PACIFIC CLIMATE IMPACTS CONSORTIUM

Preliminary Analysis of Climate Change in the Cariboo-Chilcotin Area of British Columbia

08 September 2008

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[1]Integrated Land Management Bureau, [2]Pacific Climate Impacts Consortium

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AHCCD	Adjusted Historical Canadian Climate Data
CO_2	Carbon Dioxide
ENSO	El Niño/Southern Oscillation
GCM	Global Climate Model
GDD	Growing Degree Days
ILMB	Integrated Land Management Bureau (in the Ministry of Agriculture and Lands)
IPCC	United Nations' Intergovernmental Panel on Climate Change
PDO	Pacific Decadal Oscillation
PCIC	Pacific Climate Impacts Consortium
RCM	Regional Climate Model
SWE	Snow water equivalent (depth of water from a column of melted snow)

EXECUTIVE SUMMARY

The United Nations Intergovernmental Panel on Climate Change (IPPC, 2007) has presented clear evidence that the world's climate is warming and projects future increases in global mean annual temperature of 1.1°C to 6.4°C during the 21st century, depending on levels of greenhouse gas emissions and on modelling uncertainties. The warming climate is already affecting the ecosystems and resources that humans depend on and these impacts are predicted to increase. Resource managers and stakeholders in each local area will need to adapt to these changes. Early adaptation responses will reduce future social, ecological and economic impacts.

This report provides information on past and potential future climate in the Cariboo-Chilcotin. This information will help resource managers to consider potential impacts to natural resource values included in the Cariboo-Chilcotin Land Use Plan and to begin designing local adaptation strategies. Historical climate trends presented for the Cariboo-Chilcotin are based on long-term records from Environment Canada climate stations. Future climate projections presented for the Cariboo-Chilcotin area are derived from global and regional climate models. The report also presents background information on climate science and relevant climatic cycles including El Niño and the Pacific Decadal Oscillation. A list of "References and Suggested Reading" identifies papers that may be of interest to resource managers in the Cariboo-Chilcotin. Also, many internet links to relevant information are provided throughout the report. Brief concluding sections address potential climate change impacts and recommended next steps. This report will contribute to discussions that have already started on how to adapt planning and management for the resource values included in the Cariboo-Chilcotin Land Use Plan to a changing climate.

The Quesnel weather station provides the longest continuous historical climate record within the Cariboo-Chilcotin area. In Quesnel, the mean annual temperature increased at a rate of 0.9°C/century over the period from 1895-2005 and 3.2°C/century over the shorter recent period from 1950-2001. Both of these warming trends are statistically significant despite large year to year variability. During the 1950-2001 period, statistically significant mean annual temperature warming trends of 2.2°C, 2.5 °C, 3.7°C and 3.4°C/century were measured for Tatlayoko Lake, Barkerville, Prince George and Kamloops, respectively. Night-time temperatures have increased more quickly than daytime temperatures. While both spring and summer temperatures increased consistently for the majority of the climate stations in the region, winter minimum temperatures in Quesnel and Prince George have increased dramatically over the past 50 years. These temperature changes and those projected for the future have important implications for management of watersheds and ecosystems for agriculture, forestry, fisheries, wildlife and biodiversity.

Although precipitation trends for the 1950-2001 period are presented, the majority are not statistically significant. This is because of the large variability in these records. Tatlayoko Lake was one exception, with a statistically significant decrease of 27% detected in winter precipitation.

Future Cariboo-Chilcotin climate projections from global climate models (GCMs) for temperature and precipitation are presented as box and whisker plots. These box plots show the range of climate change projected by 96 simulations produced by 15 different GCMs, each of which applied both low and high greenhouse gas emissions scenarios. These plots allow readers to see the change projected by the majority of models and the range amongst models, and to contrast the changes projected by different emissions scenarios. Differences in projected climate change for different emissions scenarios become prevalent by the 2080s. Median projected values show warming by about one degree in each 30-year period for the 2020s and 2050s with larger increases by the 2080s, in both summer and winter. Median precipitation projections for the 2080s were 13% wetter in winter but slightly drier in the summer as compared to the 1961-1990 baseline period. Projections using the higher greenhouse gas emissions scenario show greater warming than the lower emissions scenario by the 2080s, especially in winter.

While the results from different GCMs are presented to illustrate uncertainty in future climate projections, maps from a single run of the Canadian Regional Climate Model is also used to provide a spatial representation of climate change for the 2050s as compared to 1961-1990 over the Cariboo-Chilcotin. Regional Climate Models work on a finer scale than GCMs allowing a more refined representation of topography, elevation and land cover. Maps are provided for annual and seasonal changes in temperature and precipitation, as well as spring snow-water equivalent. Projections of growing degree days using empirical high resolution downscaling are also presented. All projections have uncertainties due to the inability of climate models to replicate all climate features and unknowns in the trajectory of greenhouse gas emissions.

Future work to assess potential vulnerabilities and opportunities from climate change for Cariboo-Chilcotin ecosystems and resource values is recommended. These assessments could lead to the development of specific adaptation responses to minimize the disruption to important ecological, economic and social values in the Cariboo-Chilcotin.

1 INTRODUCTION

1.1 Purpose

This report is the first component of a project designed to help resource managers in the Cariboo-Chilcotin area of British Columbia understand and incorporate the potential risks of climate into current and future land use planning efforts. This first component provides a preliminary assessment of historical and possible future climate change in the Cariboo-Chilcotin. Future work on this project depends on availability of funding and staff resources. Logical future project components would:

- identify vulnerabilities and potential opportunities resulting from climate change for key resources values and ecosystem components included in the Cariboo-Chilcotin Land Use Plan (CCLUP), and
- propose initial adaptation actions that could be taken to address the identified vulnerabilities and opportunities.

Goals of the overall project are:

- to raise awareness of local resource management professionals and stakeholders about potential climate change issues in the Cariboo-Chilcotin area;
- to gather and share the perspectives of local and provincial scientists and resource management specialists on potential resource management vulnerabilities and possible adaptation responses;
- to stimulate further discussion and action to adapt resource management and planning in the Cariboo-Chilcotin to a changing climate.

1.2 Description of the Cariboo-Chilcotin Area

The following description of the physiography of the Cariboo-Chilcotin area is adapted, with permission, from Steen and Coupe (1997):

The Cariboo Forest Region is predominantly a plateau between two mountain systems. The plateau is part of the Interior Plateau of British Columbia (Holland, 1976), a level to gently rolling landscape with incised river valleys and uplands locally rising above the general surface. Elevations of the plateau are predominantly 900-1500 m, rising to over 2000 m on local uplands. On the western side of the plateau, the landscape rises abruptly onto the leeward slopes of the Coast Mountains. Peaks in this moderately to highly dissected landscape rise to elevations of 2700 to nearly 4000 m, with several peaks in this area in the 3000-3300 m range. On its eastern side, the plateau landscape rises gradually through a broad transition to the Columbia Mountains. The landscape becomes increasingly dissected as it rises towards the Columbia Mountains, where elevations of summits are generally 2400-3600 m.

The region includes many ecologically important water features. It is bisected by the Fraser River and includes the Chilcotin, Quesnel, and Blackwater (West Road River) watersheds. While the region has very little glacier and icefield area, the Chilcotin and Quesnel watersheds have a component of glacial melt-water input (Fig. 1-1). These two watersheds both have important fisheries values including major sockeye salmon runs. The plateau area is conducive to many small water features, which provide critical habitat for seasonal and migrating birds and other wildlife, and support a way of life for residents of the area.

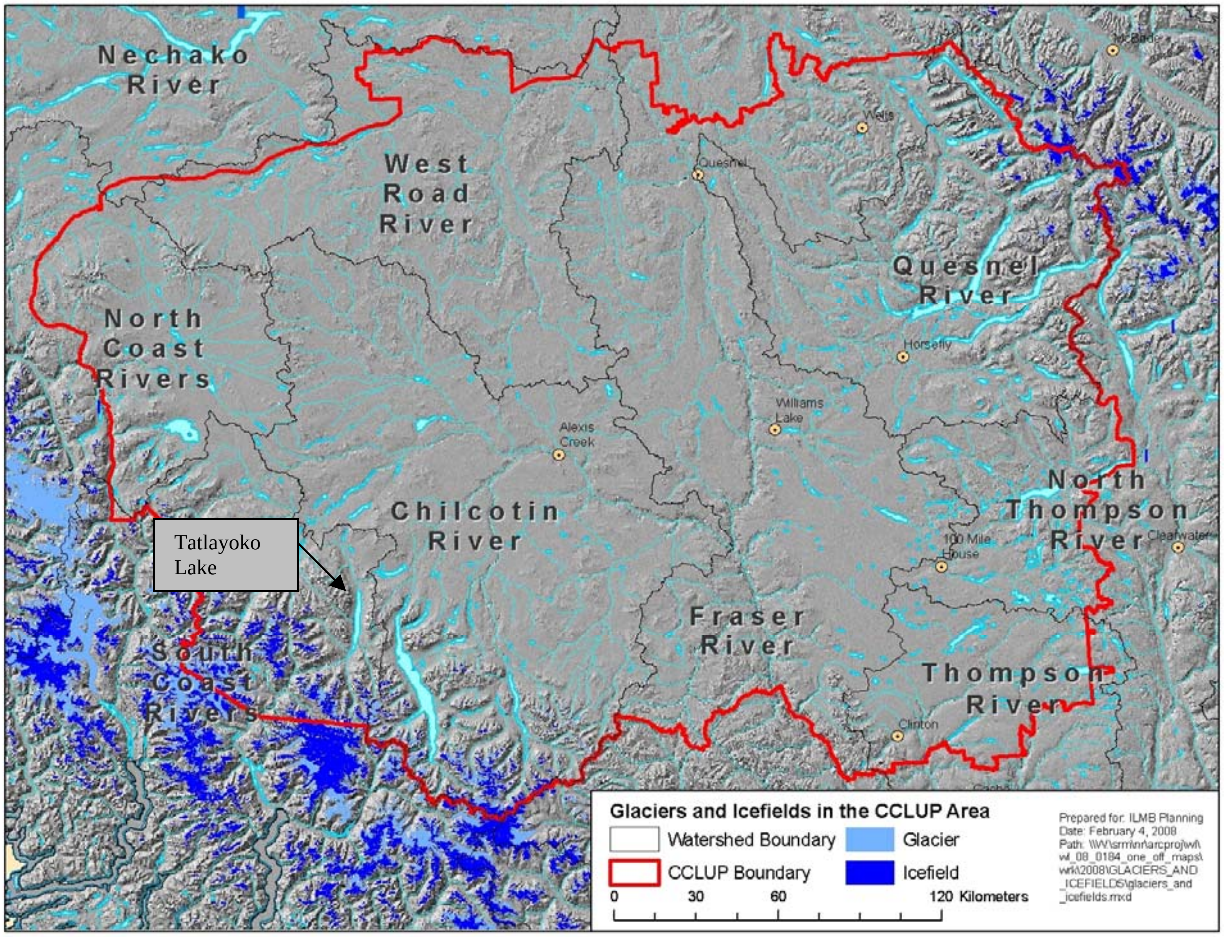


Figure 1-1 – Glaciers, ice fields and major watersheds in the Cariboo-Chilcotin

1.3 Global and Canadian Context of Climate Change

Significant variations and changes in climate occurred around the globe in the 20th century (Fig. 1-2). For example, the average global temperature increased by approximately 0.6°C over the 20th century and could continue to increase during the 21st century by 1.1°C to 6.4°C depending on the worldwide level of future greenhouse gas emissions (IPCC, 2007). Figure 1-2 shows the global changes in temperature by decade from the 1950’s to the 2000’s. In southern Canada, annual mean temperature has increased by 0.9°C over the past century on average (Zhang et al. 2000). Although these changes seem small compared to normal seasonal and even daily temperature ranges, a change of apparently small magnitude can have large impacts. For example, an average global temperature increase of ~4ºC between approximately 18,000 to 10,000 years ago was sufficient to melt the vast ice sheets that once covered much of North America (Walker and Pellatt, 2003).

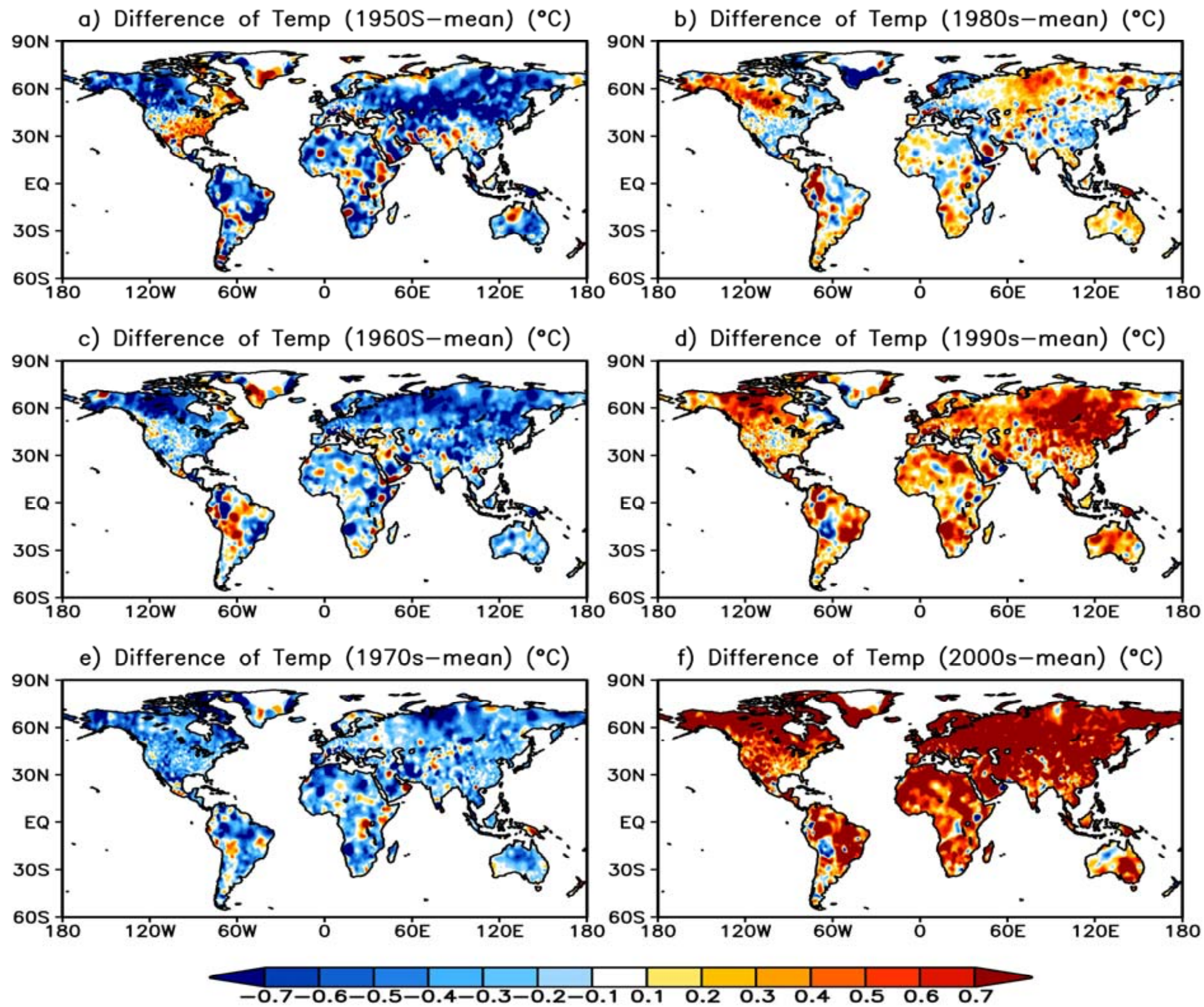


Figure 1-2 – Global mean temperature change by decade from the 1950's to the 2000's versus the mean for the 1950 to 2000 period (used with permission from Dr. Van den Dool, see Fan and Van den Dool, 2008 for methodology).

Precipitation has also changed over the last century. In the southern regions of Canada, annual precipitation increased by 5% to 35% from 1900 to 1998, but significant decreases took place during spring (Zhang et al. 2000). Zhang et al. (2007) quantified precipitation change attributable to anthropogenic forcing (i.e. human induced greenhouse gas emissions). They determined that anthropogenic forcing contributed approximately 50% to 85% of the 62 mm per century increase in annual total land precipitation between 40°N and 70°N. This indicates that the spatial distribution of precipitation is also changing because of climate change. In addition to climate change, longer time-scale variability is prevalent in the precipitation record for Western North America, such as the severe drought that occurred in the 1930s (Trenberth et al. 2007).

