Canadian Columbia Basin Climate Trends and Projections

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2007-2010 Update

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About PCIC

The Pacific Climate Impacts Consortium is a regional climate service centre at the University of Victoria that provides practical information on the physical impacts of climate variability and change in the Pacific and Yukon Region of Canada. PCIC operates in collaboration with climate researchers and regional stakeholders on projects driven by user needs. For more information, visit http://pacificclimate.org.

Disclaimer

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Acknowledgements

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Executive Summary

This document was developed to assist the Columbia Basin Trust's *Communities Adapting to Climate Change Initiative*, a pilot project focused on selected communities in the basin[1]. Climate affects many aspects of communities, including local ecosystems, tourism, forestry, energy and infrastructure. To consider climate in planning, the local climate must be well understood, including recent conditions, past trends, and projected changes to future climate.

This document provides additional information that was not available during the previous regional assessment (Murdock et al. 2007). It draws heavily on a subsequent province-wide analysis (Rodenhuis et al. 2009) and on climate model projections prepared for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007).

Climate consists of components that function at different scales, superimposed to create the actual climate record observed at a given location. In this report, information is provided on historical averages, year-to-year variability, decadal oscillations, long-term trends, and also future projected changes to average climate.

a) Climate Variability

In the Canadian Columbia Basin, year-to-year variability is heavily influenced by the El Niño/Southern Oscillation (ENSO). For example, an El Niño winter is typically 1.0°C to 1.8°C warmer than an average winter in the basin. Conversely, La Niña years are usually colder than normal. On the scale of decades, the Pacific Decadal Oscillation (PDO) displays additional warming or cooling during its positive and negative phases, respectively.

Precipitation is more complex than temperature. For example, both ENSO and PDO can influence precipitation by 20% in the region, but the effect varies depending on the season and can differ considerably over relatively short distances. Most of the basin receives less precipitation in winter during El Niño years and during the positive phase of the PDO.

b) Temperature

Temperatures have been increasing in the basin over the past century. In particular, the rate of increase in annual average temperatures in the area is 0.7°C to 1.7°C per century over the 1901-2004 period. Rates of warming are larger in the West Kootenays than the East Kootenays, for nighttime low (minimum) temperatures than daytime high (maximum) temperatures, and in winter than other seasons. The rate of temperature increase over the last century has been accelerating in most of the province but has remained quite constant in this area.

The Canadian Columbia Basin is projected to be 1.2°C to 2.7°C warmer by the 2050s according to the 10^{th} to 90^{th} percentile of an ensemble of 30 Global Climate Model (GCM) projections, compared to the baseline (1961-1990) temperature. This projected warming is more rapid than past trends.

c) Precipitation

Precipitation has been changing over the past century, but unlike temperature, the details and even the direction of the trend depend on the time period of analysis. Over the 20^{th} century, precipitation increased in all seasons in the basin, but in some seasons and locations the increase was not statistically significant.

Future precipitation is projected to increase by up to 15% in winter and decrease by as much as 14% in summer for the basin as a whole according to an ensemble of GCMs, with large regional differences within the basin indicated by a Regional Climate Model.

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[1] http://www.cbt.org/Initiatives/Climate_Change/?Adapting_to_Climate_Change

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Introduction

Communities are generally adapted to some of the past variability in climate, but future changes will result in climates during this century unlike those experienced in the past (Rodenhuis et al. 2009). These changes will stress current adaptations and will expose communities to new vulnerabilities (see Appendix A). Most importantly, an assessment of how communities are vulnerable to some of the possible secondary impacts of projected changes in climate is needed, to prioritize further analysis. For example, what information is needed to understand the possible effects of climate change on water supply, stormwater management, landslide risk, and flood risk? How can these variables and changes to extreme events be expressed in terms that can be used for community planning?

The objective of this report is to provide updated regional information for adaptation in the Canadian Columbia Basin. Regional updates such as these will be needed every few years as additional information becomes available.

The information in this update is intended to assist with adaptation planning. Maps and tables provided here can be used in workshops and meetings to communicate climate impacts to engineers, planners, and community members. Only a brief summary of results is provided; further interpretation of what the analysis means can be derived in the context of community adaptation.

This document provides historical climate trends and future climate projections only. It is not a full assessment of future impacts of changing climate conditions and has not been informed by local feedback as to the factors important to climate change adaptation. The summary consists almost entirely of figures and tables, with limited notes to guide interpretation. The interpretation of what the climate information presented here means for community adaptation is outside of the scope of this document.

Note to the Reader – Other Documents

Two documents are referenced throughout this update. First, the *Preliminary Analysis* refers to Preliminary Analysis of Climate Variability and Change in the Canadian Columbia River Basin: Focus on Water Resources (Murdock et al. 2007). The *Preliminary Analysis* was developed before the Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4) was completed (IPCC 2007).

Second, the *BC Climate Overview* refers to Climate Overview 2007: Hydro-climatology and Future Climate Impacts in British Columbia (Rodenhuis et al. 2009), a report with additional analysis throughout the province that was conducted subsequent to the *Preliminary Analysis*. This update draws heavily on the analysis completed for the *BC Climate Overview*.

Readers are encouraged to have each of these documents available for reference when reading this update. In particular, the *BC Climate Overview* contains further details regarding methodology, caveats, and interpretation while the *Preliminary Analysis* includes introductory material and definitions such as the distinction between climate variability and climate change, interpreting El Niño, Pacific Decadal Oscillation, and future scenarios. Both of these PCIC publications are available online.[2]

Subsequent to the *Preliminary Analysis* and *Climate Overview*, additional work has also been conducted on some of the secondary impacts of climate change in the region:

- Tree species suitability (Flower et al. 2011; Murdock and Flower 2009)
- Pest outbreak risk (Murdock and Flower 2009; Murdock et al. 2011)

[2] http://pacificclimate.org/publications

- Hydrological impacts (Schnorbus et al. 2011; Shrestha et al. 2011; van der Kamp et al. 2011b; Zwiers et al. 2011)
- Wildfire risk (van der Kamp and Bürger 2011)
- Wind (Curry et al. 2011; van der Kamp et al. 2011a)

Part I - Historical Climate

1. Regional Climatology

This section provides maps showing annual mean temperature and precipitation for 1961-1990 from the PRISM[3] dataset (Daly et al. 1994). PRISM is a high resolution historical dataset created using climate records from weather stations together with elevation, orientation of terrain, coastal proximity, a two-layer atmosphere (to handle inversions), topography (valley, mid-slope, ridge) and assisted by expert knowledge (Daly 2006). The resulting maps for historical climate are shown for the basin area in Figure 1-1.

Interpretation of maps in this section:

- These maps depict estimates of the 1961-1990 climate based on (sparse) climate station data at high (4 km) resolution. Estimates are based mainly on using relationships between climate and topographic features such as aspect and elevation.
- These maps are useful for showing how complex topography affects temperature and precipitation climatology.
- These maps should not be used in place of station data. Where they exist, station data should be used for historical climatology as they represent direct observations.

Summary of results for Figure 1-1 (historical climatology):

- Annual average (1961-1990) temperature ranged from 2°C to 8°C in the low elevation and very southern parts of the Columbia Basin, with the highest temperatures generally following valley bottoms. Differences in average annual temperature are due mainly to elevation and aspect.
- In high elevation areas in the central and northern parts of the basin, annual average temperatures were below 0°C and as cold as -4°C.
- Annual precipitation on the windward sides of mountain ranges (in particular the Selkirk and Purcell ranges) was as high as 1000 mm/yr to over 2500 mm/yr.
- Less precipitation occurred on the leeward side of the mountain ranges from Golden down through Kimberley and Cranbrook: from 250 mm/yr to 750 mm/yr.

Related resources:

- *Preliminary Analysis* Figures 3.4c and 3.4e show 1961-1990 temperature baselines also using PRISM.
- *BC Climate Overview* Section 1 shows identical figures but for all of BC.
- The ClimateWNA tool[4] developed by the Centre for Forest Conservation Genetics with the support of the BC Ministry of Forests and Range uses PRISM and further bi-linear interpolation and elevation corrections on temperature to estimate historical (and future) climate at any point in western North America.
- The Plan2Adapt online tool[5] also uses PRISM in conjunction with future projections from Global Climate Models to provide estimates of future climate change by regional district within BC.

