Climate Studies provides a good interface for modeling climatic trends in Canada until the 2080s. A number of models and emission scenarios are available and results are obtainable at localized scales. We suggest that a specific climate model and emission scenario (or a select few climate models and scenarios) be established so that environmental conditions are well defined and additional information and data can be acquired when necessary. This will not only aid in modeling groundwater transport but will also make the data presented in this report applicable to a wider range of modeling efforts that involve climatic and/or hydrological components.

   Response: Additional parameters added in Appendix. Section 5.6. Using computer models is discussed in Section 2.2, no further modelling undertaken but Appendix 1 created to detail parameters.

2. Provide Kiggavik site-specific data, particularly for short-term predictions. The report does not always indicate the specific scale or location at which the data are applicable. Climate change is a spatially variable occurrence and predictions vary considerably with respect to regional characteristics. For example, high latitudes are particularly susceptible to the effects of climate change; the Arctic is expected to undergo preferential warming (Kattsov et al., 2005). It is therefore necessary that data are specific to the Kiggavik site. Regional data are provided for the models available through the Canadian Institute for Climate Studies website.

   Response: Climate is now specified to Baker Lake region, Systems remain global. Appendix 1 specifies spatial scale where possible.

3. Although the report provides a summary of the major climate forcing mechanisms and the scales at which they operate, it fails to indicate the relative influence of each mechanism. This information will help indicate the sensitivity of the proposed model and how different greenhouse gas scenarios may affect the results.

   Response: The climate forcing mechanisms are global scale. Sensitivity is not described as the resolution of the models and the temperature record are too coarse to detect changes reliably.

4. The report indicates a cooling trend over the next 50 years. However, we have run 12 global circulation models under a variety of Intergovernmental Panel on Climate Change (IPCC) derived emission scenarios for the Kiggavik site. The mean, 1st quartile, 3rd quartile, minimum and maximum temperature values for the 61 experiments are indicated in Figure 1. All models present a significant and consistent warming trend over the next 50 years. We therefore suggest the short term climatic trends in this report be further examined.

   Response: Cooling over the next 50 years is now broadly anticipated by many groups due to the reduction in solar radiation and the strong negative Arctic Oscillation. The model data has deviated from the real temperatures experienced.

5. It is necessary to provide original sources and cross references in the report. This information will help confirm credibility and allow supplementary data to be obtained when necessary.

   Response: Although not all references are referenced within the text a larger proportion have been cross referenced.

Review Comments from Sennes

1. The primary weakness of the report, in my opinion, is that the report does not focus in on the climate in the vicinity of the Kiggavik mine and reaches no specific conclusions relative to the long-term effects on mine tailings storage.

   Response: The scenario has been refined to the Baker Lake area, but it should not be refined too much as there is too much uncertainty (Section 5.6). No comment is made on the tailings as that was not part of the initial requirement. Was requested only to define the future climate for modelling purposes on ground freezing.

2. In short, what the report states is that the effects of greenhouse gases on climate forcing will be limited to the next 500 years, after which everything goes back to normal and the primary influences on climate change are the same ones that have been operating on the earth's climate in the past 10,000 years. There is reason to question this fundamental assumption in the report.

   Response: This part is correctly understood. A future energy scenario is added to the document in Section 2.2. In addition the return to CO_2 in balance with earth temperature is discussed. CO2 logarithmic relationship with CO2 is discussed. The cyclical nature of the drivers for climate change must be considered and are not adequately dealt with in the IPCC models – this is also discussed.

3. However, the underlying premise for this projection of future climate assumes that once the effect of current climate warming due to greenhouse gases is over in the next 500 years, the Arctic ice cap will reform and that everything returns to the same state that is was in after the last ice age.

   Response: This part is not correctly understood. A return to ice age conditions will start at some point between now and a time of 50000 years into the future. The decline into an ice age is a slow saw tooth process with both warm and cool periods. The scenario that has been developed clearly shows that after the cooling in the near future there will be warming and then a long period with variable warming and cooling. This is anticipated to be similar to the period 5000YBP in Appendix 1.

4. As for the long-term climate projection present in SRK's Figure 4.7, the projection is remarkably stable over the next 50,000 years. The past 10,000 years have exhibited an unusually stable climate relative to what has happened in previous interglacial periods, and the SRK report projects that the future climate will remain stable for another 50,000 years. This does not seem credible in view of the evidence from ice cores and ocean sediment data used to reconstruct climate change over the past 800,000 years. Therefore, while I credit SRK for having pulled together a good summary of the climate change cycles that may influence our climate over the next 10,000 years, I am sceptical about their application of those cycles to project the potential changes in the 1,000-10,000 year and longer time frame.

   Response: The interglacials are typically 10000 years and we are currently at a point where we are roughly 10000 years from the last glacial period. This interglacial is however anticipated to last for 10000 to 30000 years as originally indicated in Section 5.3.1. There may well be small cold and warm periods during this time, but Berger et al (2008) who focussed on this point think this is likely to be a very long interglacial. As the whole area of knowledge is still under development the Berger et al paper was considered to be one of the likely options as they could demonstrate a causal link with solar radiation and therefore it fits with the base assumption in this report that the main climate driver is the sun.

5. It seems to me that this is perhaps the most critical issue for the near term climate change scenario presented by SRK. What happens to the Kiggavik tailings storage if the permafrost is lost in the next 1,000 years?

Response: The point is accepted but the original briefing was to provide possible climate parameters that could be used for modelling the freeze operation at Kiggavik. No requirement was made for describing the tailings as part of this report.

Review Comments from AREVA

1. We would like your report to incorporate a reference to the Arctic Ensemble Scenarios (http://yukon.cccsn.ca/?page=ensemblescenarios) and the proposed temperature change at Baker Lake for the 2011- 2100 period.

   Response: The Arctic ensembles have been included. Baker Lake data and Ensemble data are plotted and presented along with a description of the data and an extraction of the rate changes expected. To ensure this data is in context I have also added a section comparing IPCC predictions against observed records for Baker Lake for the past 25 years where these are available. Section 5.6.

2. It would be also appropriate to include reference to The Nunavut Climate Change Strategy 2003.

   Response: This has been added and the guiding principles and climate change map have been included in the text. It also refers to an earlier section where the Nunavut people`s perception of climate change is reported. Section 5.6.

3. Please make sure that the conclusion of your report (including Figure 70) includes the climate change scenario we have been using to estimate permafrost degradation and tailings thermal behavior; that is a 5 degree rise over 100 years from a mean annual surface temperature of -7 °C to -2 °C.

   Response: The trend line has been added to the final graph. Section 5.6.