A number of uncertainties about the rate and timing of future climate change remain. In addition to uncertainties in modelling the climate system, the rate of climate change over the next century depends on the amount of greenhouse gas emissions produced globally. By the end of the 21st century, even the most conservative projections suggest a new average annual temperature similar to the warmest years of the 20th century, for British Columbia. The less optimistic projections suggest that we might even expect the coldest years at the end of the 21st century to be warmer than the warmest years of the past century (Rodenhuis et. al., 2007).

1.4 Overview of the Report

- Section 2 of this report describes concepts such as weather, climate variability, climate change and general methodology for the climate analyses. It provides a foundation for the chapters that follow.
- Section 3 describes historical trends and future climate projections in the Cariboo-Chilcotin and adjacent areas. It also includes a more specific description of the climate analysis methods used for this report.
- Section 4 lists types of potential climate change impact in the Cariboo-Chilcotin.
- Section 5 describes potential next steps in this project.

2 CLIMATE CONCEPTS, TERMS AND MEASUREMENT[1]

The science of climate variability and change incorporates specialized concepts, technical terminology and measurement practices. This section defines and discusses concepts and terms, giving additional attention to those that are often misunderstood.

2.1 Climate Time Scales, Concepts and Terms

2.1.1 Climate and Weather

Climate	Climate in a narrow sense is usually defined as the "average weather" or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over time periods ranging from months to thousands or millions of years. The traditional period is 30 years, as defined by the World Meteorological Organization (WMO). The climate of an observational site is often described by an average value of relevant observations, such as temperature, precipitation, or wind. Climate in a wider sense is the state of the global climate system, including a statistical description of all five components of the climate system: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere and the interactions between them.
Weather	The term 'weather' describes the day-to-day and hour-by-hour changes in atmospheric conditions at a given location.

Although the terms "climate" and "weather" are often used interchangeably, there is an important distinction. Weather describes the atmospheric conditions at a given time and location. Climate is the synthesis of day-to-day variations into a set of average conditions, often based on a statistical summary such as the average of a 30-year record of weather observations. Figure 2-1 shows the relationship between weather and climate.

[1] This section is based on a report prepared for the Columbia Basin Trust (Murdock et. al., 2007). Definitions are based on the Intergovernmental Panel on Climate Change (IPCC 2001 Annex B) and supplementary information provided by PCIC and other contributors. Environment Canada's website *http://www.ec.gc.ca/climate/* provides detailed information on other climate concepts.

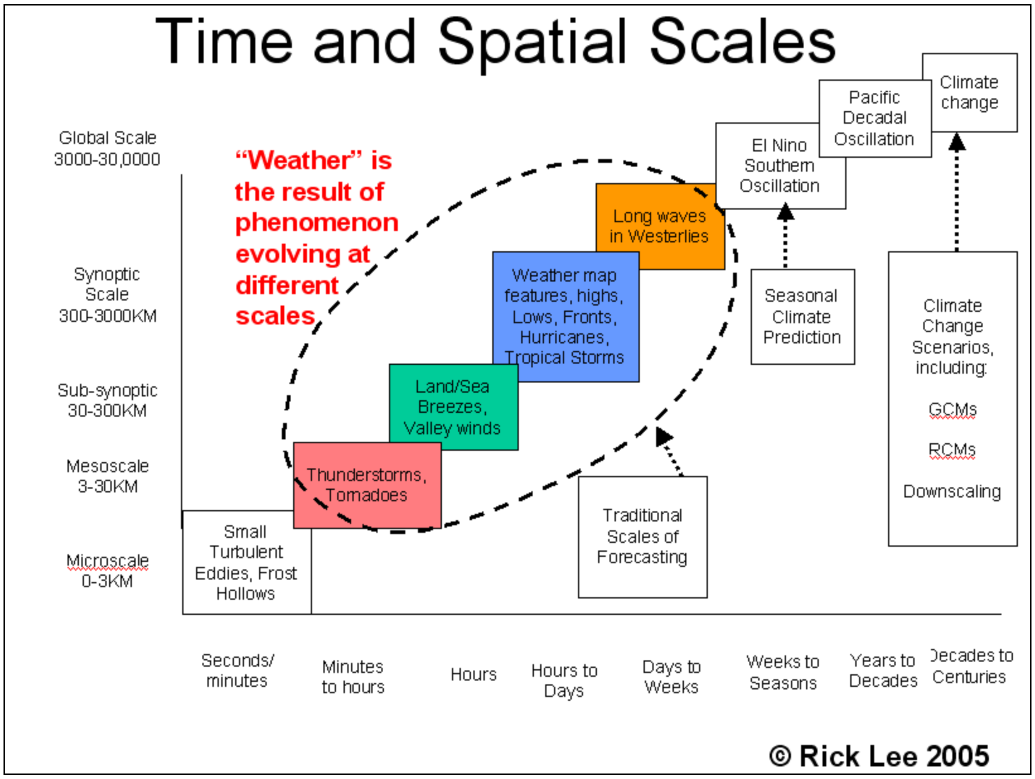


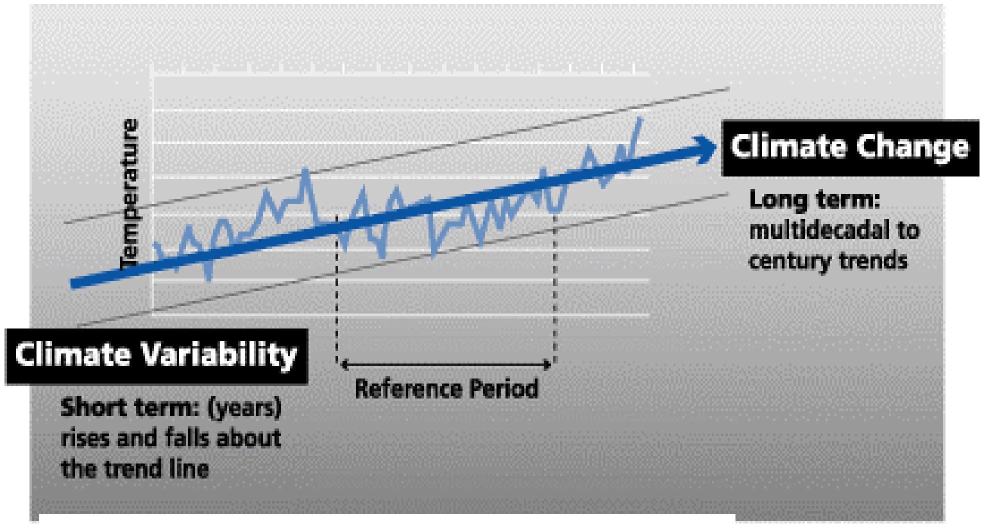
Figure 2-1 – Time and spatial scales of weather and climate

2.1.2 Important aspects of climate variability and climate change

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Climate change: Climate change refers to a statistically significant change in either the mean state of the climate or in its variability, over an extended period (typically several decades or longer). Climate change may be due to natural internal processes or external forcing such as persistent anthropogenic changes in the composition of the atmosphere or in land use.

The terms "climate variability" and "climate change" are sometimes used interchangeably just as weather and climate are, though they too denote different concepts. The convention adopted in this document is to distinguish between the two based on time scale only. Recall from 2.1.1 that climate can be defined on various time scales. Consider for this report a standard period of a few decades. Climate variability then refers to oscillations and variations experienced on shorter time scales such as years or decades, and climate change refers to changes on longer time scales such as half a century or more. Figure 2-2 shows the time scales of climate variability and change as they are used in this document.



WLAP 2002

Figure 2-2 – Time scales of climate variability and climate change

Climate variability is caused by several different mechanisms that redistribute the heat and motion of the atmospheric-ocean-and hydrological system of the Earth. In particular, the Pacific Northwest as a whole, including the Cariboo-Chilcotin, is strongly influenced by changes to the sea surface temperature of the Pacific Ocean and the hemispheric atmospheric flow patterns that develop as a consequence. In particular the El Niño/Southern Oscillation (ENSO) influences climate variability on the scale of seasons to years, while the Pacific Decadal Oscillation (PDO) occurs over 20-30 years. These two patterns, as well as other global factors affecting climate variability are described below.

- **El Niño/Southern Oscillation (ENSO)**

ENSO is an irregular tropical Pacific ocean-atmosphere phenomenon that influences climate around the world. Its effects are different from one episode to the next, depending on the strength and structure of ENSO. ENSO tends to shift between the two extremes and the neutral state irregularly within a two to seven year period. Usually it does not remain in either the warm or cold phase for any longer than a year or two although longer instances have occurred. Figure 2-3 documents this alternation between warm and cool phases and the relative strength of episodes over the last 58 years using the “multivariate ENSO index” which is calculated from six meteorological variables (Wolter, K., and M.S. Timlin, 1993).

The influence on B.C.’s climate is strongest in spring and winter, and ENSO can enhance or reduce the normal seasonal variations in climate. During the “warm phase” (El Niño) of ENSO, when sea temperature is relatively high off the western coast of South America, generally warmer than normal winter and spring temperatures occur in western Canada, accompanied by reduced precipitation. During the “cool phase” (La Niña), western Canada normally experiences cooler and wetter winters. For example, most of the Cariboo-Chilcotin region is 3°C to 5°C warmer and receives 5% to 15% less precipitation on average during El Niño winters. See Figures 3-3 and 3-4 for maps of the ENSO effect on the temperature and precipitation in the Cariboo-Chilcotin.

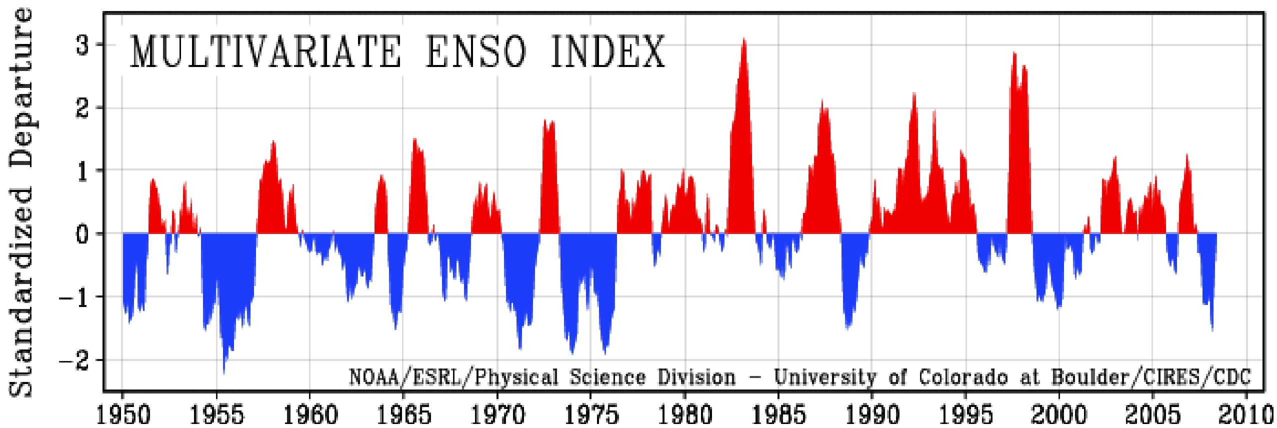


Figure 2-3 – Monthly Average Values for the Niño ENSO Index. Positive (red) index values indicate an El Niño event. Negative (blue) values indicate a La Niña event.

- **Pacific Decadal Oscillation (PDO)**

The PDO is a large-scale climate oscillation characterized by spatial variations in the sea surface temperature and atmospheric pressure anomalies in the northern Pacific Ocean (Zhang *et al.* 1997; Mantua *et al.* 1997). It has a warm and a cool phase; during the 20th century it remained in each phase for 20 to 30 years. In B.C., average air temperatures and precipitation have fluctuated with this cycle. The PDO amplifies or dampens the effects of ENSO (Mantua *et al.* 1997, Newman *et al.* 2003). For example, during the warm phase of the PDO, El Niño years tend to be warmer than they are during the cool PDO phase, and La Niña years are coolest during the PDO cool phase. Similarly, El Niño events that occur during warm phases of the PDO are drier during winter.

Sea surface temperature records indicate that the PDO was in a cool phase from about 1890 to 1924 and from 1947 to 1976 and was in a warm phase from 1925 to 1946 and from 1977 until at least the mid-1990s (Hare and Mantua, 2006). A change from warm to cool may have occurred since the mid to late-1990s, but it is difficult to positively identify the change between phases until sufficient records have been accumulated, many years after the shift occurs.

- **Natural and human-induced climate change**

Climate change typically occurs over long time scales. Natural factors, including variations in solar output, the orientation of the earth's axis, and the shape of the earth's orbit vary over hundreds to hundreds of thousands of years and are associated with longer-term global climate change. The term "climate change", however, is sometimes used to refer exclusively to the effect on climate made by humans through releasing greenhouse gases by burning fossil fuels and changing land use. This type of climate change is occurring over shorter time scales than natural climate change has in the past. Today, both natural and human-induced influences are at work simultaneously. The empirical view used in the historical climate analysis in this report makes no distinction between natural and human-caused climate change. The future climate projections included in this report are based on results from climate models that are driven by scenarios of future greenhouse gas emissions and other human-induced forcings such as aerosols.

2.1.3 Extreme weather events and climate change

Extreme weather event: An extreme weather event is an event that is rare within its statistical reference weather distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place.

Natural climate variability normally includes temperature, precipitation and wind events at the outer margins of that observed on a regular basis. Events are characterized by their 'return periods' as 100-year or 50-year events, for example, and a particularly severe event would have a longer return period. Individual extreme weather events cannot be tied directly to climate change. However, climate change may change the frequency (the return period) or the magnitude of such events compared to what would be expected from return periods based on historical observations.

2.2 Measuring and Analyzing Historical Climate

2.2.1 Paleoclimate

The paleoclimate record is based on terrestrial and marine records such as fossils, tree rings, pollen, sand dunes, and other information preserved in sediments and glacial ice. Such records are affected by climate and can be used to provide evidence about the climate that existed prior to the recording of instrumental observations.

In addition to providing information about climatic conditions over long periods of time, paleoclimatic analysis can provide useful information about ecosystem responses to climate variability and change that have occurred in the past and can be considered when projecting realistic responses to future climate change. The BC Chapter of a Natural Resources Canada national assessment of climate change adaptation (Walker and Sydneysmith, 2008) includes paleoclimate information for BC. No analysis of paleoclimate is included in this report.

2.2.2 Historical Weather Measurements and Climate

The Meteorological Service of Canada (Environment Canada) has maintained weather stations at locations throughout the country for over a century. At these stations, instruments record temperature, precipitation, wind speed and other weather conditions. Information from these stations is the foundation for the weather reports and forecasts that citizens are familiar with. In the Cariboo-Chilcotin region, only the Quesnel weather station has a century-long continuous climate record that continues to the present.

The historical climate dataset used for this report is Environment Canada's *Adjusted Historical Canadian Climate Data* (AHCCD) (Environment Canada, 2005). The records from these stations have been refined specifically for climate research in order to account, where possible, for station moves, changes in instruments or exposure and changes in observing practices during the period of record.

Air temperature is a weather variable that is used to describe climate. It is easily measured, directly observable, spatially coherent and is of ecological and socioeconomic importance. Table 2.1 describes common observations and calculations used to measure temperature.

Table 2-1 – Temperature measures

Measure	Observation/calculation
Daily minimum	Usually occurs near dawn
Daily maximum	Usually occurs during the afternoon
Daily average or mean	The average of measured minimum and maximum temperature. Also, less commonly, hourly temperatures are used to compute a daily average, or mean.
Daily diurnal temperature range	The difference between daily maximum and minimum temperatures.
Extreme minimum or maximum	Respectively the lowest and highest recorded values. Must be accompanied by time period to which it refers – daily, monthly annually or period of record. (Not reported in this analysis).
Growing Degree Days	Calculated as the sum of the daily growing degrees for each day over a given season. Daily GDD is daily mean temperature minus a selected base temperature.

Precipitation is also an important property of weather and climate. It is highly variable spatially because of the influence of local features such as topography, elevation, aspect and exposure. Not only is total (accumulated) precipitation over a time important, but also the rate at which it falls, the form (rain or snow) and its spatial distribution.