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[3] http://www.prism.oregonstate.edu/
[4] http://climatewna.com/
[5] http://plan2adapt.ca/

a) b)

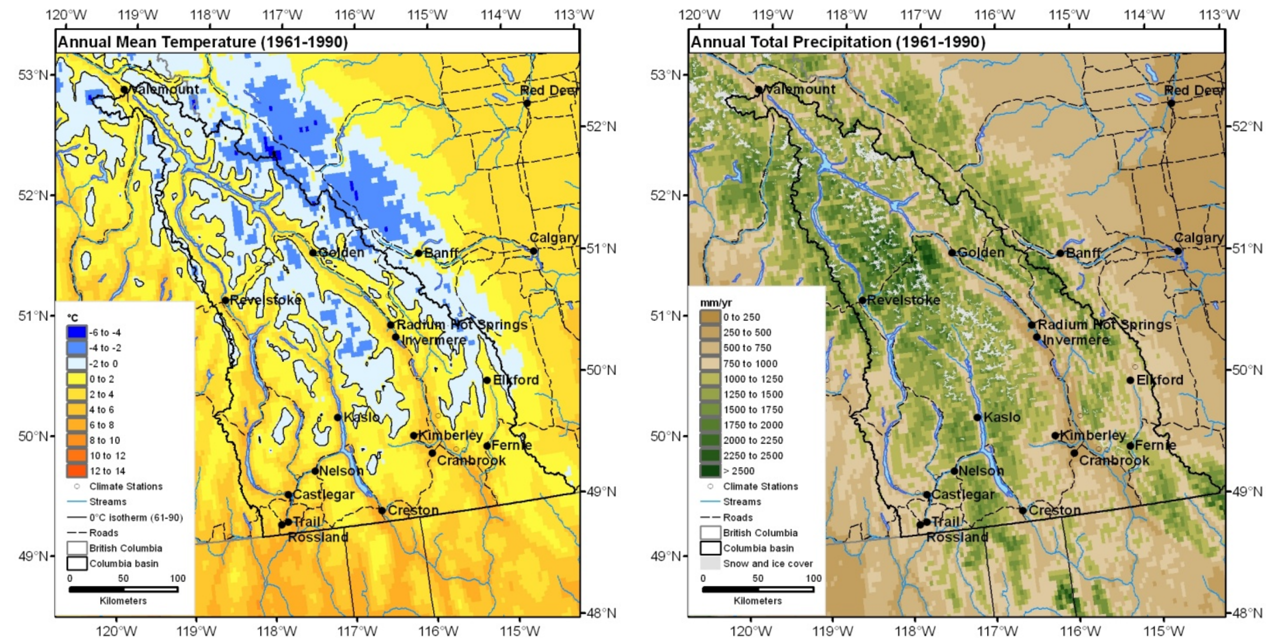


Figure 1-1: Baseline map of a) annual mean temperature and b) annual total precipitation for the Canadian Columbia Basin (1961-1990).

2. Historical Trends

2.1 Regional Trends

All of the maps in this section show seasonal and annual trends in minimum (nighttime low), maximum (daytime high), and mean (average of minimum and maximum) temperatures and total precipitation. Trends are calculated using the CANGRID (Zhang et al. 2000) gridded dataset (~50 km resolution) for 1900 to 2004 and are given as changes in °C per century for temperature and change per decade as a percentage of 1961-1990 baseline for precipitation. Black solid circles represent statistically significant results (p=.05). Statistical techniques appropriate for use with climate data were used to ensure that the trends themselves and the test for whether or not the trends are significant were robust to outliers (an iterative approach to pre-whitening, testing for trend and determining magnitude of trend using Theil-Sen method, and significance assessed with the Mann-Kendall test – see Rodenhuis et al. 2009 for details).

Interpretation of maps in this section:

- The maps depict station data interpolated to 50 km gridded resolution. At this resolution, given the low density of stations, interpolated values are uncertain and do not fully reflect small scale variations related to factors such as surface topography.
- The maps show 20th century trends (based on a 105-year period). Station density changes through time with the lowest number of stations in the earliest parts of the record. Thus, long period trends contain additional uncertainty due to whether or not stations were available within the vicinity of the grid box in the early part of the record.
- Trends based on the more recent past only (e.g., last 50 years) generally show more rapid warming in most of BC (Pike et al. 2010), but most of the basin shows fairly constant temperature trends (not shown). Precipitation trends shown here must be interpreted in the context of the period over which they are computed (e.g., the full century includes the dry "dust bowl" period near the beginning of the record). More recent precipitation trends (e.g., most recent 50- or 30-year periods) would differ in spatial pattern, magnitude, and even direction (Pike et al. 2010).
- Confidence is generally greater for temperature trends than precipitation trends, as reflected in the larger number of statistically significant trends for temperature.
- The maps are useful for showing the regional differences in past trends, but should not be taken to represent the trends at all points within the grid boxes. In particular, the gridded trends should not be used in place of station data where such data exists.
- For more details on these maps see Section 2 of the *BC Climate Overview* (Rodenhuis et al. 2009).
- For more information on climate trends in the basin, including the importance of the time period selected, see Sections 2.1 and 2.2 of the *Preliminary Analysis* (Murdock et al. 2007).

Summary of results for Figure 2-1 (annual trends):

- Mean annual temperature increased at a rate of 0.7°C to 1.7°C per century during the 1901-2004 period. More warming took place in the southwest area of the basin, and for nighttime lows (minimum) than daytime highs (maximum).
- Annual precipitation increased during this period, at a rate of up to 4% per decade. The largest increases were in the southern portion of the Rocky Mountain Trench.
- These trends are in most cases statistically significant throughout the basin (denoted by small dots in the centre of grid boxes).

- These trends are similar to those in a previous analysis based on stations only in Sections 2.1 and 2.2 of the *Preliminary Analysis* (Murdock et al. 2007).

Summary of results for Figure 2-2 (seasonal mean temperature trends):

- The amount of warming in the basin over the past century varied seasonally, with the most warming in the winter, followed by spring, summer then fall. With the exception of fall temperatures in the northern and eastern portions of the basin, the increases were statistically significant throughout the basin in every season.
- In the winter, mean temperatures increased by 1.4°C to 2.6 °C per century during the 1901-2004 period. The greatest warming occurred in the western portion of the basin.
- Spring temperatures increased 1.1°C to 2.2°C and summer temperature increases ranged from 0.5°C to 1.6°C, with the greatest warming in the south.
- During fall, warming trends were up to 1.2°C, but in many locations were not statistically significant.

Summary of results for Figure 2-3 (seasonal minimum temperature trends):

- The greatest nighttime low (minimum) temperature increases took place in winter with significant trends of 2.0°C to 3.2°C per century for most of the basin, with the western portion of the basin warming the most.
- Nighttime low temperature increases were largest in the south in spring (1.5°C to 2.0°C per century) and summer (2.0°C to 2.5°C per century). Most of these trends were statistically significant. Warming trends were smaller in fall (0.0°C to 1.0°C per century) than other seasons, and were not significant in the northern and eastern portions of the basin.

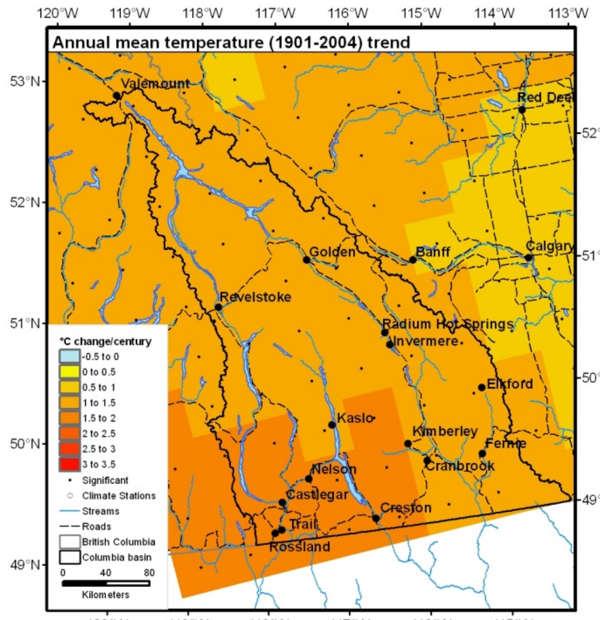
Summary of results for Figure 2-4 (seasonal maximum temperature trends):

- Daytime high (maximum) temperature increases were smaller than nighttime low trends for all seasons.
- Winter maximum temperatures increased from 1.4°C to 2.4°C per century, followed by 1.0°C to 1.6°C increases in spring for most of the basin and up to 1.2°C increases in summer and fall.
- Winter and spring temperature increases were quite uniform across the basin and most were statistically significant. Larger increases occurred towards the south and west areas of the basin in summer and fall. Summer trends were not statistically significant in the north and most of the fall trends were not significant.

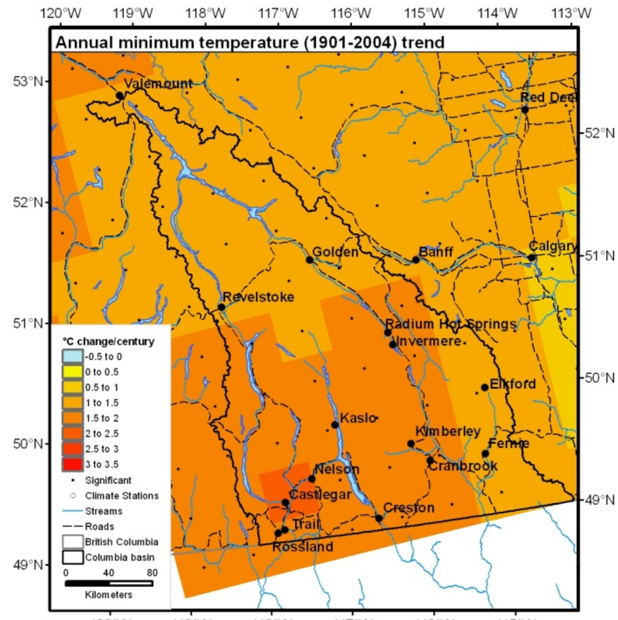
Summary of results for Figure 2-5 (seasonal precipitation trends):

- Total precipitation increased during 1901-2004 across all seasons in the basin, though in some seasons and locations the increase was not statistically significant.
- The greatest increase in precipitation occurred in spring, from 3% to 7% per decade.
- Summer precipitation increased by 1% to 4% per decade over most of the basin, with smaller (and not significant) increases on the east side of the basin and increases up to 5% per decade in the northern tip of the basin.
- Winter precipitation increases were generally not significant, though they ranged from 0% to 4% per decade at some locations, with much of the basin experiencing 0% to 2% increases per decade.
- Fall increases were not significant and varied over small distances, with most increases in the 0% to 1% per decade range in the north and 1% to 3% per decade in the south.

a)



b)



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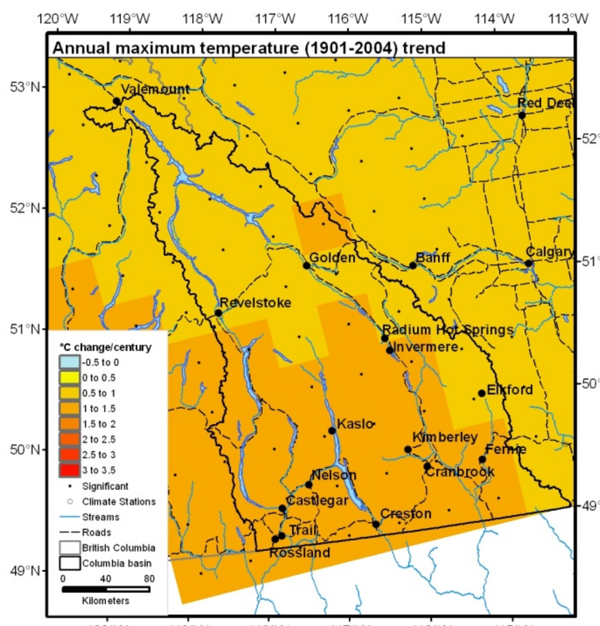

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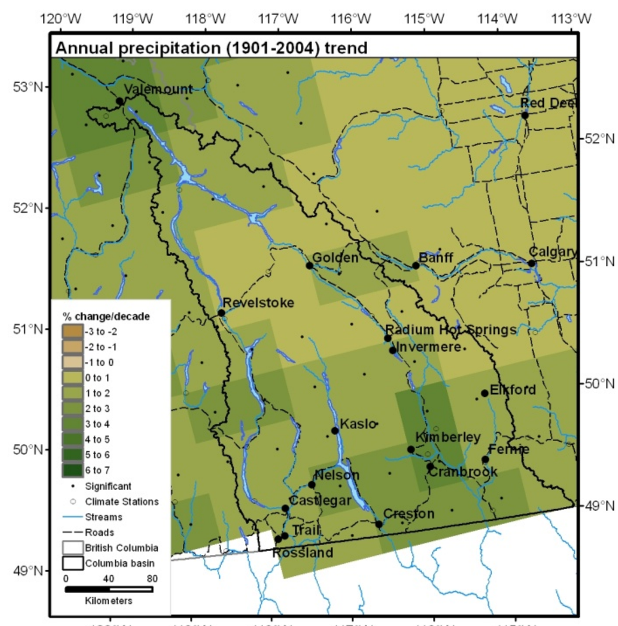

Figure 2-1: Annual Temperature and Precipitation trends (1901-2004) for Canadian Columbia Basin a) mean temperature, b) minimum temperature, c) maximum temperature and d) precipitation.

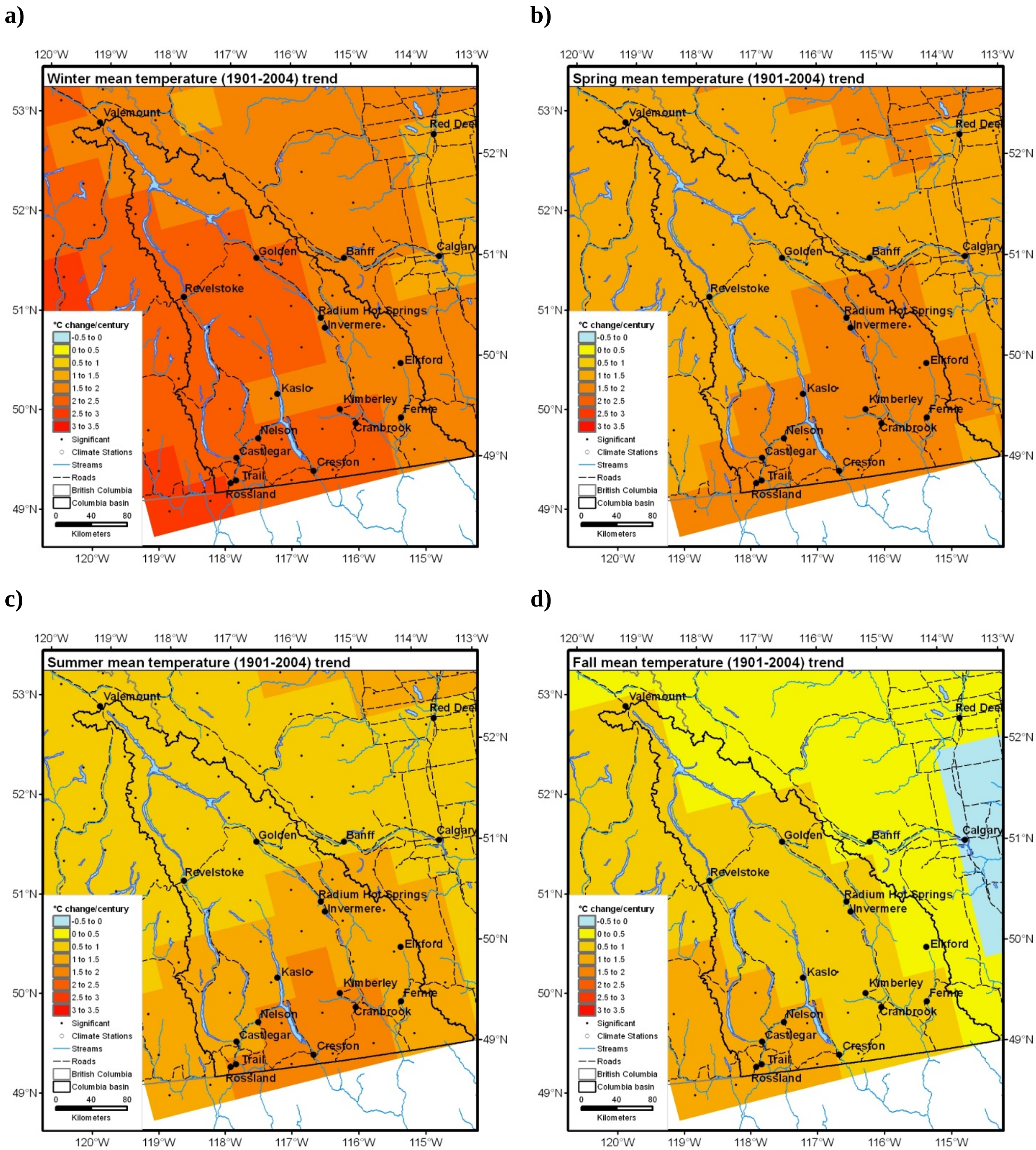

Figure 2-2: Seasonal Mean Temperature trends (1901-2004) for Canadian Columbia Basin a) winter, b) spring, c) summer and d) fall.