Table 2-2 – Precipitation measures

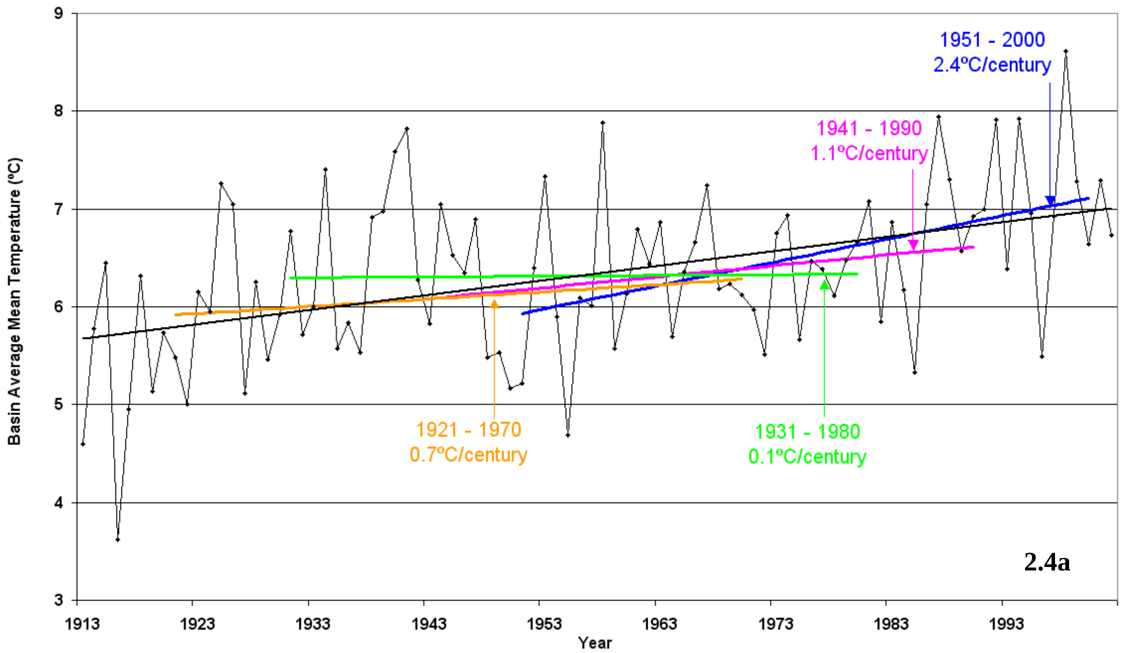
Measure	Observation/calculation
Rainfall	Amount of precipitation falling as rain (mm)
Snowfall	Amount of precipitation falling as snow (cm)
Precipitation	Total precipitation: rainfall plus snowfall converted to equivalent amount of rain (mm)
Snowpack/ snow depth	Depth of snow on ground (cm)
Snow water content / snow water equivalent	Amount of water in snowpack (kg/m^2, mm)
Snowcover	Area covered by snow (km^2)

2.2.3 Analysing Historical Climate Trends

Climate trends provide a picture of how much change has occurred in the past, for example over a period of 50-100 years. Climate trends are derived from statistical analysis of historical climate data or from analysis of paleoclimate records (before direct measurements) such as tree rings.

A historical climate trend based on past weather observations describes the climate that occurred over a certain period. To determine whether climate trends reflect climate variability or climate change, the statistical significance of trends over time periods of several decades must be considered, and comparisons of trends between stations and between adjacent regions need to be made. A linear trend cannot be extrapolated into the future because the climate system is non-linear**.**

Assuming that data of sufficient quality exist, historical records can be tested for trends. However, assigning the causes for trends can be far more difficult. One of the challenges in identifying whether trends for the study area reflect climate variability or change is to determine the influence of PDO and ENSO. The effect of the start date on historical temperature trends is shown in Figure 2-4 for mean temperature. The figure, from the Canadian part of the Columbia Basin, demonstrates that the trend must be interpreted in the context of the time period from which it was derived. For example, of the mean temperature trends that go to the end of the century, the largest change occurred between 1971-2000, followed by 1951-2000, and then 1913-2002 with equivalent rates of increase per century of 4.2°C, 2.4°C, and 1.4°C respectively. In this case, the shorter trend reflects the combined influences of more warming towards the end of the century as well as the larger influence of variability, particularly PDO. Note that the larger influence of climate variability in the shorter time periods implies neither that the trends are not robust nor that they are inconsistent with the long-term trend. Trends in longer records must also be interpreted with care. Precipitation in the early part of the 20th century, for example, was very low in comparison to later decades due to large-scale drought in North America during the dust bowl years (Mote et al., 2005).



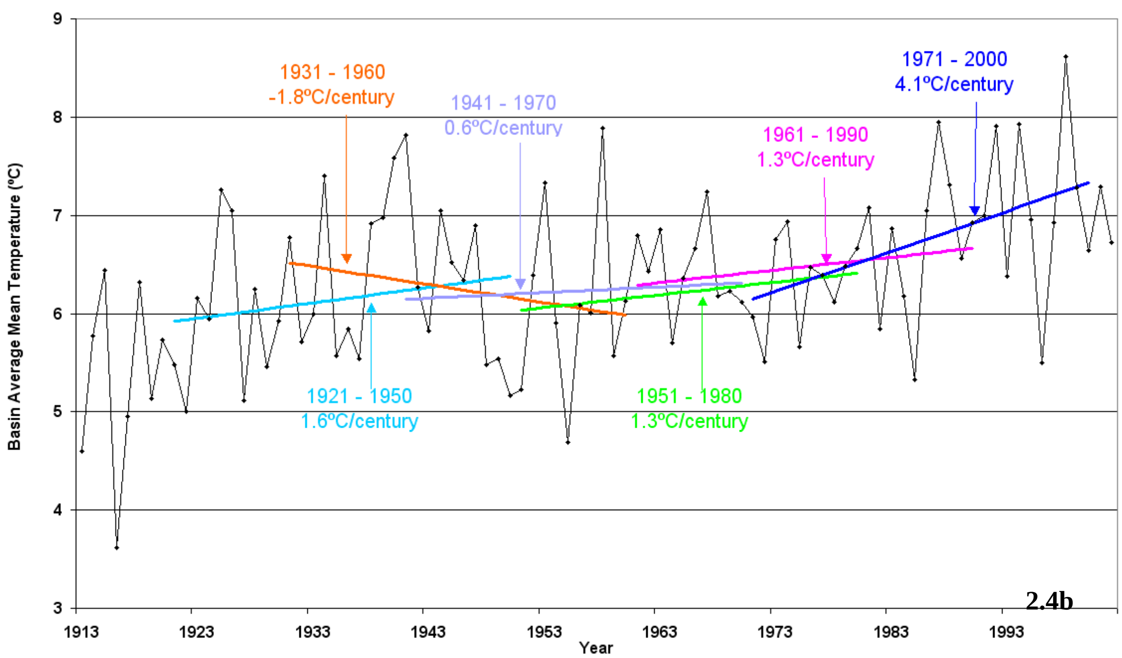


Figure 2-4 – Mean temperature trends for Canadian portion of the Columbia Basin for (a) 50-year trends and (b) 30-year trends. From Murdock et. al. 2007.

2.3 Projections of Future Climate

This report uses the following terms with respect to future climate:

Climate model	A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. At present, coupled atmosphere/ocean/sea ice global climate models (GCMs) provide the most comprehensive representation of the climate system. There are dozens of GCMs, each run by a different research group, and most future climate change projections are based on the use of more than one GCM. In this report, the results from a Regional Climate Model (RCM) are also presented. Regional Climate Models are driven by GCMs at the perimeter of their focus area and thus large-scale circulation is constrained by the GCM they are connected to. Like GCMs, RCMs include numerical representation of the climate system, but operate on a finer geographic scale. This allows for better representation of landscape features such as mountains, shorelines, and land cover.
Climate projection	A projection of the response of the climate system to altered forcings, such as changing greenhouse gas emissions or concentrations, typically based on simulations by climate models. The use of the word ‘projection’ rather than ‘prediction’ reflects a far lower level of certainty.
Emissions scenario	Plausible future greenhouse gas emissions, based on assumptions about future socio-economic and technological developments. There are a number of emissions scenarios, based on different sets of assumptions.
Ensemble of projections	A collection of projections can provide a range of plausible future outcomes from different models run with different emissions scenarios. Climate models are imperfect, and there is considerable uncertainty regarding the release (amount and timing) of future greenhouse gases worldwide over the next century. The uncertainty is partially reflected by the use of a range of plausible climate projections, rather than a single projection.
Climate scenario	A climate scenario (or climate change scenario) is information about future climate used for decision-making. Use of scenarios in developing policy and resource management plans requires caution because of the significant uncertainty associated with these projections. Although there are many kinds of climate scenarios, the most commonly used scenarios are *ensembles of GCM projections* – and the two terms are often used interchangeably.

Climate baseline	Average climate during a historical reference period, usually a 30-year period. In this report, the period from 1961-1990 is used for the climate baseline.

2.4 Continuing Emergence of Climate Information

Investigations into climate variability and change are continuing to generate new information and insights. For example, a national assessment of climate change adaptation was recently completed by Natural Resources Canada (Walker and Sydneysmith, 2008). The recently released Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) presents an international peer-reviewed consensus of thousands of climate researchers (IPCC, 2007). IPCC has published several reports on: the physical basis of climate change; impacts, adaptation, and vulnerability and mitigation of climate change. IPCC summary documents for policy makers as well as technical documents are publicly available at http://www.ipcc.ch/.

3 CLIMATE CHANGE IN THE CARIBOO-CHILCOTIN: PAST TRENDS AND FUTURE PROJECTIONS

This section focuses on climate of the Cariboo-Chilcotin region. It documents baseline climate for the 1961-1990 period, examines historical climate trends, and projects possible future climate based on global and regional climate models.

3.1 Baseline Climate for the Cariboo-Chilcotin

Section 3.1 provides two types of climate information for the 1961-1990 period. First, tabular summaries of climate data from three weather stations within the region are presented. Then maps of the baseline temperature and precipitation are shown. Note that the 1961-1990 climate is used as a baseline against which the climate change projections shown in section 3.3 are compared.

3.1.1 1961-1990 Station Climatology Data

Table 3-1 and 3-2 show baseline temperature and precipitation data for the two largest population centres in the region and one additional station west of the Fraser River. While these three stations cannot adequately represent the diversity of the regional climate, they do provide reference points to examine the mean and variability of seasonal climate during the baseline period. Both the mean and variability of seasonal temperatures affect many ecological and hydrological processes. Mean annual and maximum winter temperatures are less than 0°C for all three climate stations: Quesnel Airport, Tatlayoko Lake and Williams Lake Airport. The variability (standard deviation) of minimum, maximum and mean temperatures is much higher in winter than in summer for all stations. Minimum temperatures in winter are more variable than maximum temperatures while the opposite is true in summer.

Table 3-1 – 1961-1990 baseline temperature data for three stations in the Cariboo-Chilcotin

Station elevations are: 1) Quesnel Airport - 545m, 2) Tatlayoko Lake - 870m, 3) Williams Lake Airport - 940m.

		Annual			**Winter**			**Summer**		
		Min Temp (°C)	Mean Temp (°C)	Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)	Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)	Max Temp (°C)
Quesnel A	Mean	-1.2	4.8	10.8	-11.5	-7.0	-2.5	8.2	15.6	23.0
1096630	St dev	0.9	0.8	0.9	2.6	2.2	1.9	0.7	0.8	1.4
Tatlayoko Lake	Mean	-3.0	3.9	10.8	-11.1	-5.8	-0.4	4.2	12.9	21.6
1088010	St dev	0.7	0.6	0.7	1.9	1.7	1.5	0.6	0.8	1.4
Williams Lake A	Mean	-1.4	4.1	9.6	-11.3	-7.0	-2.6	7.9	14.6	21.2
1098940	St dev	0.8	0.8	0.9	2.2	1.9	1.7	0.7	1.0	1.4

In addition to the total precipitation, the proportion that falls as snow, the timing of snow melt and the variation in snow depth between years all have important ecological and hydrological implications and are likely to be affected by climate change. During the 1961-1990 baseline period, the proportion of total precipitation from snowfall varies from 27% at Tatlayoko Lake, to 35% at Quesnel Airport to 45% at Williams Lake Airport. Snowpack depth is greater on December 31st than it is on March 31st for Quesnel Airport and Williams Lake Airport, perhaps because snow is lost to sublimation or melt between December and March. As indicated by the coefficients of variation (Cf var), snowfall varies more from year to year relative to the mean than annual precipitation at Quesnel Airport and Tatlayoko Lake. Williams Lake shows similar variation between years for snowfall and total precipitation. Overall, precipitation at all stations is relatively low compared to other areas in BC.

Table 3-2 – 1961-1990 baseline precipitation and snow depth for three stations in the Cariboo-Chilcotin

		Annual				
		Precipitation (mm)	Rainfall (mm)	Snowfall (cm)	Snow Depth March 31st (cm)	Snow Depth December 31st (cm)
Quesnel A 1096630	Mean	536.1	375.9	188.7	8	26
	St dev	87.7	66.9	67.0	15	16
	Cf var	0.2	0.2	0.4		
Tatlayoko Lake 1088010	Mean	438.9	317.0	121.9	NA	NA
	St dev	97.6	99.3	49.1	NA	NA
	Cf var	0.2	0.3	0.4		
Williams Lake A 1098940	Mean	424.4	268.2	191.6	12	28
	St dev	95.5	88.4	59.6	15	17
	Cf var	0.3	0.3	0.3		

3.1.2 1961-1990 Climatology Maps

Figures 3-1 and 3-2 display the spatial distribution of mean annual temperature and mean annual precipitation for the Cariboo-Chilcotin during 1961-1990. Baseline climate maps were developed using PRISM data. The Parameter-elevation Regressions on Independent Slopes Model (PRISM) interpolates station-based measurements of monthly and annual temperature and precipitation to regularly spaced (~4km by ~4km) grid cells (Daly et al., 1994). Orographic effects are modelled by employing a digital elevation model (DEM) and regression techniques (Daly et al., 1994). Stations are weighted to account for “spatial variation in climate caused by elevation, terrain orientation, effectiveness of terrain as a barrier to flow, coastal proximity, moisture availability, a two-layer atmosphere (to handle inversions), and topographic position (valley, midslope, ridge)” (Daly, 2006). Complex climatic extremes, such as rain shadows, coastal effects, and temperature inversions, were modelled with the assistance of expert knowledge[2]. Station data used to create PRISM in BC and the Yukon was provided by

[2] http://www.prism.oregonstate.edu/

Environment Canada, including 41 precipitation and 48 snow course stations, and the global historic climatology network (GHCN)[3] (Simpson et al., 2005).

As described by Steen and Coupe (1997) the climate of this area "is largely determined by physiographic features and their effects on principal air masses. The region is affected by three principal air masses: warm, moist pacific air from the west; cold dry arctic air from the north; and warm dry Great Basin Air from the south." The following climate summary was adapted, with permission, from Steen and Coupe (1997).

Since the Cariboo-Chilcotin is in the lee of the Coast Mountains, the moist Pacific air does not have a major effect on the climate. Western potions of the Fraser Plateau which are strongly affected by the Coast Mountains rain shadow are amongst the driest parts of the region. In the Northern part of the region the effects of the Coast Mountains are less intense and interactions between Pacific and Arctic air masses are more frequent resulting in greater precipitation.

As the Pacific air moves eastward across the Fraser Plateau, humidity and precipitation increase slightly. Further eastward from Williams Lake, the westerly flow of air rises over the Quesnel Highland, and eventually the Cariboo Mountains resulting in rapidly increasing precipitation. Elevations of the eastern Fraser Plateau and bottoms of major valleys in the Quesnel Highland are generally below 1100 m and, as a result, temperatures are warmer than on the higher plateau in the western parts of the Fraser Plateau. In addition the higher humidity and cloud cover results in less radiative cooling during the summer, and [growing season] frosts are less frequent.

During summer months, the westerly flow of Pacific air is diminished by the large Pacific high pressure centre. Much of the precipitation during the summer is the result of numerous convective storms.

The Arctic air mass is well north of the Cariboo-Chilcotin region during most of the summer but affects the climate during the winter months resulting in periods of very cold weather. However, the Rocky Mountains shield the region from the full effects of the cold Arctic air. High snowfall events occur when cold Arctic air invades the region and interacts with moister Pacific air. Northern parts of the region are more affected by Arctic air incursions and thus experience colder snowier winters and cooler summers.