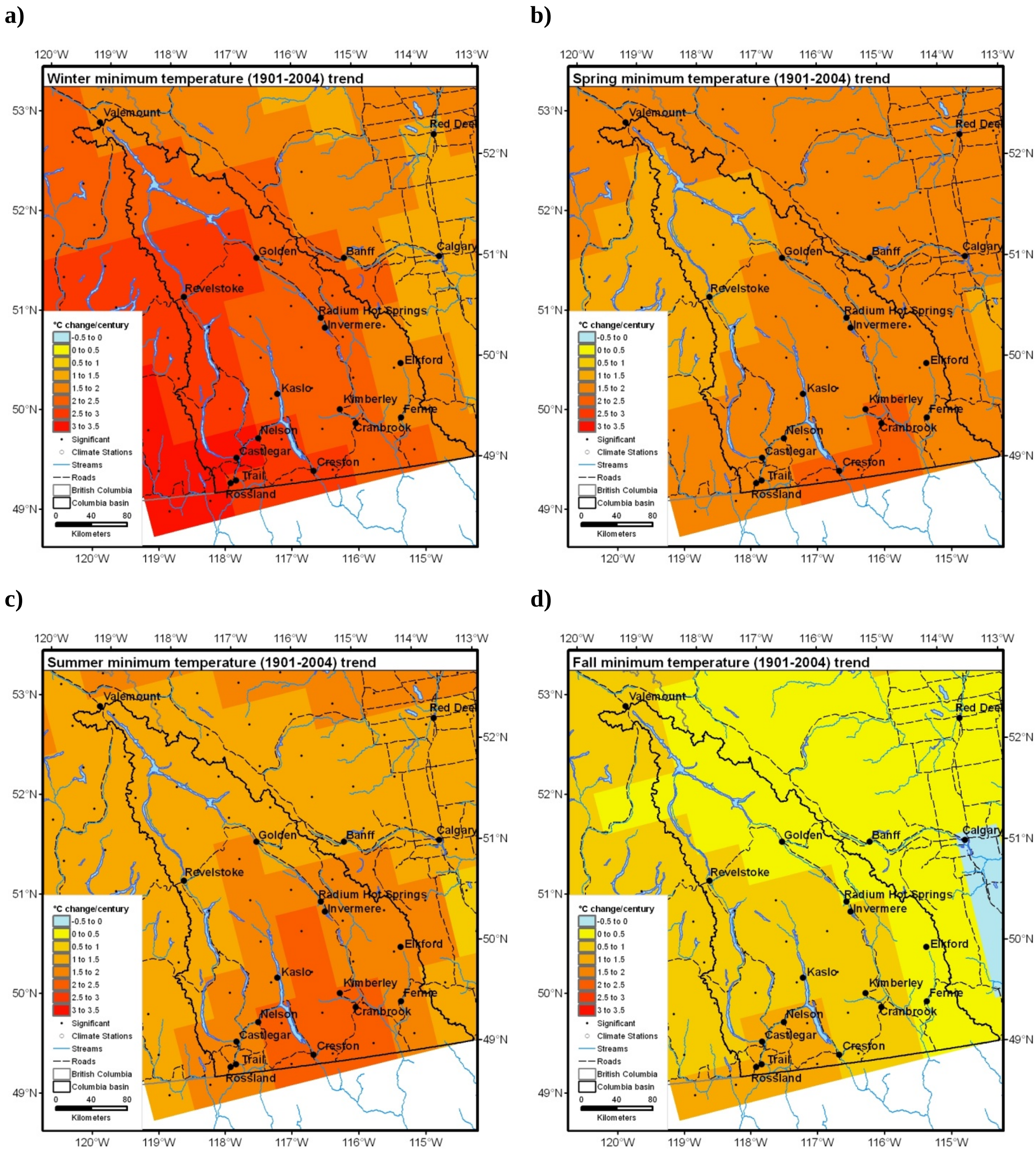

Figure 2-3: Seasonal Minimum Temperature trends (1901-2004) for Canadian Columbia Basin a) winter, b) spring, c) summer and d) fall.

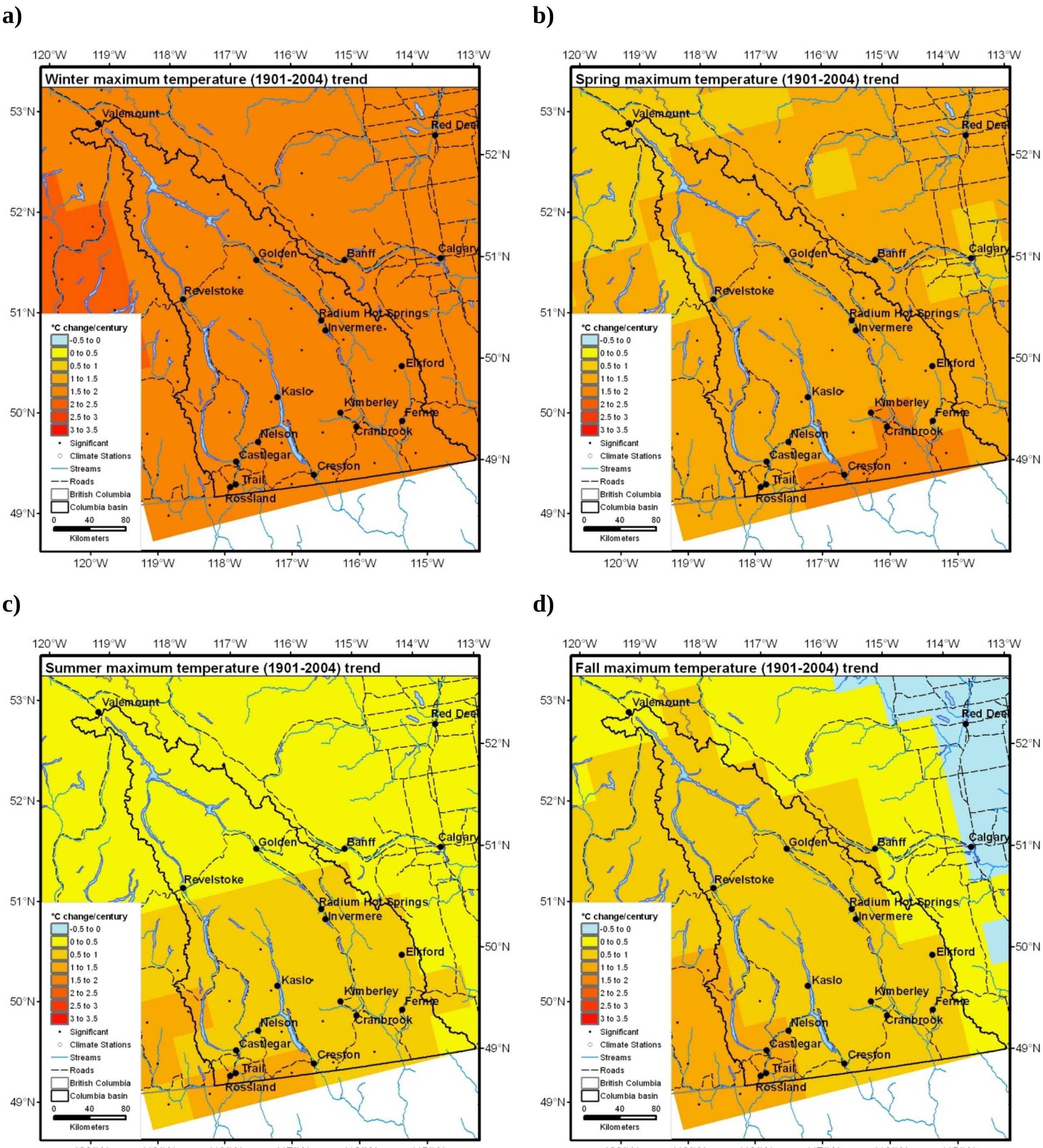

Figure 2-4: Seasonal Maximum Temperature trends (1901-2004) for Canadian Columbia Basin a) winter, b) spring, c) summer and d) fall.

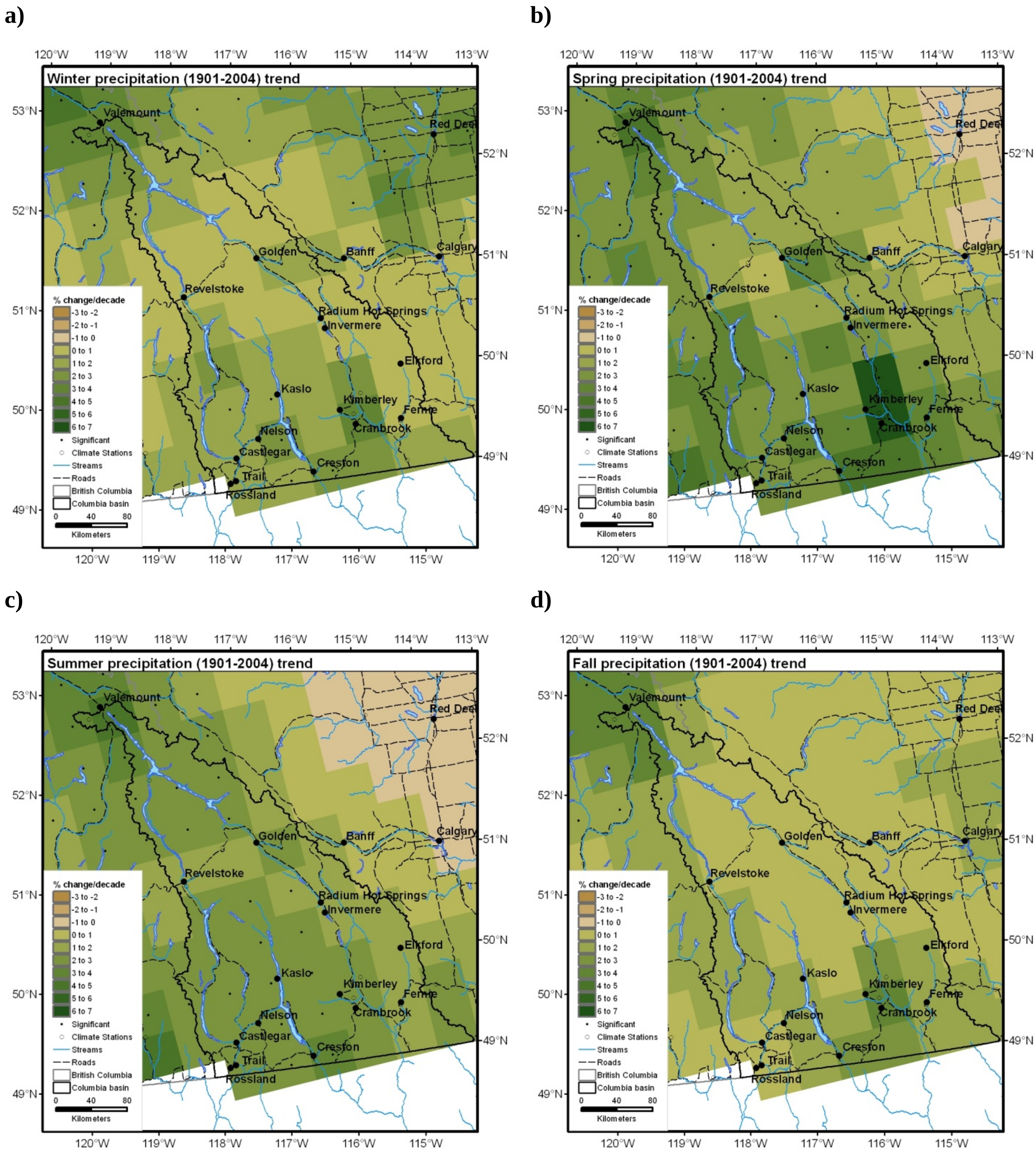

Figure 2-5: Seasonal Precipitation trends (1901-2004) for Canadian Columbia Basin a) winter, b) spring, c) summer and d) fall.

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3. Climate Variability

Section 1 of this report showed the historical baseline climate (1961-1990) while Section 2 provided historical trends over the past century. Sections 4 through 6 provide future projected climate change for the 2050s (2041-2070). It is important to remember that the year-to-year sequence of events that is experienced in a future climate will still include variability on time scales shorter than the 30-year period over which the 2050s projections are averaged.

This section provides an illustration of the magnitude of two important aspects of year-to-year and decadal variability over the past century: El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). Seasonal and monthly composites are provided of the average differences in temperature and precipitation during the positive and negative phases of each. Note that future projections of changes to variability are not addressed in this report. More information on climate variability is available in Section 2.1 of *Preliminary Analysis* (Murdock et al. 2007) and Section 3 of *BC Climate Overview* (Rodenhuis et al. 2009). Both publications are available online.[6]

3.1 Seasonal

Climate variability for temperature in El Niño, La Niña, warm PDO and cool PDO phases, is shown below by season. The maps show *composites*: the difference between the average of all years in question (e.g., all El Niño years in Figure 3-1a) from the average of all years in the complete time period (see figure labels for time periods). The source of the data was CANGRID, at a resolution of 50 km (Zhang et al. 2000).

Interpretation of maps in this section:

- Each map shows the difference between El Niño, La Niña, positive PDO, or negative PDO years (years as defined in Fleming et al. 2007) from all years in the full period.
- Individual El Niño and La Niña events will differ in response from the composites; these maps show the response by averaging several years but each year will have additional variability.
- The maps depict station data interpolated to 50 km gridded resolution. At this resolution, given the low density of stations, interpolated values are uncertain and do not fully reflect small scale variations related to factors such as surface topography.
- The maps show composites based on a period of 99 to 104 years. Station density changes through time with the lowest number of stations in the earliest parts of the record. Thus, the composites are affected by additional uncertainty due to whether or not stations were available within the vicinity of the grid box in the early part of the record. This means that the maps are useful for showing past regional climate variability, but individual results at single grid boxes are less robust than regional patterns. In particular, these composites should not be used in place of station data where such data exists.
- For more details on the maps see Section 3 of the *BC Climate Overview* (Rodenhuis et al. 2009).
- For more information on seasonal climate variability in the basin, see Section 2.1 of the *Preliminary Analysis* (Murdock et al. 2007).

[6] http://pacificclimate.org/publications

Summary of results for Figures 3-1 through 3-3 (winter temperature variability):

- The composite maps of winter temperatures in Figures 3-1, 3-2, and 3-3 all show that the basin was warmer than normal on average during El Niño years (by 1.0°C to 1.8°C), and warmer than normal on average during the warm phase of PDO. Conversely, the basin was usually colder than normal during La Niña years and the cold phase of the PDO.
- Nighttime low (minimum) temperatures responded to both ENSO and PDO more than daytime high (maximum) temperatures, as shown in Figures 3-2 and 3-3.
- The northern and eastern portions of the basin generally had a larger temperature response to ENSO and PDO (Figures 3-1 through 3-3).

Summary of results for Figure 3-4 (winter precipitation variability):

- The composite maps of winter precipitation show that the basin experienced less than normal precipitation during El Niño years and more than normal during La Niña. Similarly, much of the basin experienced less than normal precipitation during the warm phase of the PDO and more than normal during the cold phase. The response was generally small and in many locations less than a 2.5% difference from normal.

Summary of results for Figure 3-5 (spring precipitation variability):

- The composite maps of spring precipitation show that the basin experienced little response to ENSO in spring precipitation. However, much of the basin experienced more than normal precipitation during the warm phase of the PDO and vice versa. Although the response was generally small and in many locations less than a 2.5% difference from normal, it should be noted that the spring PDO composite is opposite to the winter PDO composite overall.

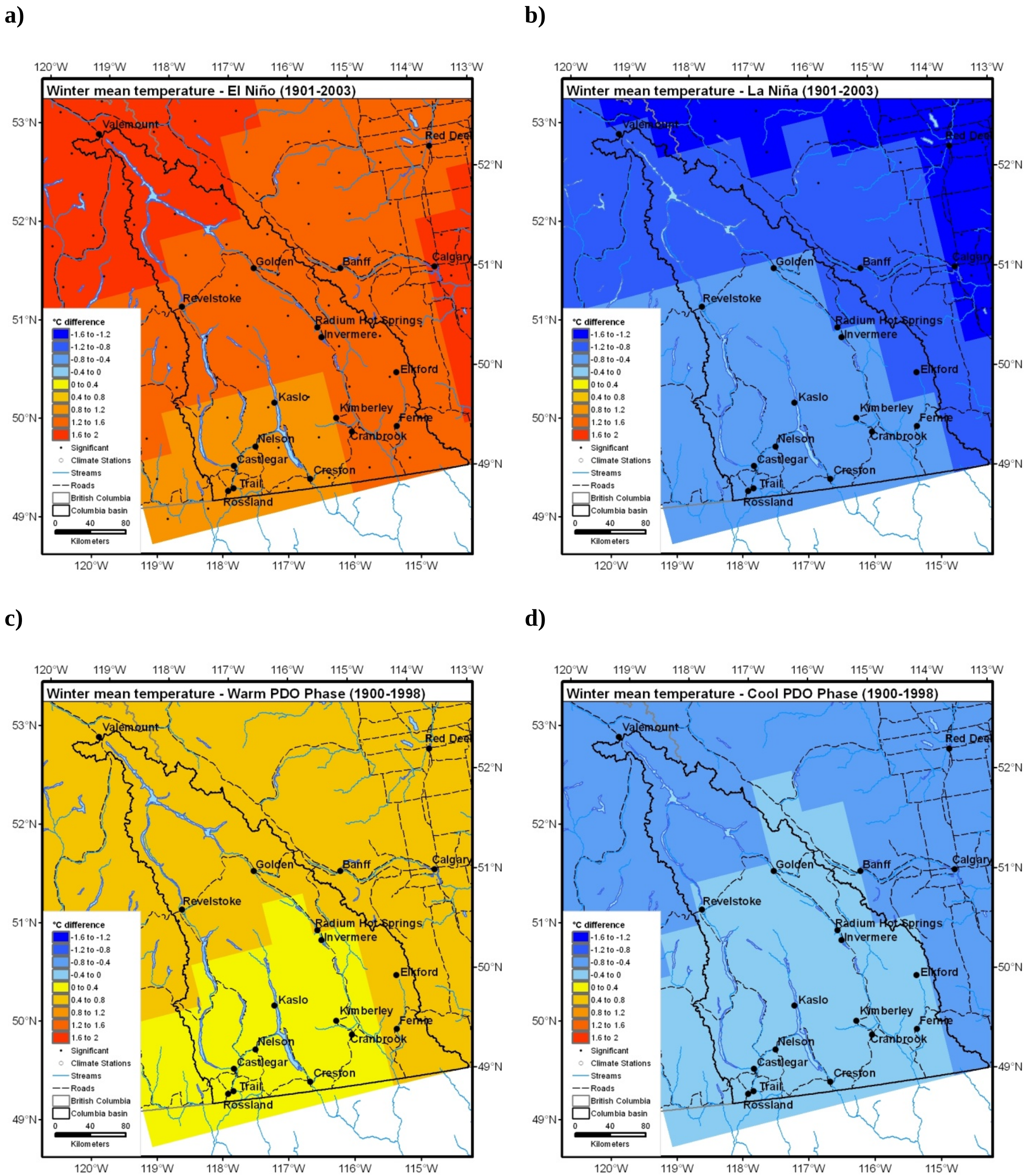


Figure 3-1: Seasonal climate variability for mean temperature in the Canadian Columbia Basin a) El Niño winter mean temperature b) La Niña winter mean temperature c) Warm PDO winter mean temperature and d) Cool PDO Winter mean temperature.