Warm Great Basin air has relatively little effect in the region's climate except in the Fraser River Valley south of the Chilcotin River confluence. During the summer, hot, dry air can penetrate the region from the south resulting in high daytime temperatures and clear skies. Incursions of this air are limited by the Cascade and Coast mountains, the relatively high elevations of the Fraser Plateau and the narrowness of the Fraser River Valley.

The interpolated average annual temperature map in Figure 3-1 closely reflects the temperature patterns described by Steen and Coupe. Annual average air temperature ranged from -5°C to 0°C at the highest elevations that include the lee side of the Coast Mountains west of Tatlayoko

[3] http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php

Lake, the Rainbow, Ilgachuz and Itcha ranges in the vicinity of Anahim Lake, and the Cariboo Mountains in the northeast part of the region. High plateau areas west of the Fraser River have average temperature from 0°C to 2°C while plateau areas to the west of the Fraser River are slightly warmer. The warmest annual average temperatures of 4°C to 6°C are found along the Fraser River Valley and in the areas of Clinton and 100 Mile House.

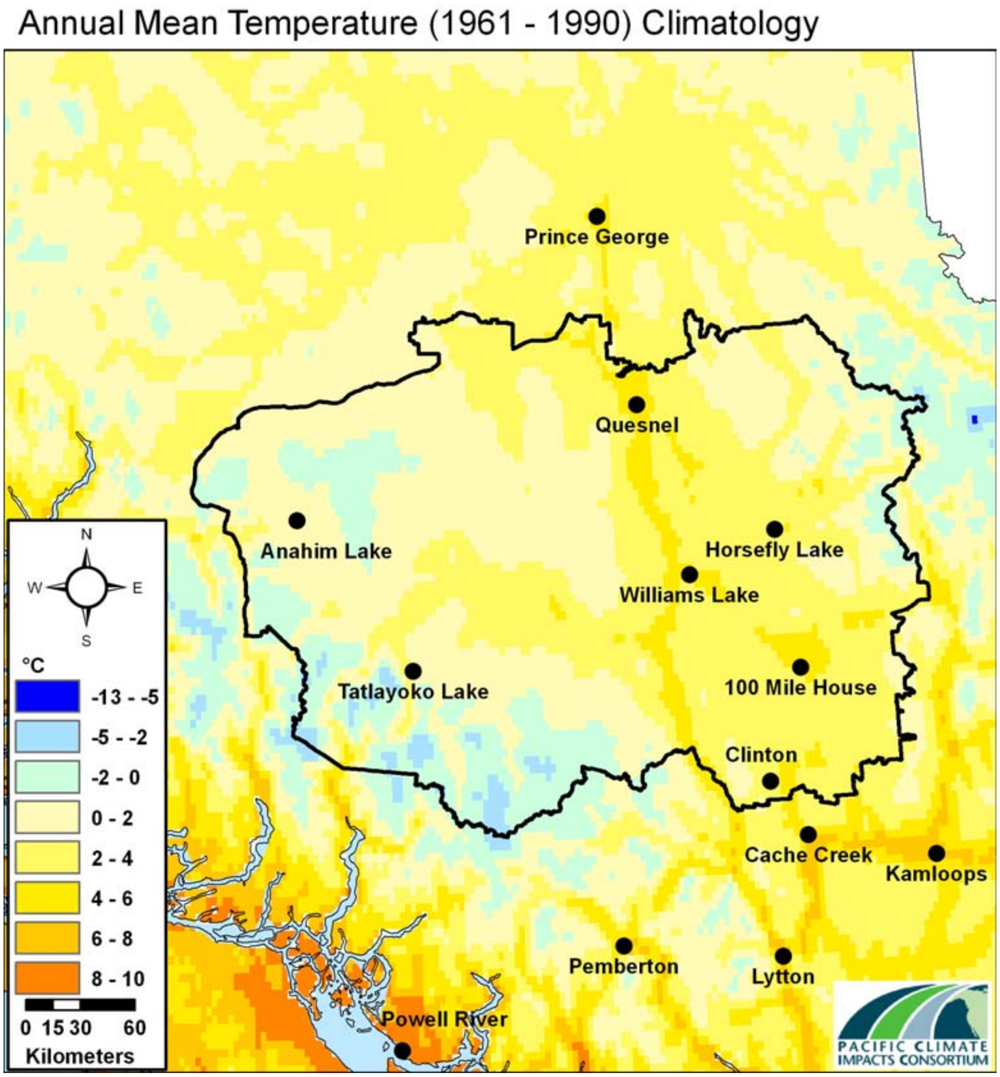


Figure 3-1 – Baseline map of mean annual temperature for the Cariboo-Chilcotin (1961-1990).

The baseline annual mean precipitation map (Fig. 3-2) also closely reflects the patterns described by Steen and Coupe. Some of the lowest annual precipitation amounts in BC are found in the central Chilcotin Plateau and the Fraser Valley in the southern part of the region, receiving only 250 mm - 350 mm annually. The majority of the area consisting of the Fraser Plateau east and west of the Fraser River receive 350 mm - 650 mm per year on average. Higher elevations in the SW on the lee of the Coastal Ranges and in the NE in the Cariboo Mountains are wetter with precipitation amounts of 750 mm per year and higher.

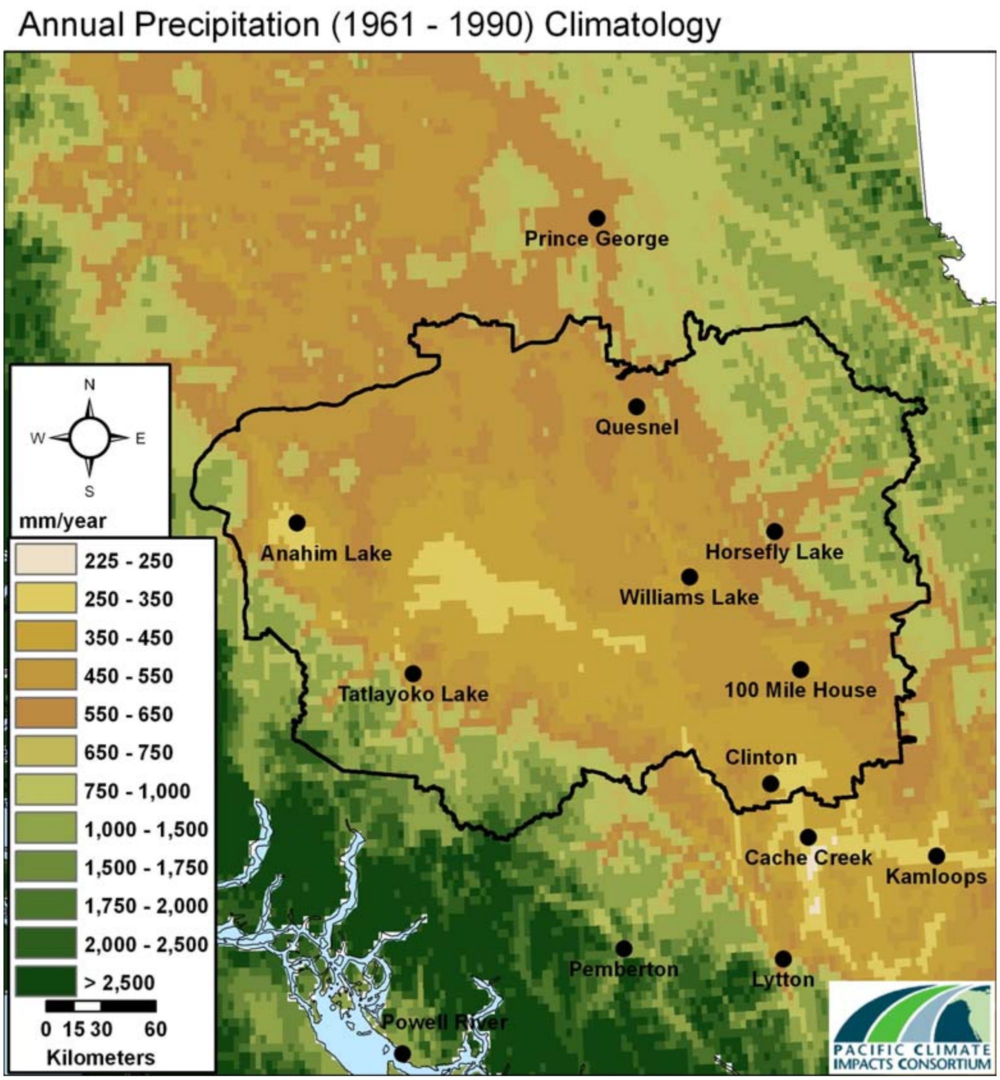


Figure 3-2 – Baseline map of mean annual precipitation for the Cariboo-Chilcotin (1961-1990).

3.1.3 Climate Variability

In addition to any longer term climatic trends, warmer or cooler than average conditions that occur in BC can be attributed to natural cycles of variability. Two modes of variability were described in section 2.1.2 - ENSO (El Niño Southern Oscillation) and PDO (Pacific Decadal Oscillation). The effects in the Cariboo-Chilcotin of each of these two modes of variability are shown for temperature in Figure 3-3 and for precipitation in Figure 3-4. Results are provided for winter when the effects are strongest. These maps are composites from 1900-2004 (ENSO) and 1900-1998 (PDO) data and calculated as differences from the long-term average for the warm and cool modes. The source of the data was CANGRID, at a resolution of 50km (see Rodenhuis et. al. 2007 for more detailed explanation).

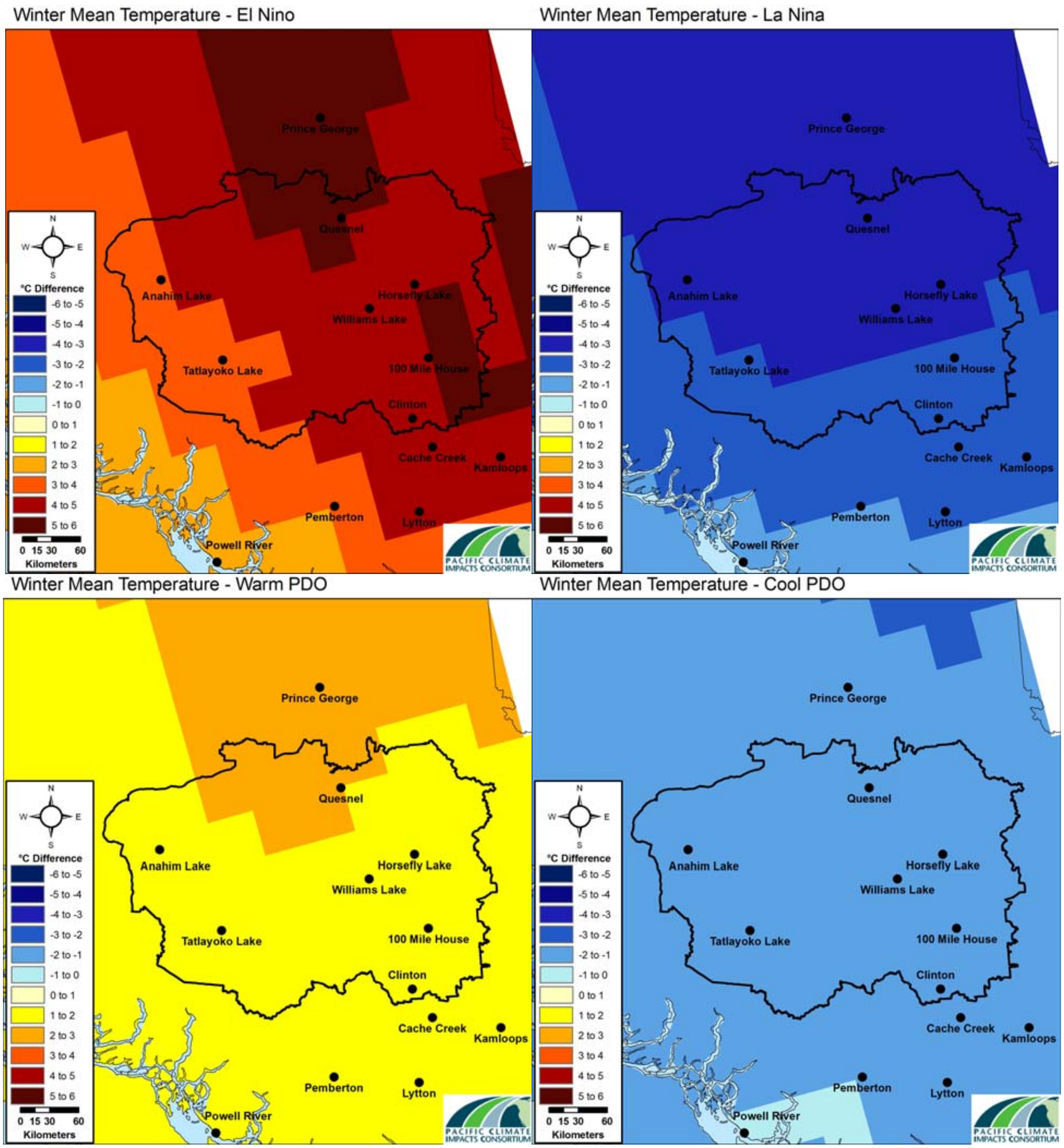


Figure 3-3 – Historical effects of ENSO and PDO on winter temperature in the Cariboo-Chilcotin.

On average, Cariboo-Chilcotin winter temperatures are 3°C to 6°C warmer during El Niño years than the long-term average and 1°C to 3°C cooler than average during La Niña years. Changes to temperature are modulated during the warm- and cool-PDO phases by 1°C to 3°C (warm-phase) or 1°C to 2°C (cool-phase). These modes of variability reinforce each other when they are in phase, i.e. when an El Niño event falls within the warm-PDO period it tends to be warmer than an El Niño event if it were to occur during the cool-PDO period.

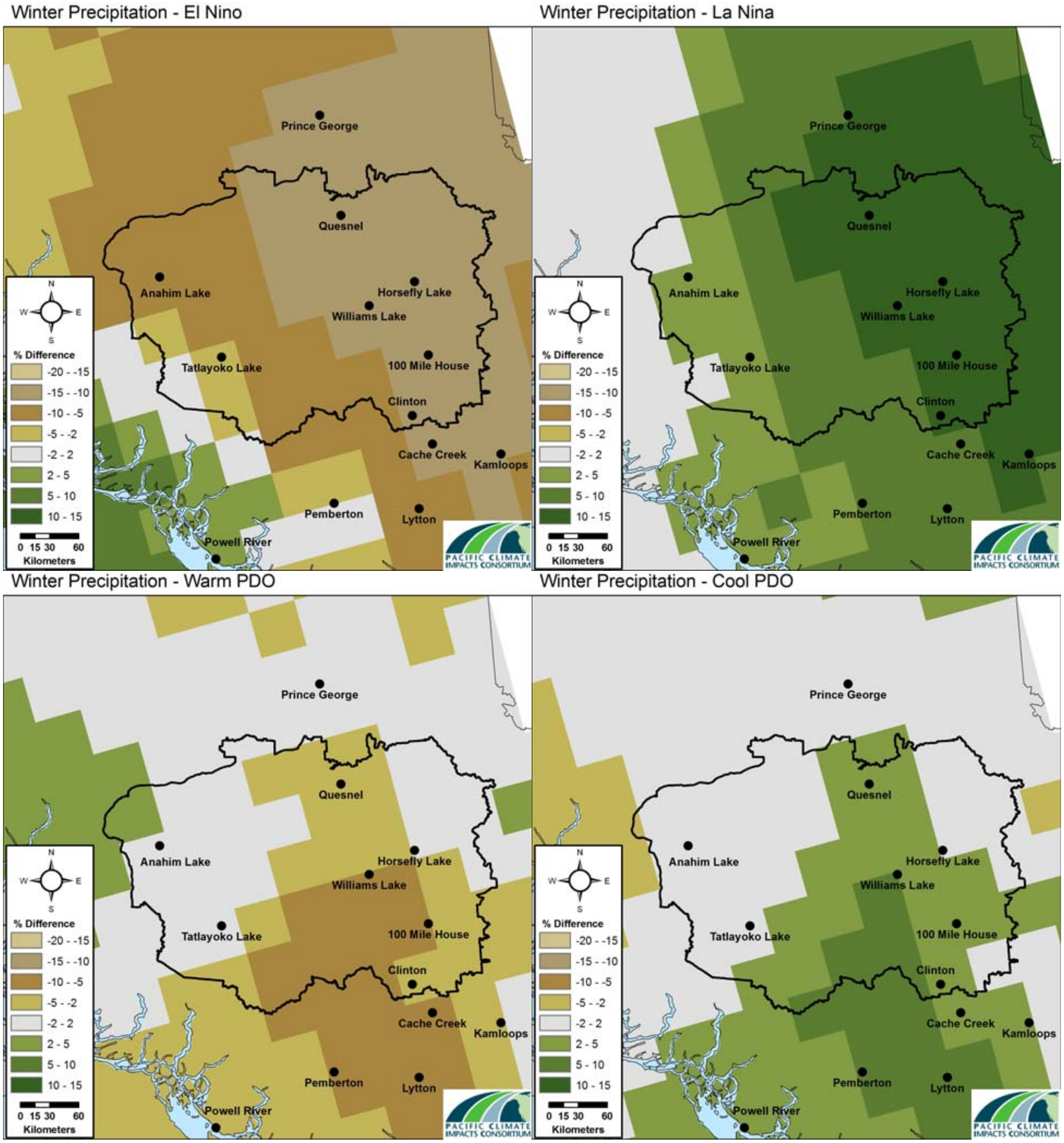


Figure 3-4 – Historical effects of ENSO and PDO on winter precipitation in the Cariboo-Chilcotin.