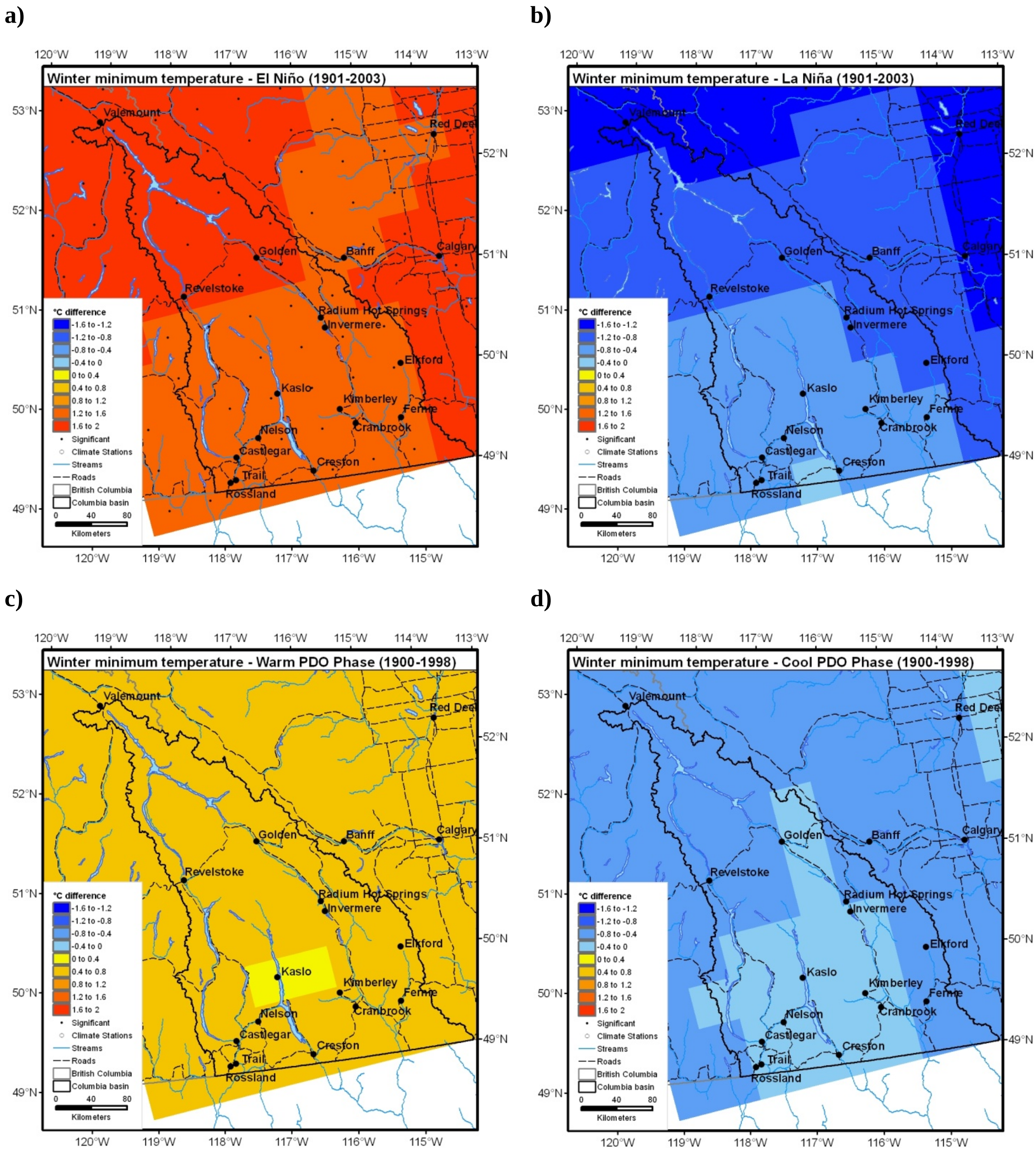


Figure 3-2: Seasonal climate variability for minimum temperature in the Canadian Columbia Basin a) El Niño winter minimum temperature b) La Niña winter minimum temperature c) Warm PDO winter minimum temperature and d) Cool PDO winter minimum temperature.

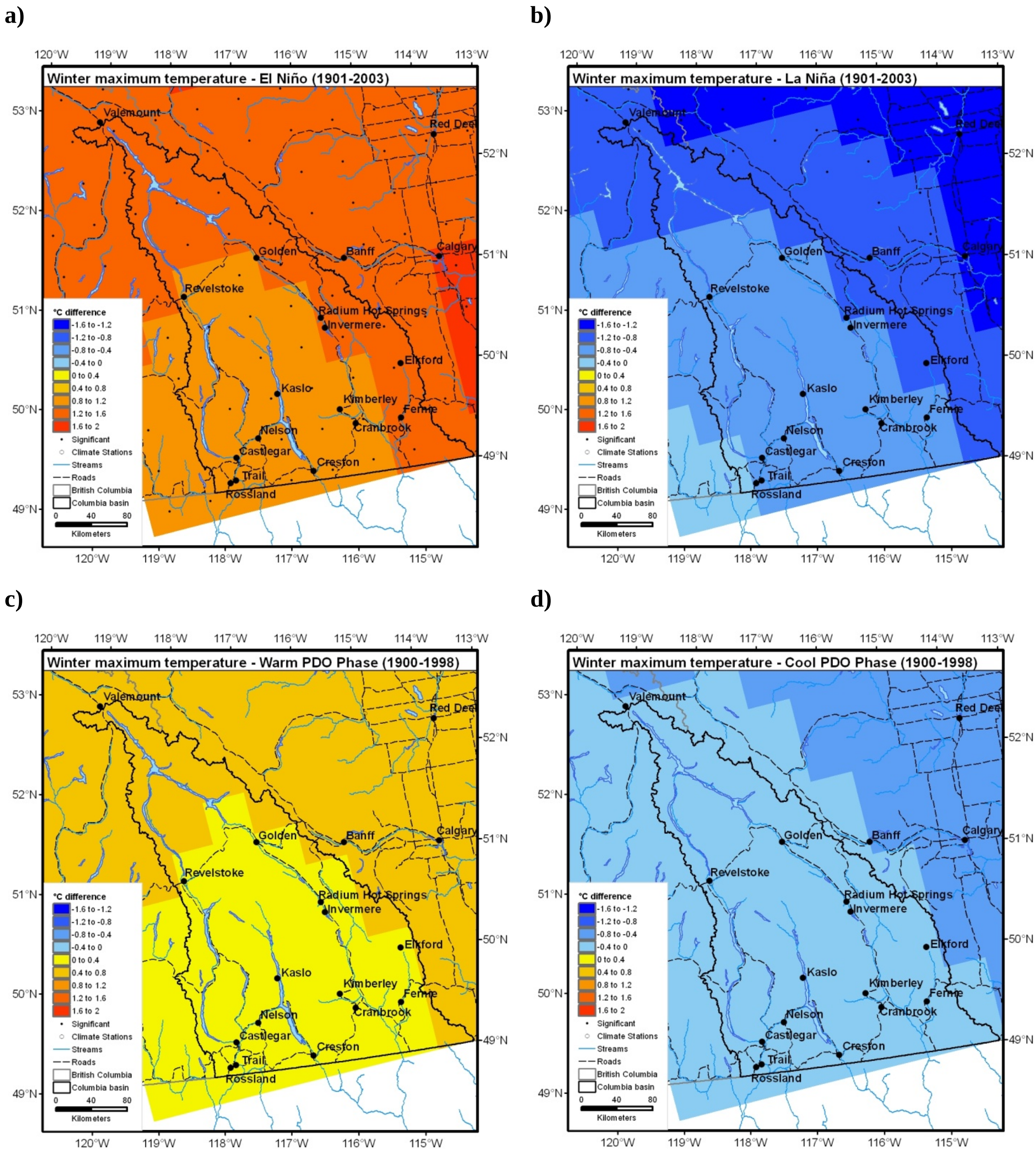


Figure 3-3: Seasonal climate variability for maximum temperature in the Canadian Columbia Basin a) El Niño winter maximum temperature b) La Niña winter maximum temperature c) Warm PDO winter maximum temperature and d) Cool PDO winter maximum temperature.

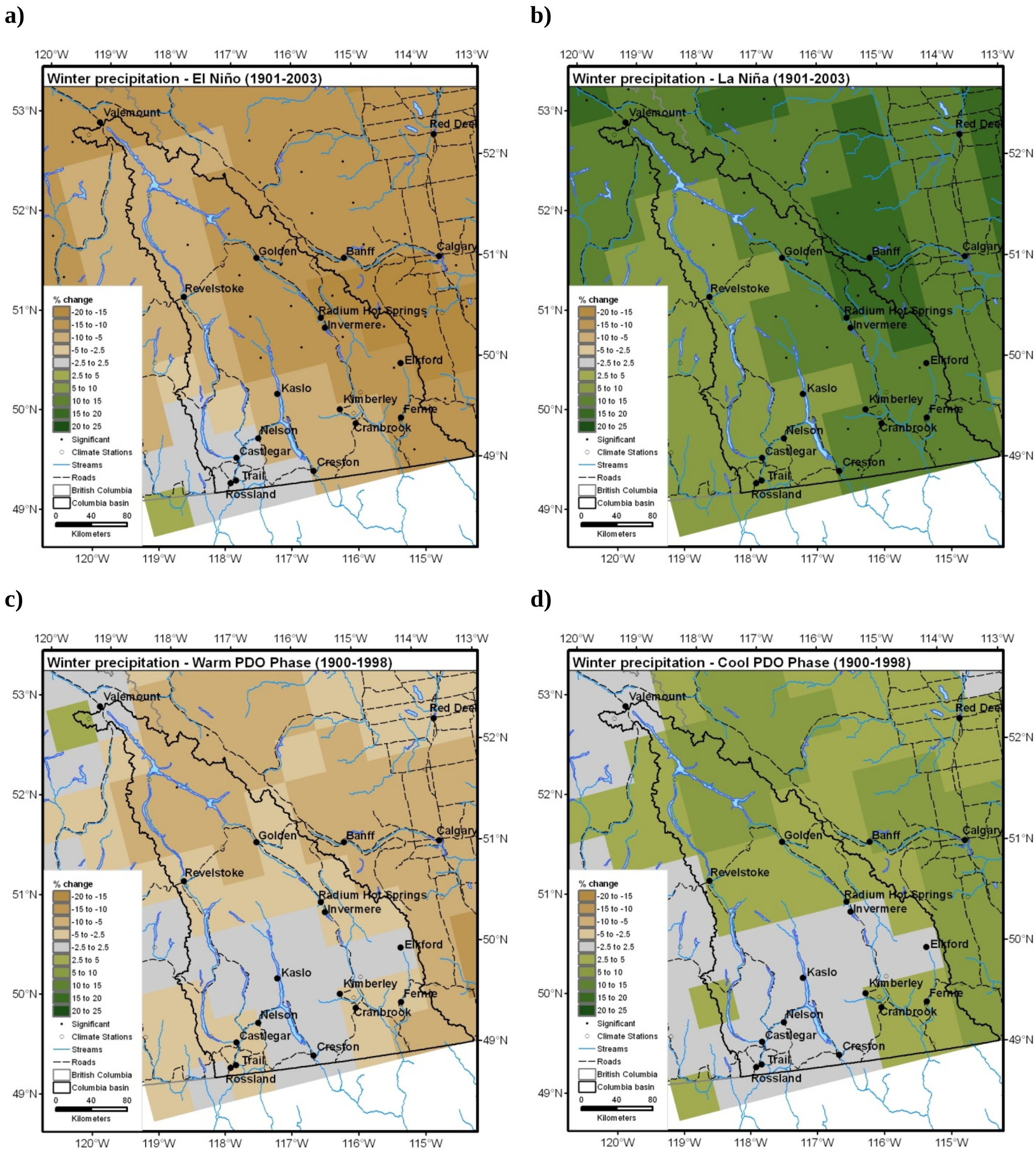


Figure 3-4: Seasonal climate variability for precipitation in the Canadian Columbia Basin a) El Niño winter precipitation b) La Niña winter precipitation c) Warm PDO winter precipitation and d) Cool PDO winter precipitation.

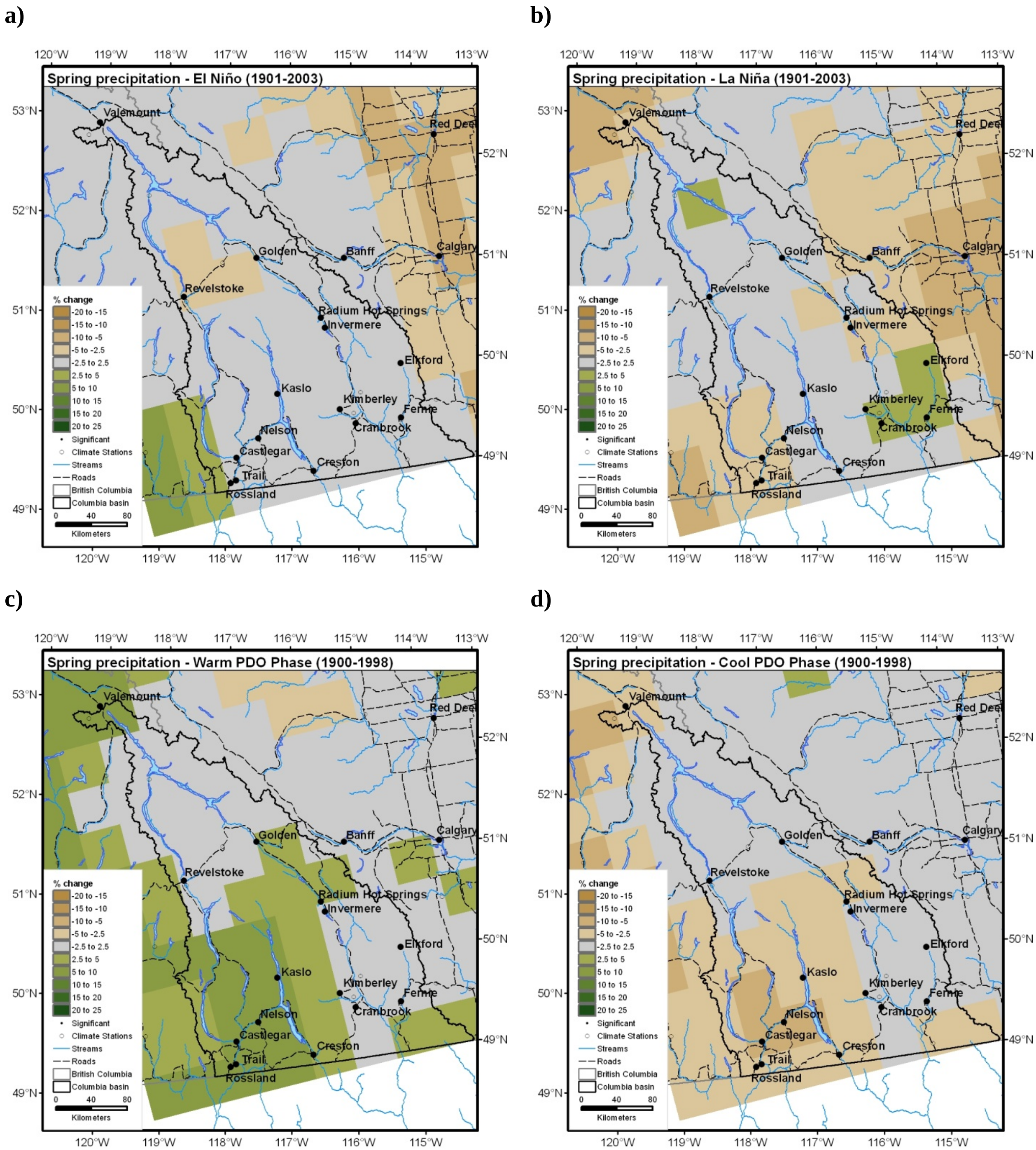


Figure 3-5: Seasonal climate variability for precipitation in the Canadian Columbia Basin a) El Niño spring precipitation b) La Niña spring precipitation c) Warm PDO spring precipitation and d) Cool PDO spring precipitation.

3.2 Monthly

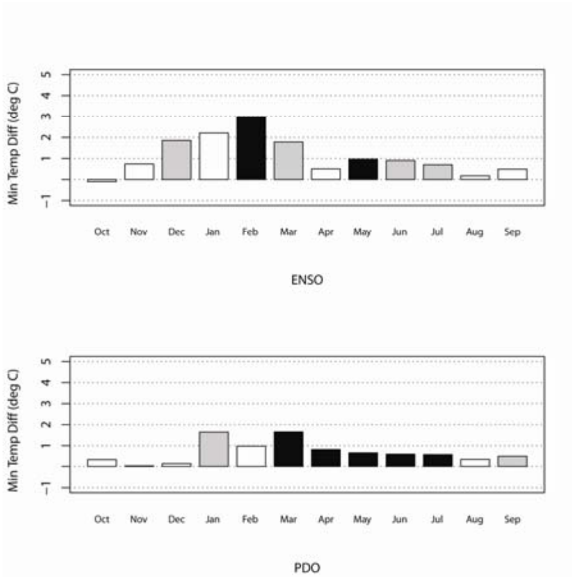
To illustrate whether the seasonal climate variability results displayed in maps above affect seasonal averages only, or if there is any coherent response by month of the year, the bar plots in Figure 3-6 were constructed. They show differences, according to CANGRID gridded climate data averaged over the Canadian Columbia Basin, between warm and cold phase responses for each month of the year. That is, the figures show La Niña subtracted from El Niño and cool PDO subtracted from warm PDO for minimum, maximum and mean temperatures (°C), and precipitation (%). Statistical significance is indicated by grey (p=.1) or black (p=.05) shading. All months of the year are shown in the figures, for the "water year" – from October through September.