ENSO affects winter precipitation across the Cariboo-Chilcotin more than PDO (Fig. 3-4). During El Niño events, precipitation is typically 2% to 15% less than the long term average while during La Niña events precipitation is 2% to 15% greater. In the south and central portions of the region, drier conditions occur during warm-PDO (2% to 10%) and wetter conditions during cool-PDO (2% to 10%).

Awareness of the local ENSO and PDO effects can assist managers to anticipate resulting temperature and precipitation variability and therefore increase community resiliency through pre-emptive planning. The effects of ENSO and PDO also overlay and interact with the longer-term trends resulting from global climate change.

3.2 Historical Climate in the Cariboo-Chilcotin

Historical data from Quesnel, covering a 110 year period, are presented to show longer-term climatic variability and trends. Quesnel is the only location in the region with a continuous, century-long climate record that continues to the present day. Shorter term trend data from 1950-2001 are also presented for Quesnel, Barkerville and Tatlayoko Lake within the Cariboo-Chilcotin area and for Kamloops and Prince George from adjacent areas. All data used were extracted from Environment Canada's Adjusted Historical Canadian Climate Database[4]. This data has been quality controlled and adjusted to correct for non-climate related changes, such as station relocation and instrument changes. To allow for consistent comparison, the 1950-2001 time period used for the Environment Canada analyses presented in Table 3-1 and 3-2 was also used for the analyses of Quesnel and Tatlayoko Lake temperatures included in Figures 3-5, 3-6 and 3-7.

Figure 3-5 shows the long-term (1895-2005) mean annual temperature data for Quesnel. Mean annual temperature was highly variable but showed a warming trend (0.9°C/century) over the whole period. A higher rate of warming (3.2°C /century) for the 1950-2001 period reflects both the colder than average temperatures near the beginning of the period and the warmer than average temperatures near the end of the period. Both trends are statistically significant at the 95% confidence level. Comparison of these two trends demonstrates the importance of the time period used in determining climate trends. Therefore, trends need to be carefully examined in the context of longer-term climate patterns and natural variability. Care must also be taken when comparing different seasons and locations to ensure that the same time period and season is being compared.

The Tatlayoko Lake weather station is in the western Chilcotin area (Fig. 1-1). Similar to Quesnel, Figure 3-6 shows the mean annual temperature is highly variable between years but shows a small warming trend over the longer term (0.8°C/century for 1930-2004) with a greater rate of warming more recently (2.1°C/century for 1950-2001).

[4] Environment Canada Climate data: http://www.cccma.bc.ec.gc.ca/hccd/

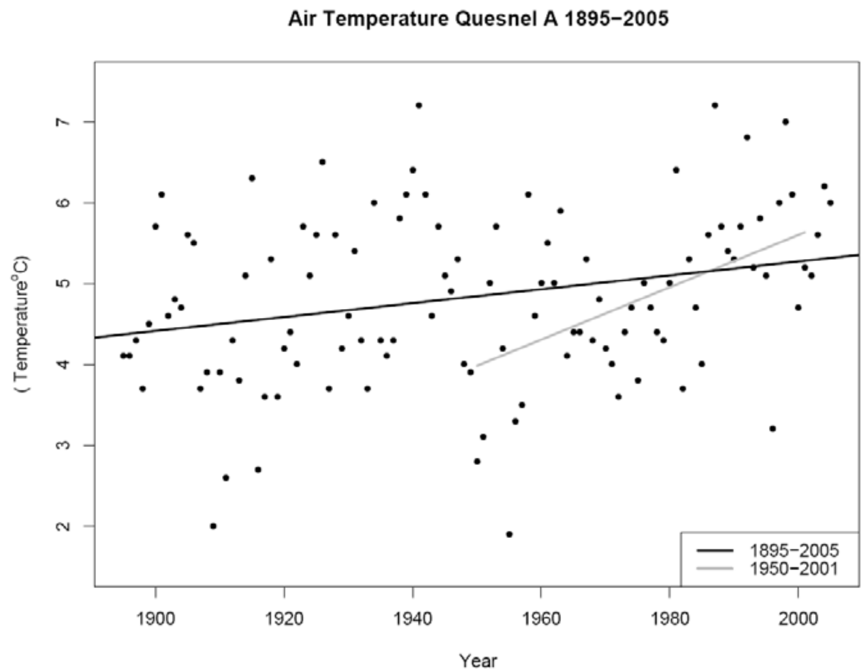


Figure 3-5 – Quesnel mean annual temperature trend 1895-2004 and 1950-2001. Both trends are significant at the 95% confidence level ($p<0.05$).

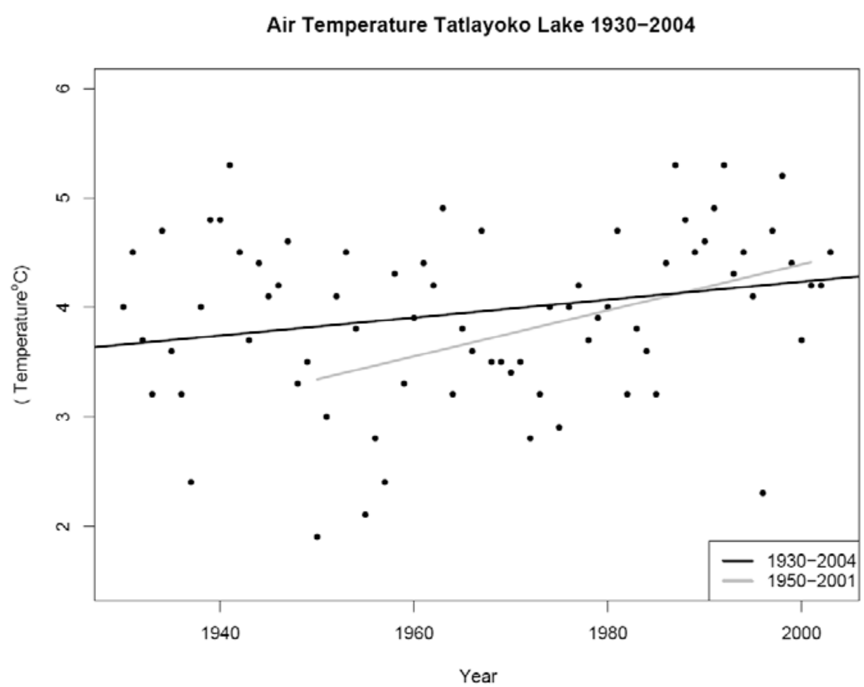


Figure 3-6 – Tatlayoko mean annual temperature trend 1930-2004 (not significant) and 1950-2001 (significant at the 95% confidence level, $p<0.05$).

Table 3-3 presents additional climatic trends for three Cariboo-Chilcotin stations for the 1950-2001 period.[5] This data was not available for Williams Lake Airport but was available for Barkerville, a high elevation station (1265m) east of Quesnel. As previously discussed, the analysis period chosen strongly affects the magnitude of the trend. All three stations show statistically significant increases in annual temperatures over the 1950-2001 period. Mean annual temperature for Quesnel showed statistically significant warming trends over both the long-term (0.9°C /century for 1895-2005) and over the shorter term (3.4°C /century for 1950-2001).

All three stations show statistically significant warming of minimum temperatures in both spring and summer. Quesnel also showed a significant warming of winter minimum temperatures, but with a lower level of statistical significance due to higher variability in winter temperatures. This pattern of greater warming of minimum nighttime temperature than maximum daytime temperature is common throughout the province. Few of the seasonal or annual precipitation trends are statistically significant, reflecting higher variability and less consistent patterns of change than for temperature.

Table 3-3 shows both temperature and precipitation trends per decade based on the 52 year period. Statistically significant trends (P<0.10 or better) are in bold. Seasons are defined as follows: winter includes December-February, spring includes March-May, summer includes June-August, and autumn includes September-November.

Table 3-3 – Climate trends for three Cariboo-Chilcotin weather stations 1950-2001.

Station Name	Element (trend 1950-2001)	Winter	Spring	Summer	Autumn	Annual
Quesnel Airport, BC	Tmin (ºC/decade)	**0.70+**	**0.51****	**0.21***	0.16	**0.39***
	Tmax (ºC/decade)	0.33	**0.35***	0.10	0.14	**0.28+**
	Tavg (ºC/decade)					**0.34***
	Prec (% change/decade)	-4.3	1.4	-0.04	3.2	0.05
Tatlayoko Lake, BC	Tmin (ºC/decade)	0.31	**0.41*****	**0.25***	0.18	**0.31+**
	Tmax (ºC/decade)	0.21	**0.30****	-0.11	0.10	**0.14+**
	Tavg (ºC/decade)					**0.22***
	Prec (% change/decade)	-5.2+	5.8	6.3	-0.9	2.6
Barkerville, BC	Tmin (ºC/decade)	0.24	**0.36***	**0.25***	0.13	**0.29***
	Tmax (ºC/decade)	0.28	**0.34***	0.23	0.02	**0.19***
	Tavg (ºC/decade)					**0.25***
	Prec (% change/decade)	-5.7	-2.8	-0.3	-1.5	-5.8

*+ significant at P<0.10, *significant at P<0.05, **significant at P<0.01, ***significant at P<0.001*

[5] Adapted from Environment Canada Climate information at: http://www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_data_e.cfm#dataset

At Quesnel, which provides the region's longest continuous climate record, the warming trend in winter minimum temperatures over the 20th century is dramatic even though year-to-year variation is high. The temperature record for January, the coldest month of the year, further illustrates the greater warming in winter temperatures for Quesnel as compared to the mean annual temperature. While the mean annual temperature increased from 1895-2005 at a rate of 0.9°C /century, the average minimum January temperature over the same period increased at a rate of 2.3°C /century (Fig. 3-7). For the 1950-2001 period, mean temperature rose at a rate of 3.2°C /century while the January minimum temperature rose at a rate of 15.1°C/century. Also, the frequency of very cold January temperatures has decreased. While 7 years during the 72 years from 1985-1969 had very cold average minimum January temperatures of less than -25°C, no month of January in the subsequent 39 years has been that cold.

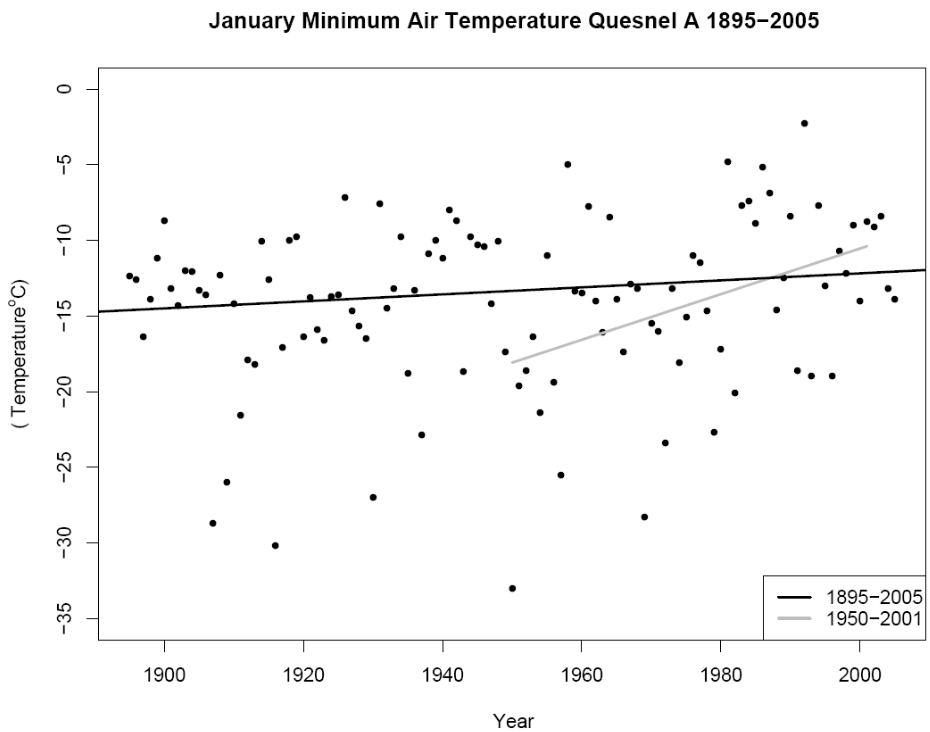


Figure 3-7 – Quesnel average January minimum temperature trend from 1895-2005 and 1950-2001 (statistically significant at the 95% confidence level , $P<0.05$, for 1950-2001 and 90% confidence level , $P<0.1$, for 1895-2005)

Figures 3-8 and 3-9 show changes in temperature by season for Prince George (1913-2001) and Kamloops (1895-2001). These two long-term stations are outside of, but adjacent to, the Cariboo-Chilcotin region to the north and south – and so, with Quesnel, help us to understand long-term trends for the region. As in Quesnel, temperatures for Prince George and Kamloops show a clear warming pattern over the past 30-50 years, especially in the winter, spring and summer minimum temperatures. They also show a similar decrease in frequency of very cold winters in recent decades. These Figures also clearly show the much greater year-to-year temperature variation in winter compared to the other seasons.

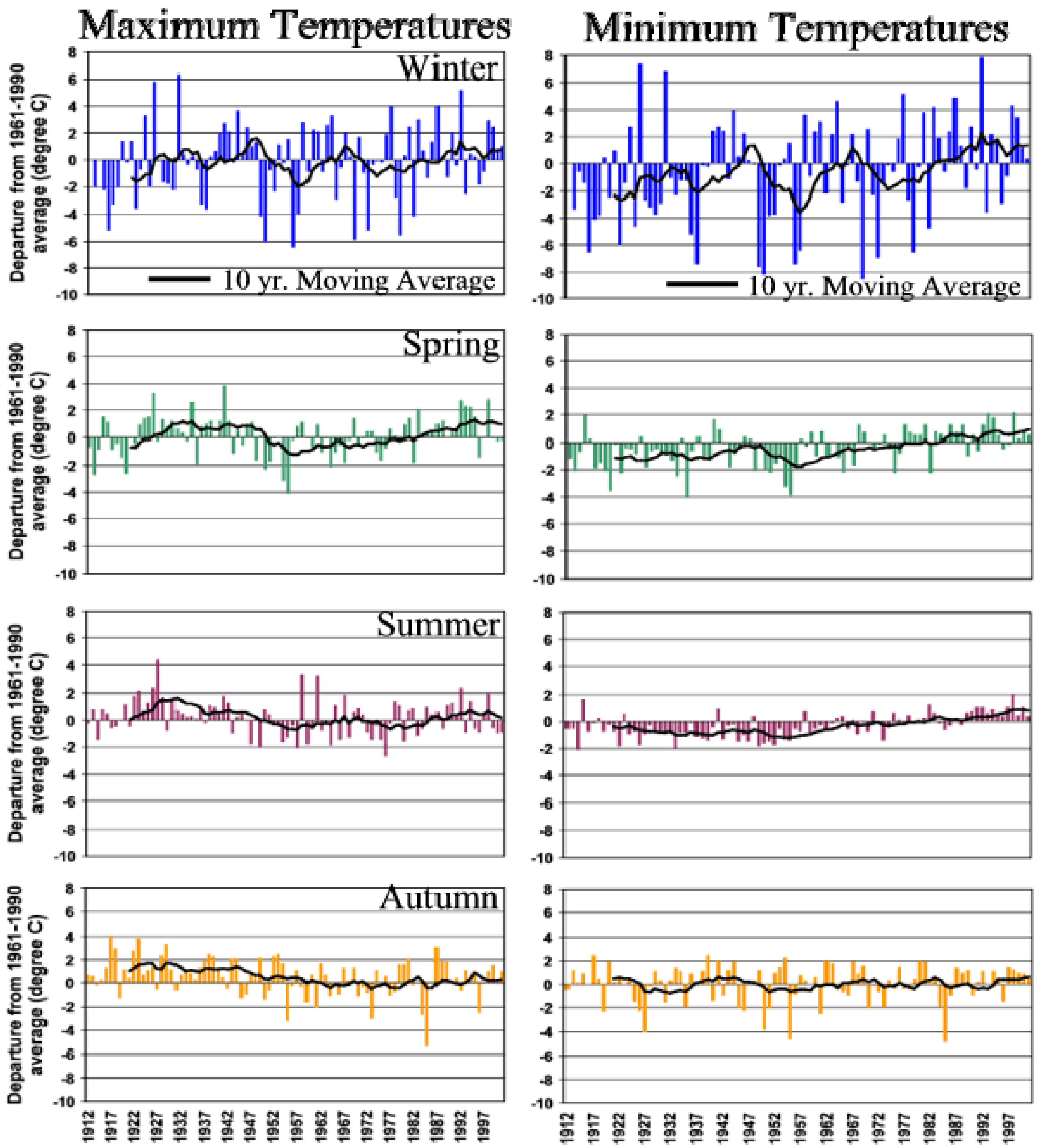


Figure 3-8 – Prince George seasonal minimum and maximum temperature, 1912-2001.

From Environment Canada Website:
http://www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_data_e.cfm#dataset

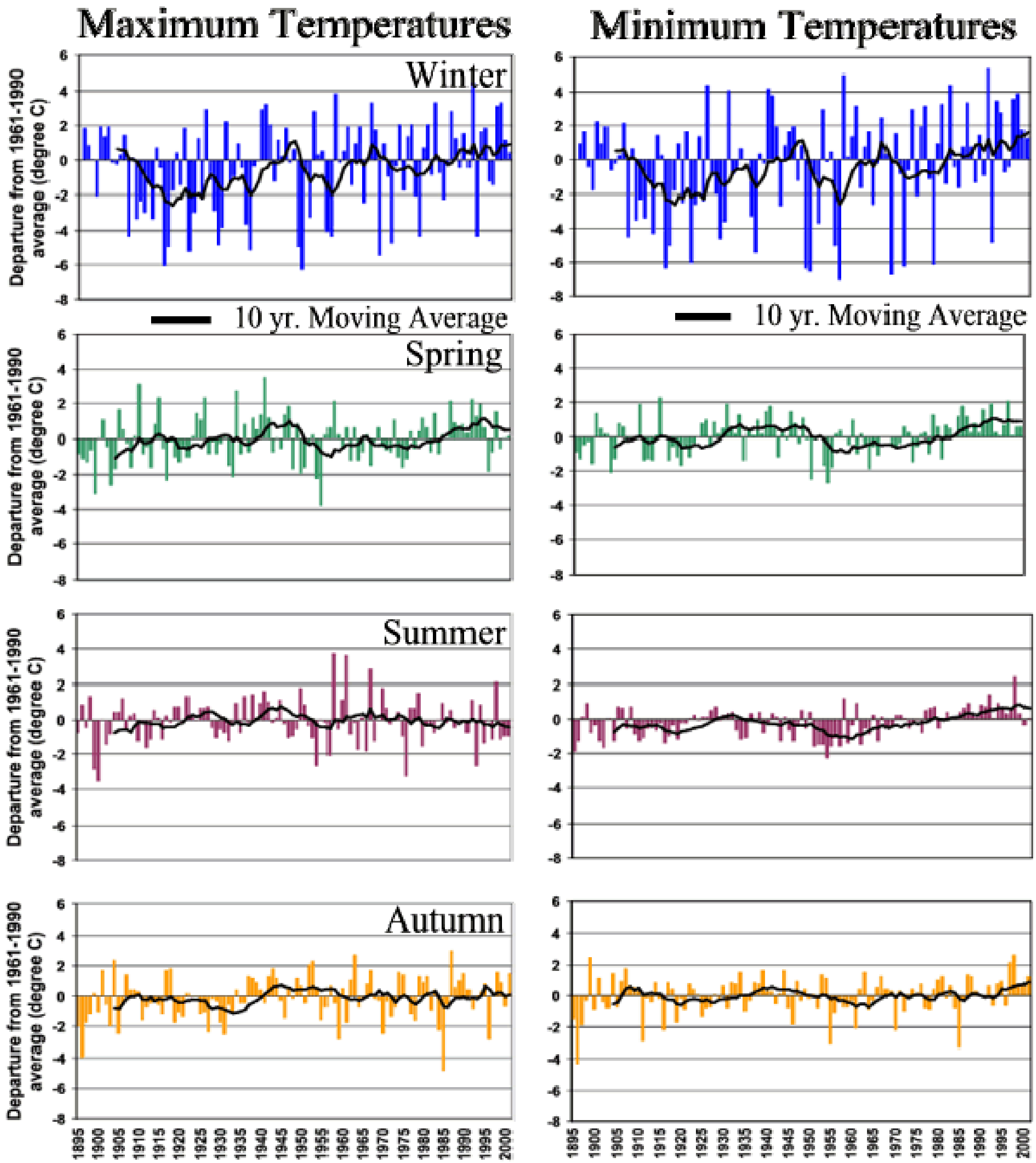


Figure 3-9 – Kamloops seasonal minimum and maximum temperature, 1895-2001.

From Environment Canada Website:
http://www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_data_e.cfm#dataset

Climate trends for 1950-2001 for Prince George and Kamloops (Table 3-4) are similar to those at the three Cariboo-Chilcotin stations. Nighttime warming was larger and more statistically significant then daytime warming. Statistically significant increases in precipitation occurred at Kamloops, but not in Prince George. Both locations had large and statistically significant increases in the number of frost free days. In Kamloops, the number of frost free days increased by 33 days over the 50 year period.

Table 3-4 shows both temperature and precipitation trends per decade based on the 52 year period. Statistically significant trends (P<0.10 or better*)* are in bold. Seasons are defined as follows: winter includes December-February, spring includes March-May, summer includes June-August, and autumn includes September-November.

Table 3-4 – Climate trends for Prince George and Kamloops 1950-2001.

Station Name	Element (trend 1950-2001)	Winter	Spring	Summer	Autumn	Annual
Prince George Airport, BC	Tmin (ºC/decade)	**0.76+**	**0.54****	**0.38*****	0.14	**0.42****
	Tmax (ºC/decade)	0.34	**0.43***	0.16	0.09	**0.31***
	Tavg (ºC/decade)					**0.37****
	Prec (% change/decade)	-3.8	3.5	-0.04	-0.5	-0.8
	Increase in Frost Free Days (days/decade)					**4.1****
Kamloops Airport, BC	Tmin (ºC/decade)	0.58	**0.48****	**0.50*****	0.19	**0.48*****
	Tmax (ºC/decade)	0.43	**0.46****	-0.03	0.05	0.19
	Tavg (ºC/decade)					**0.34****
	Prec (% change/decade)	-4.8	**8.8****	**6.6+**	6.0	**4.0***
	Increase in Frost Free Days (days/decade)					**6.7****

***+** significant at P<0.10**, *****significant at P<0.05, ******significant at P<0.01, *******significant at P<0.001*

3.2.1 Summary

Long-term climate trends show that considerable warming has taken place in the Cariboo-Chilcotin and surrounding areas over the last century. An approximately 1°C increase in mean annual temperature occurred in the region over the last century. Increases in Quesnel minimum temperatures for the month of January were roughly two times as great. In the last half century, the rate of warming has increased, with changes in mean annual temperature ranging from 3-4°C /century over the 1950-2001 period and Quesnel minimum January temperatures warming at a rate of 15°C /century during this period. Even though data show a clear warming trend, there are large year-to-year variations in temperature. ENSO and PDO climatic cycles had a strong impact on temperature and precipitation. Historical changes in precipitation are less clear and consistent than for temperature. However, temperature increases have clear implications for important hydrological variables including snow accumulation and timing of snowmelt. Divergence in temperature and precipitation from average conditions due to natural cycles and climate change has affected ecosystems and resource management over the past century in this region.

Understanding potential future climate change in the Cariboo-Chilcotin will help planners and managers adapt to the coming changes.

3.3 Future Climate in the Cariboo-Chilcotin

This section will provide two different types of future climate projections for the Cariboo-Chilcotin. As described in more detail below, a collection or "ensemble" of many Global Climate Model (GCM) runs is used to present future temperature and precipitation projections. Secondly, a Regional Climate Model (RCM) is used to present more refined, high resolution, map-based projections of future climate for the Cariboo-Chilcotin. While the ensemble of GCMs portrays a variety of possible futures, the RCM depicts the climate projection of only one model run, but in much greater spatial detail. Together, the two types of projections provide a fuller picture of potential future climate.

3.3.1 Global Climate Model Projections

The climate projections in this report were adapted by PCIC for the Cariboo-Chilcotin using the PCIC Regional Analysis Tool[6]. Projections are based on results from 15 Global Climate Models (GCMs) each run with two different greenhouse gas emissions scenarios (A2 and B1). A2 represents a future where little action is taken to reduce our dependence on greenhouse gases for energy production. B1 emissions scenarios are those which emulate a future in which less fossil fuels are used globally (IPCC, 2007). The ensemble of model runs compiled for use in this report uses the latest projections prepared for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment, which is referred to as AR4.

The ensemble of projections is presented in this report as "box and whisker plots" that show the range of projections for the region in the future (e.g., Figure 3-10). Future climate conditions will consist of climate change superimposed on a climate which is already variable on different time scales (such as ENSO and PDO) that react non-linearly with the mean state and with each other. Because historical climate trends cannot be extrapolated, dynamic climate models based on physical principles are used (see climate model definition in section 2.3). A climate projection refers to an individual set of results for temperature, precipitation and other parameters from a given climate model run under a specified set of assumptions about global climate systems and the amount of greenhouse gases released into the atmosphere. Projections are generally run over the 21st century and results are analyzed on 30-year average periods: for the 2020s (average of 2010-2039), the 2050s (2040-2069), and the 2080s (2070-2099).

The ranges of projected future climate reported in this section include uncertainties in both GCMs and emissions scenarios. The portion of uncertainty attributable to GCMs arises from differences in the way GCMs represent the climate. The portion of uncertainty attributable to emissions scenarios arises because future technological developments and economic, social, and policy choices that influence greenhouse gas emissions are unknown. Ensembles of projections following the B1 and A2 emissions scenarios are presented in this report. GCM uncertainty was

[6] http://www.pacificclimate.org/tools/select

found to be larger than the difference between emissions scenarios in the 2050s projections for BC (Rodenhuis et al., 2007). There was relatively less uncertainty in the ensemble average projection for temperature than for precipitation for the 2050s (Rodenhuis et al., 2007); temperature projections from most models had the same direction of change. However, with precipitation, some models projected an increase while others projected a decrease and there was also more spatially variability. Some of these attributes will also be apparent in the results for the Cariboo-Chilcotin region presented below.

GCM results for this report are computed using only those model grid points that are in close proximity to the Cariboo-Chilcotin region. The "boxes" in the box plots show the range (25^{th} to 75^{th} percentiles) of values projected by various projections from several models. Therefore, the box includes the 50% of model projections nearest the median value. The "whiskers" at the end of the vertical lines indicate the highest and lowest model projections[7]. The black horizontal bar within the box indicates the median value of the model projections. Hence, the box plots are valuable for showing both the main theme projected by the majority of model runs as well as the level of variation among models. Individual model results, regional data, plots and seasonal results are also available online[8].

For the A2 scenarios, the results from CGCM3 are presented for the 2050s with a red horizontal line. This helps to show where the CGCM3-A2 results place relative to the ensemble of models and provides valuable information for interpreting the higher resolution results from the CRCM4, which was driven at the boundary with the CGCM3.

3.3.2 High Resolution Regional Climate Model Projections

High resolution climate projections presented in this report are from the latest version of the Canadian Regional Climate Model (CRCM4)[9], which was run at a 45 km resolution. They are presented in the form of maps that show the difference between future projected climate and the 1961-1990 baseline climate. The CRCM4 was developed by the Ouranos Consortium in collaboration with the Canadian Centre for Climate Modelling and Analysis of Environment Canada. CRCM4 projections provided here are forced by boundary conditions at the edges of its domain (North America) by the approximately 350 km resolution projection from the Canadian Global Climate Model (CGCM3) following the A2 emissions scenario which represents a future where little action is taken to reduce green house gas emissions. The CRCM4 results are portrayed as maps showing the differences in climate projected for the 2041-2070 period as compared to the 1961-1990 baseline. The CRCM uses dynamical downscaling that improves the representation of elevation and includes physical and dynamical processes as well as land surface characteristics at a higher resolution than Global Climate Models (GCMs). It is important to note that these projections are from only one RCM run (forced by CGCM3-A2, run 4) and tend to be warmer and wetter than the ensemble median for all the models, especially during winter. It is preferable to analyze multiple runs to better assess the uncertainty of a given

[7] If the maximum or minimum projection is further from the median than 1.5 times the difference between the 25^{th} and 75^{th} percentiles, then value that is 1.5 times the range between the 25^{th} and 75^{th} percentiles is shown at the whisker, and the maximum or minimum is indicated with an asterisk.
[8] http://www.PacificClimate.org/tools/regionalanalysis/
[9] http://www.cccma.bc.ec.gc.ca/models/crcm.shtml

projection. However, extensive comparison of results from many RCMs and to other downscaling methods is not yet available.

Please see Section 4.2 – RCM Projections in “Hydro-climatology and Future Climate Impacts in British Columbia” for more details[10] (Rodenhuis et al., 2007).

3.3.3 Temperature

The Global Climate Model (GCM) box plots show a pattern of steadily increasing temperature in relation to the 1961-1990 baseline with a median increase of about one degree in each 30 year period for all seasons and emissions scenarios up until the 2050s and with larger increases by the 2080s (Fig. 3-10). Projections using the high greenhouse gas emissions scenario (A2) show greater warming by the 2080s than B1 scenarios, especially in the winter. While all models making up each scenario showed a similar pattern of increase over time, some models projected a larger increase while others projected a smaller increase.

The 2050s GCM projection (CGCM3-A2, run 4) on which the regional climate projections in Figures 3-11 and 3-12 are based is shown in Figure 3-10 by the red horizontal lines in the 2050 A2 projection boxes. This model projects temperatures 0.9°C warmer in the winter and 0.1°C cooler in the summer than the median value for all 15 models. Readers should be aware of these differences when interpreting the mapped RCM projections in Figures 3-11 and 3-12.

The RCM projection of annual temperature (Fig. 3-11) shows a warming of between 2.0°C to 2.5°C for the majority of the region by the 2050s. A 2.5°C warming in mean annual temperature in Quesnel would give a mean annual temperature the same as the 1960-1990 baseline temperature at the Kelowna Airport in the Southern Interior of BC and slightly warmer than the more southerly Westwold or Merritt stations.

RCM projected increases in 2050s summer temperature range from 1.0°C to 3.5°C (Fig. 3-12), the majority falling within the 2.0°C to 2.5 °C range. Winter temperatures are projected to increase by 2.0°C to 2.5°C in the southern part of the region and 3.0°C to 3.5°C in the north by the 2050s.

The RCM projection suggests greater future warming in winter than summer. This projection should be used with caution. Historical winter temperatures in Quesnel, and many other weather stations around the province, have increased faster than summer temperatures over the 20th century. However, not all stations show this pattern and future trends will not necessarily correspond to historical trends. The median projection for 48 different GCM runs does not show this seasonal difference by the 2050s, but does begin to show greater winter warming by the 2080s. Modelling improvements and acquisition of more data over time will provide greater clarity on whether the Cariboo-Chilcotin winters will warm faster than summers.

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[10] http://www.pacificclimate.org/publications

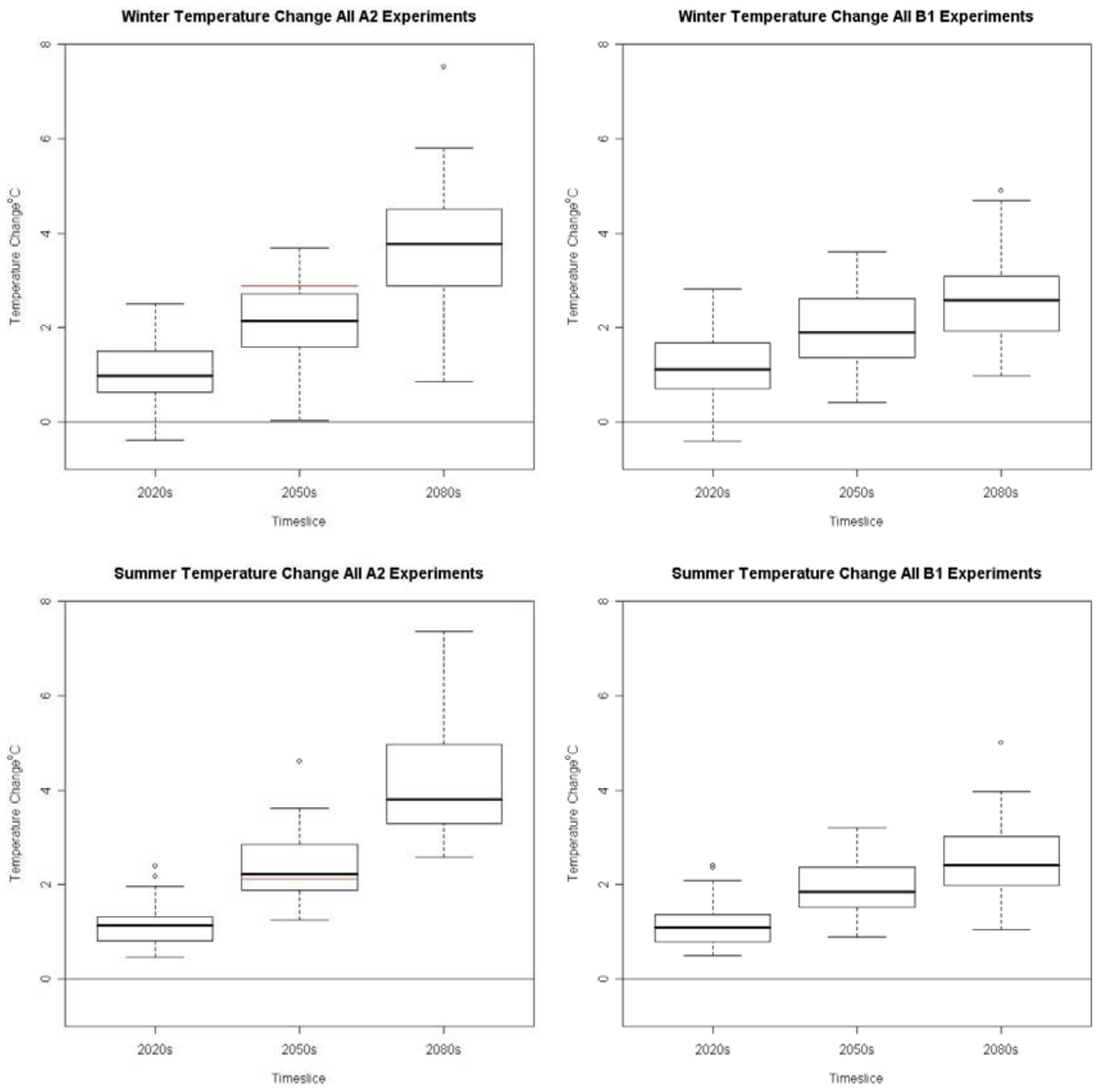

Figure 3-10 – Box plots of GCM projected change in seasonal mean temperature in the Cariboo-Chilcotin as compared to the 1961-1990 baseline.

Analyses are for 30-year periods centered on 2025, 2055 and 2085 in the winter (top) and summer (bottom) for the A2 (left) and B1 (right) greenhouse gas emissions scenarios using 15 GCMs. The red line indicates the value for the Canadian model CGCM3 run4 results. The A2 scenario, where little action is taken to reduce greenhouse gas emissions is contrasted with the B1 scenario where less fossil fuels are used globally (IPCC, 2007).

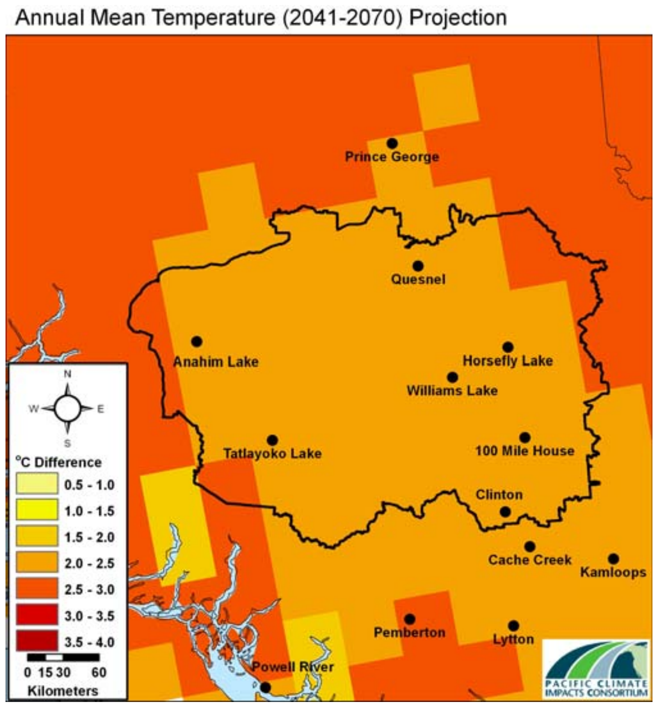

Figure 3-11 – RCM projected change in B.C. 2050s (2041-2070) mean annual temperature as compared to the 1961-1990 baseline.

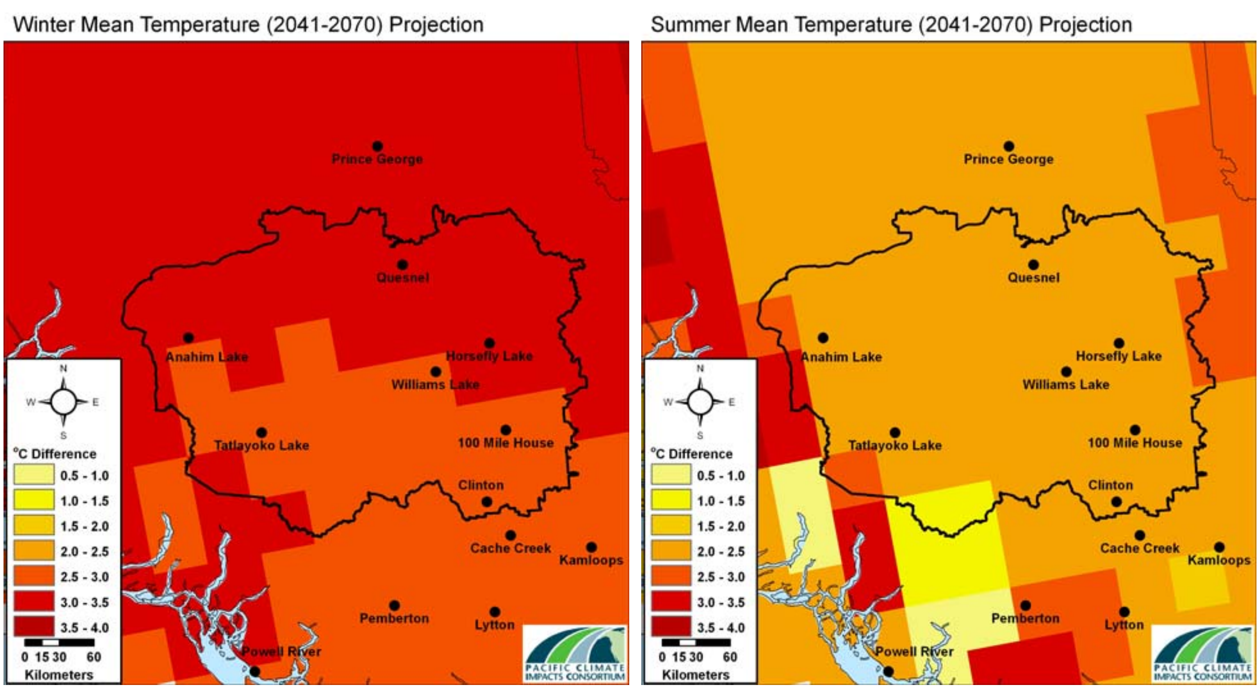

Figure 3-12 – RCM projected change in B.C. 2050s (2041-2070) mean seasonal temperature as compared to the 1961-1990 baseline in winter (left) and summer (right).

3.3.4 Growing Degree Days

Annual growing degree day values (GDD) are calculated as the sum of the daily growing degrees for each day over the growing season. Daily GDD is the average of the daily temperature minus a base temperature selected to suit the needs of particular crops of interest. A 5°C base temperature was used for this analysis. For agriculture, growing degree days determine what crops can be grown as well as what insect pests could be a problem. GDD also affects many processes in natural ecosystems including the timing of budding, growth and flowering of many plants and the long-term distribution and survival of numerous plant and animal species.

High-resolution projections (4 km) of Growing Degree Days (GDD) were produced using empirical downscaling of a projection from the Canadian model (CGCM3) following the A2 emissions scenario (run 4) using the ClimateBC[11] downscaling tool. This method demonstrates the influence of elevation on local climate, which is important to consider with BC's complex topography. Empirical downscaling uses elevation and aspect to adjust GCM projections and applies the high resolution representation of historical climatology provided by PRISM. Because these projections are based on one individual GCM projection they should be used with caution, interpreted in context of the CGCM3 data from which they were derived, and compared to results from an ensemble of GCM projections (see box plots). Please see Section 4.3 – High Definition Climate Projections in "Hydro-climatology and Future Climate Impacts in British Columbia" for more details[12] (Rodenhuis et al., 2007).

Figure 3-13 compares 1961-1990 GDD with projected GDD for 2041-2070. The 1961-1990 GDD ranges between 0 to 500 in the mountainous areas in the south-western portion of the region, between 500 to 1500 in lower lying areas mostly east of the Fraser River, and between 1500 to 2000 in the bottom of the Fraser Valley. Projections for the 2041-2070 period illustrate the expansion of the 1500 to 2000 GDD range in the major valley systems in the region and an expansion of the 500 to 1500 GDD range to larger areas both East and West of the Fraser River.

Table 3-5 shows baseline average GDD figures for several B.C Interior weather stations. The projected increase in areas with a GDD of 1500 to 2000 would mean a significant increase in areas within the Cariboo-Chilcotin with a similar GDD to Westwold and Salmon Arm. For reference, some examples of GDD requirements relevant to BC are 1000 for clover, 1145 for alfalfa, strawberries and wheat, and 1290 for apples and tomatoes. (Thie and Ironside, 1976).

Table 3-5 – Mean growing degree days (5°C base) for selected stations in the B.C. Interior in 1961-1990.

Station	Growing degree days
Kelowna Airport	1864
Kamloops Airport	2259
Salmon Arm	1962
Westwold	1594
Vernon	2044
Quesnel Airport	1469
Williams Lake Airport	1281

[11] http://www.genetics.forestry.ubc.ca/cfcg/climate-models.html
[12] http://www.pacificclimate.org/publications

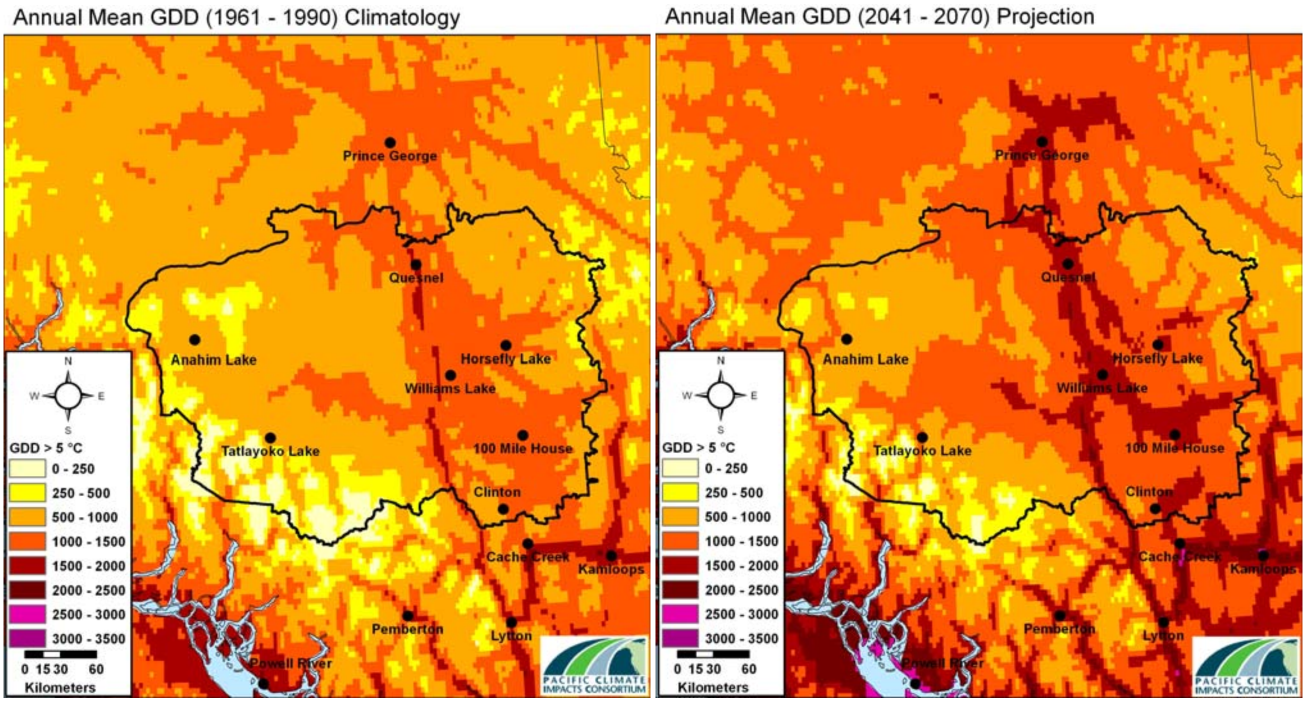

Figure 3-13 – RCM projected change in growing degree days (5°C base) for B.C. 2050s (2041-2070) (right) as compared to the 1961-1990 baseline (left).

3.3.5 Precipitation and Snowpack

Global Climate Models are less consistent in their projections of future precipitation as compared to future temperature. The GCM box plots project a wide range of possible changes in total precipitation in the future (Fig. 3-14). While the majority of models tend to indicate small decreases in summer precipitation in relation to the 1961-1990 baseline, a few project an increase. The majority of models project modest increases in winter precipitation over time under the A2 emissions scenario with a median increase of 8% in the 2050s and 13% in the 2080s.

The 2050s GCM projection on which the regional climate projections in this section are based (CGCM3-A2, run 4) is 2% wetter in the winter and 11% wetter in the summer than the median value from the box plots for the Cariboo-Chilcotin region. Model results for the B1 emissions scenarios are provided for comparison. Under B1 emissions, increases in winter precipitation and decreases in summer precipitation are not as large by the 2080s as with A2 emissions.

Figure 3-15 projects an annual precipitation increase of 5% to 20% by the 2050s. A 20% increase in annual precipitation at the Williams Lake Airport would provide similar levels of annual precipitation as Quesnel or Salmon Arm received during 1961-1990. Most of this projected change is during winter: an increase by up to 30% by the 2050s (Fig. 3-16). Projections of summer precipitation changes are near zero (-5% to 5%) for about half of the region with increases of 5% to 15 % for the remainder of the region. The RCM projected precipitation changes in Figures 3-15 and 3-16 must be interpreted very carefully because of the wide range of GCM projections shown in the box plots and because the RCM projections are based on only one model.

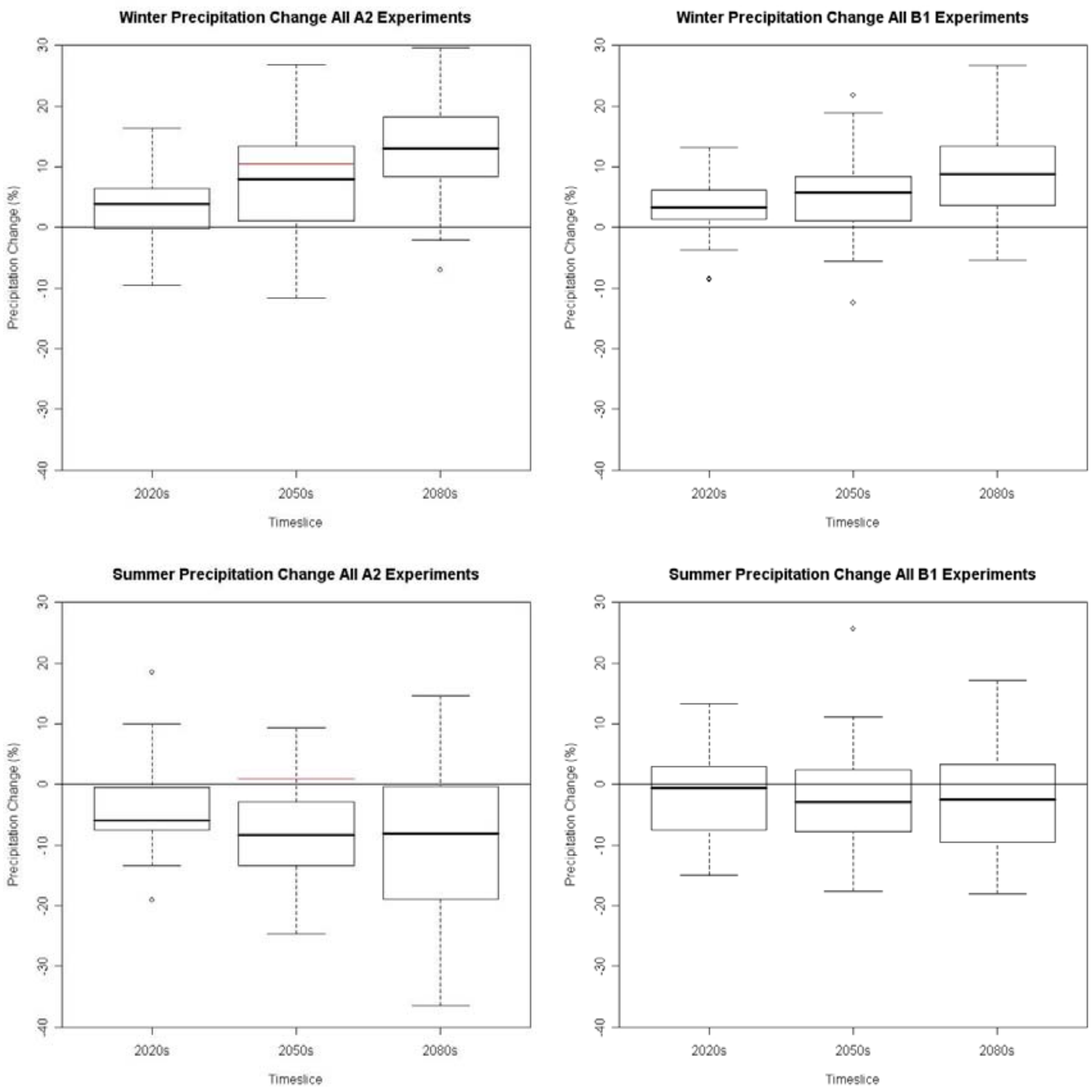

Figure 3-14 – Box plots of GCM projected change in mean seasonal precipitation in the Cariboo-Chilcotin as compared to the 1961-1990 baseline.

Analyses are for 30-year periods centered on 2025, 2055 and 2085 in the winter (top) and summer (bottom) for the A2 (left) and B1 (right) greenhouse gas emissions scenarios using 15 GCMs. The red line indicates the value for the Canadian model CGCM3 run4 results. The A2 scenario, where little action is taken to reduce greenhouse gas emissions, is contrasted with the B1 where less fossil fuels are used globally (IPCC, 2007).

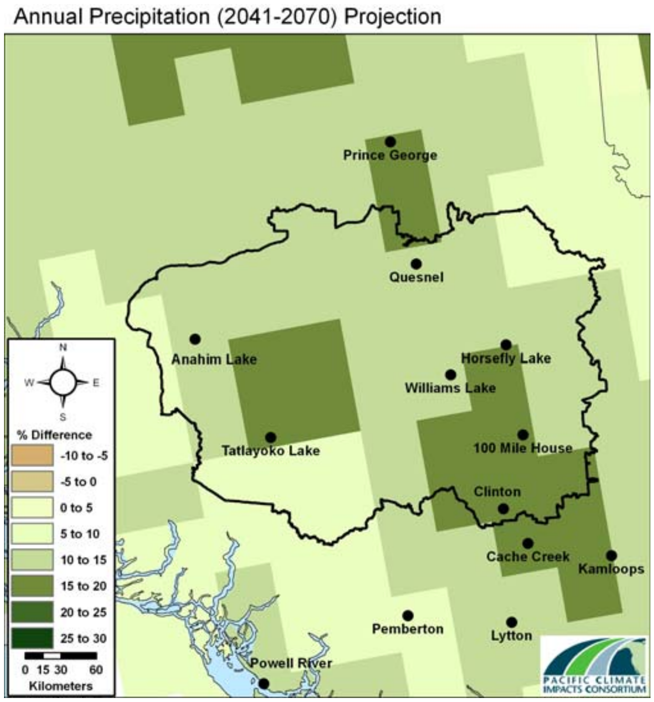

Figure 3-15 – RCM projected change in B.C. 2050s (2041-2070) annual precipitation as compared to the 1961-1990 baseline.

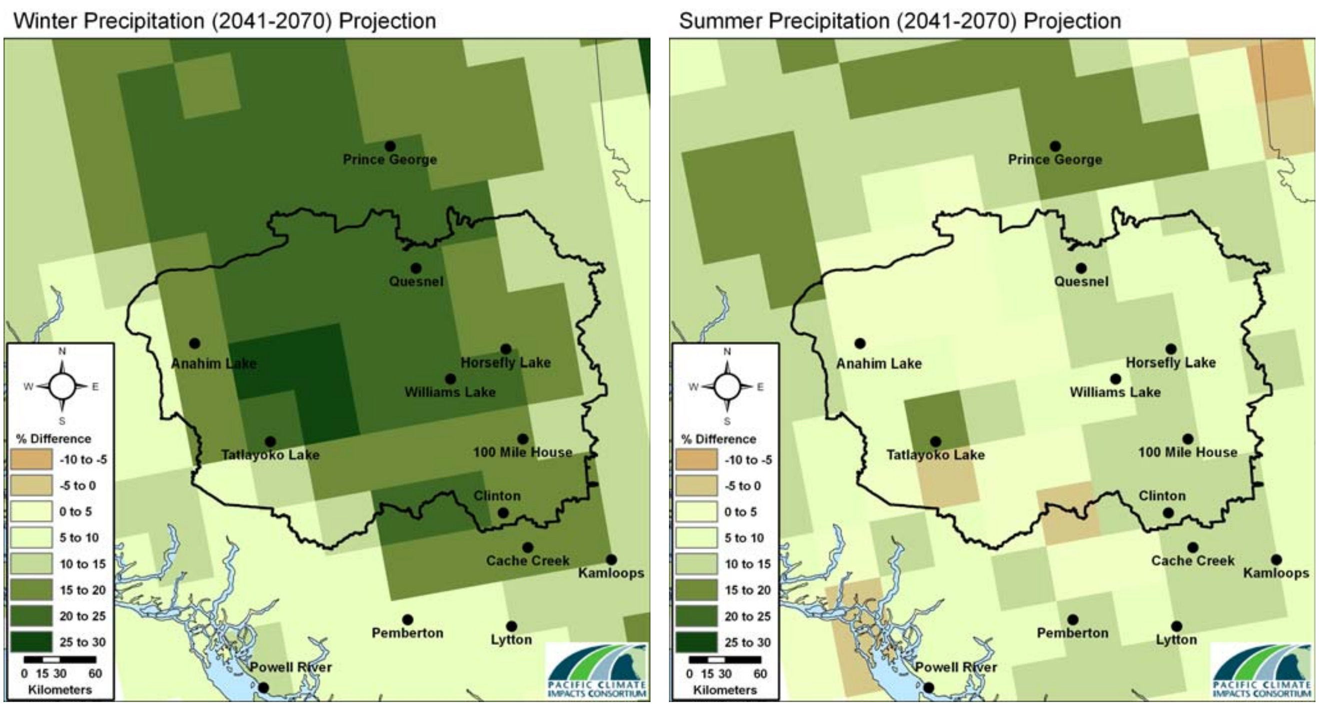

Figure 3-16 – RCM projected change in B.C. 2050s (2041-2070) seasonal precipitation as compared to the 1961-1990 baseline for winter (left) and summer (right) precipitation.

Spring snow water equivalent is the average amount of water that is stored as snow during March-April-May of each year. It integrates the effects of both precipitation and temperature over preceding seasons. The level and distribution of water stored as snow at the end of the winter has great impacts on the hydrological regime and on numerous ecological processes.

Based on the regional climate model projections for 2050, spring snow water equivalent (SWE) is projected to decrease more in the northern portion of the region than the south, where some increases are projected. The majority of the region (-5% to -20%), except for some increases in the southern areas (5% to 10%), Figure 3-17. Changes near zero (-5% to 5%) are projected for several southern and central areas. SWE is affected by both seasonal temperature and precipitation and therefore SWE projections are affected by any uncertainties in projecting both of these variables.

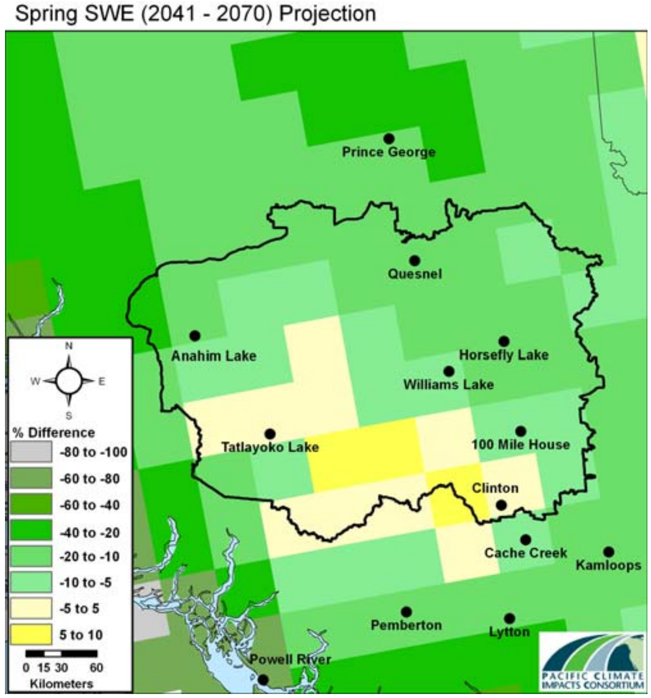

Figure 3-17 – Projected change in B.C. 2050s (2041-2070) spring snow water equivalent as compared to the 1961-1990 baseline, expressed as percent change.

3.3.6 Summary

The Global Climate Model (GCM) box plots representing 15 different models show a pattern of steadily increasing future temperature with a median increase of about 1°C for each of the 2010-2040 and 2041-2070 periods compared to the baseline, in both winter and summer. By 2071-2100 the less conservative A2 greenhouse gas emissions scenario projects further increases of approximately 2°C for both summer and winter. GCMs are less consistent in their projections of future precipitation than for temperature with wide variation amongst models. Median precipitation values for the 15 models project slightly drier summers and moderately wetter winters for the Cariboo-Chilcotin.

The Regional Climate Model (RCM) projects a spatial pattern of climate change by 2050s for the Cariboo-Chilcotin region. Projected summer and annual temperature increases are uniformly distributed across the region while, in the winter, the northern part is projected to warm more that the south. The area with growing degree-day values similar to Salmon Arm’s 1961-1990 baseline is projected to expand across the major valleys in the region by the 2050s. Projected changes in annual and summer precipitation are greatest in the central Chilcotin Plateau and in a north-south band east of the Fraser River. Winter precipitation is projected to increase over most of the region, especially in the north-west and north-central areas. Spring snow-water equivalent (SWE) is projected to decrease in roughly three quarters of the region and to stay the same or increase in the south-west.

Note that the Regional Climate Projections (CRCM4) are driven by the CGCM3 model which was shown to be one of the wetter and warmer GCMs when compared to the median from the other model runs for the area encompassing the Cariboo-Chilcotin. Thus, while providing useful spatial information, the uncertainty in RCM projections must be evaluated and incorporated into planning and decision-making. Future modelling may provide better information on the range of projected climate for mapped projections.

All model projections are for average climatic conditions. Since natural cycles such as the ENSO and PDO will still provide large year-to-year variation in the climate, planners must also incorporate this type of climatic variation into their analysis and decision-making.

4 POTENTIAL IMPACTS OF CLIMATE CHANGE IN THE CCLUP AREA

The climate projections documented in Section 3 could affect many ecological processes and aspects of resource management in the Cariboo-Chilcotin. A next logical step would be to identify and describe possible vulnerabilities and opportunities from climate change related to resource values included in the CCLUP. Recent reports have begun to document potential impacts of climate change on resource values, ecosystems and ecological process in British Columbia and neighboring areas. These include the topics of hydrology (Pike et. al., 2008, Rodenhuis et. al. 2007, Murdock et al., 2007), forest and range management (Spittlehouse, 2008), grasslands (Pitt, 2007, Nitschke, 2007), wildlife and fisheries (ISAB, 2007, Nelitz, 2007 et. al.), and biodiversity (Compass Resource Management, 2007, Gayton, 2008).

Examples of vulnerabilities that might be considered when looking at future impacts of projected climate change on resource values in the Cariboo-Chilcotin Land Use Plan include:

- hydrological factors including the timing of runoff, the amount of precipitation falling as snow versus rain, the amount of evapo-transpiration and the sustainability of glacial inputs to rivers.
- aquatic ecosystems including the biological effects of changing water temperature and the amount and timing of water in rivers, streams, wetlands and ponds.
- ecological processes in forests including: level of disturbance due to fire and insects, changes in ecological capability to maintain current tree species and understory plant communities.
- operational forestry requirements and outputs.
- ecological processes affecting wildlife habitat including requirements for rare and endangered species.
- ecological processes affecting biodiversity and geographic shifts in ecological communities.
- agricultural capability for crops needing more heat and potential increases in pest species.
- level of demand for various land uses.
- social factors including supply and demand for water and recreational opportunities.

5 NEXT STEPS

This report compiles information on past and possible future climate conditions in the Cariboo-Chilcotin region. More work is required to understand the potential impacts of climate change for the specific ecosystems and resource values in the region and to develop approaches to adapt to future changes and uncertainties. Current initiatives, including the Future Forest Initiative of the Ministry of Forests and Range[13], Cariboo-Chilcotin Beetle Action Committee[14], B.C. Climate Exchange[15], the Nature Consevancy of Canada's Central Interior Ecoregional Assessment[16] and Biodiversity BC's Climate Change Assessement[17], are beginning to address some aspects of climate change assessment and adaptation in the interior of British Columbia. Further work specific to the ecosystems and land use planning in the Cariboo-Chilcotin is required. The following list summarizes possible steps towards the development of climate change adaptation strategies for the resource values included in the Cariboo-Chilcotin Land Use Plan.

1. Compile additional climate information:
    - projections of additional future climate variables
    - update climate analyses as new data and analysis approaches become available

2. Analyse and report on:
    - potential climate change impacts on locally important ecological processes and resource values including:
        - Terrestrial ecosystem processes
        - Hydrology and aquatic ecosystem processes
        - Forestry
        - Agriculture
        - Water for people and wildlife
        - Wildlife/ Biodiversity
        - Recreation and Tourism
    - Changes in supply and demand for Cariboo-Chilcotin natural resources
    - Objectives, scope and approach of local, Provincial and National initiatives related to climate change impacts and adaptation
    - Climate change adaptation approaches
    - Research and monitoring needs

This analysis could include some or all of the following:
- literature review,
- review of current provincial initiatives,

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[13] http://www.for.gov.bc.ca/hts/Future_Forests/
[14] http://beta.c-cbac.com/index.php
[15] http://www.bcclimateexchange.ca/
[16] http://science.natureconservancy.ca/centralinterior/central.php
[17] http://www.biodiversitybc.org/EN/main/26.html#component

- interviews with provincial experts in: 1) climate and climate modelling, 2) key ecosystem processes affected by climate, and 3) climate impacts and adaptation,
- interviews and/or questionnaires with local resource specialists.

3. Facilitate information exchange among multiple stakeholders in the Cariboo-Chilcotin related to potential climate change impacts, ecosystem or resource vulnerabilities and adaptation approaches.

4. Develop and refine adaptation approaches for key ecosystems and resource values in the Cariboo-Chilcotin including coordination with other provincial and local initiatives.

5. Implement and monitor adaptation strategies.

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