Summary of results for Figure 3-6 (monthly variability):

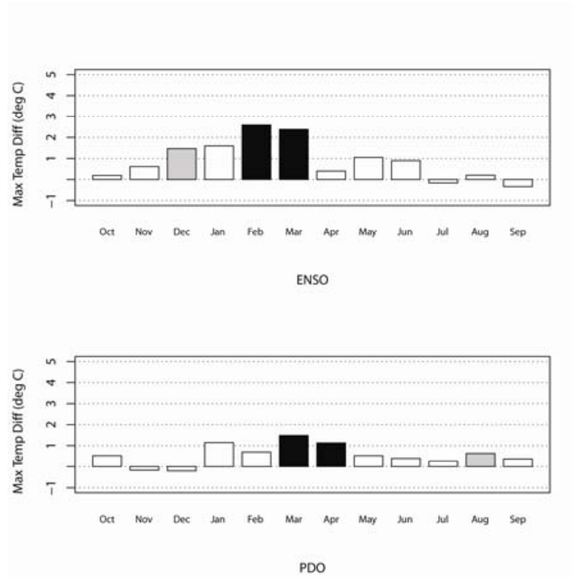
Generally, for the Canadian Columbia Basin:

- Temperatures were higher during El Niño years than during La Niña years by roughly 1.5°C to 3.0°C between the months of December through March.
- During March and April in warm PDO phases, temperatures were higher by roughly 1.0°C to 1.5°C than during cool PDO phases. Throughout the summer during warm PDO phases, minimum and mean temperatures were higher than during cool PDO phases.
- Precipitation in El Niño years was generally 15% to 35% lower than during La Niña years from October through March.
- Precipitation during warm PDO phases was not significantly different from cool PDO phases.

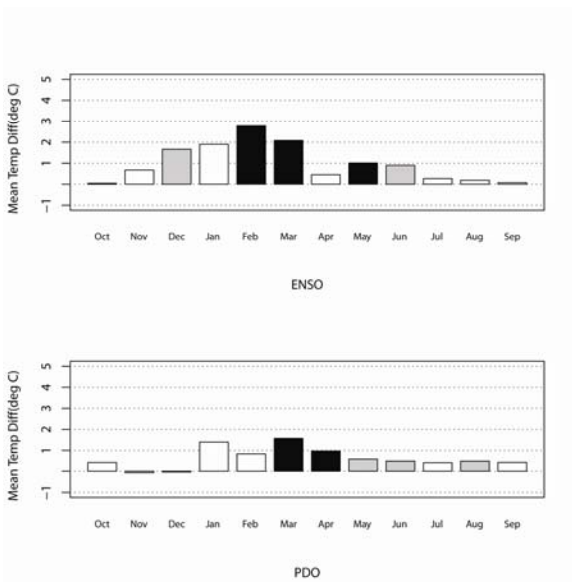
a) Columbia Basin – Min. Temperature



b) Columbia Basin – Max. Temperature



c) Columbia Basin – Mean Temperature



d) Columbia Basin – Precipitation

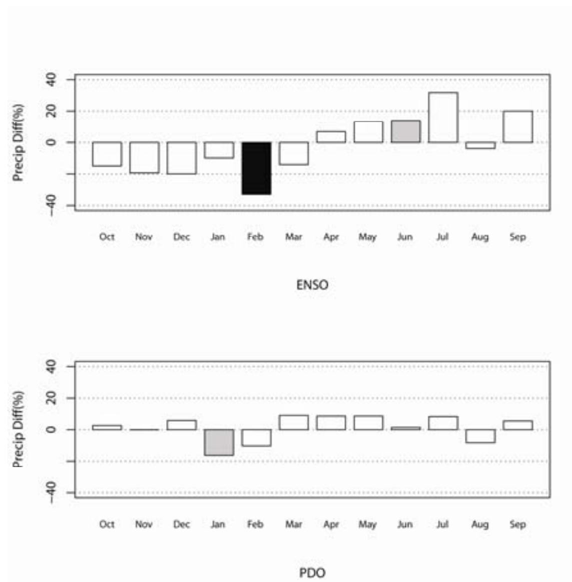


Figure 3-6: ENSO and PDO monthly responses in the Canadian Columbia Basin for a) minimum temperature b) maximum temperature c) mean temperature, and d) precipitation. Period for ENSO (La Niña subtracted from El Niño) is 1900-2004; for PDO (negative phase subtracted from positive phase) is 1900-1998.

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Part II - Future Climate

In Part II of this report, future climate projections are presented.

Each of the following three sections progress from the broad continental scale to the finer scale, by using projections from each the following sources:

- Section 4 - Global Climate Models (coarse resolution) – this section provides a range of projected changes in temperature and precipitation for the Canadian Columbia Basin region.
- Section 5 - Regional Climate Model (higher resolution) – this section shows results from a single regional climate model, which provides a sense of the amount by which temperature and precipitation projections for areas within the basin may differ from the projections for the region as a whole in the previous section.
- Section 6 - Empirical downscaling (high resolution) – this section shows projections for temperature, precipitation and growing degree days.

More information on impacts that may be expected to result from the changes shown in these sections are explored in a separate report (Lane et al. 2010).

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4. Global Climate Model Projections (Coarse Resolution)

The projections in this section were prepared by climate modelling centres for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), and were not available at the time of publication of the *Preliminary Analysis* (Murdock et al. 2007). That report used modelling results prepared for the IPCC Third Assessment Report (TAR). Differences between the models and emissions scenarios available between the IPCC TAR and AR4 reports are described in the *BC Climate Overview* (See Rodenhuis et al. 2009 Part II Introduction, Section 4.0 and Section 4.1).

Climate projections of temperature and precipitation from 30 Global Climate Model (GCM) projections are presented for those model grid squares that are within or in close proximity to the Canadian Columbia River Basin (7 or 8 grid boxes). The ensemble includes projections from 15 GCMs, with one run driven by each of two greenhouse gas emissions scenarios (A2 and B1)[7]. Projections are provided as differences from the 1961-1990 baseline in °C for temperature and as a percentage change from the 1961-1990 baseline for precipitation.

Interpretation of figures in this section:

- As these figures incorporate results from a range of future climate projections, they are the most appropriate for quantifying uncertainty. The ranges are based on the 10th to 90th percentile of changes for the Canadian Columbia River Basin according to 30 future climate projections.
- Boxplots show the range of values projected by the various models with "whiskers" at the end of the vertical lines to indicate the full range of model projections. The top and bottom of the box shows the 25th and 75th percentiles of projected changes, and the horizontal bar within the box indicates the median value of projected change. Thus, 50% of the projections are enclosed by the box. Boxplots are valuable for showing both the climate change projected by the majority of model runs as well as the range of differences between models.
- While boxplots show the 25th and 75th percentiles as a convention, when quoting the range of future climate projected numerically, it is common to use the 10th and 90th percentiles in order to give a better indication of most of the full range. Each of these measures is reported in the tables summarizing the projections and is the basis for reporting projected changes.
- The Canadian Global Climate Model (CGCM3 run 4 following the A2 emissions scenario) projections are displayed on the boxplots as a red line, because these are used to drive higher resolution projections from Regional Climate Models (RCMs) and empirical downscaling (in Sections 5 and 6). It is important to note that for the basin area, the projected changes to temperature and precipitation with this run were warmer and wetter than the ensemble median in most cases, and warmer and wetter than the 75th percentile for some cases.

[7] For more information on emissions scenarios, see Section 2 in "General guidelines on the use of scenario data for climate impact and adaptation assessment Version 2." IPCC, June 2007. http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

Summary of results for Table 4-1 and Figure 4-1 (temperature):

- Mean annual temperature is projected to increase throughout the 21st century, as well as across each season. Projected winter (December-January-February), summer (June-July-August), and annual changes are shown in Table 4-1 and Figure 4-1 below.
- By the 2050s, the mean annual temperature is projected to rise by 1.2°C to 2.7°C compared to the 1961-1990 baseline.

Summary of results for Table 4-2 and Figure 4-2 (precipitation):

- Total precipitation is projected to increase over the course of the 21st century according to the majority of global climate model projections.
- By the 2050s, the projected precipitation change compared to the 1961-1990 baseline ranges from a 2% decrease to a 9% increase.
- Projected precipitation increases in winter are larger on the upper end of the range than those for the annual average: up to a 15% increase by the 2050s.
- Projected changes in summer precipitation range from a 14% decrease to a 1% increase by the 2050s. Note however that extreme precipitation could increase even if average precipitation decreases.

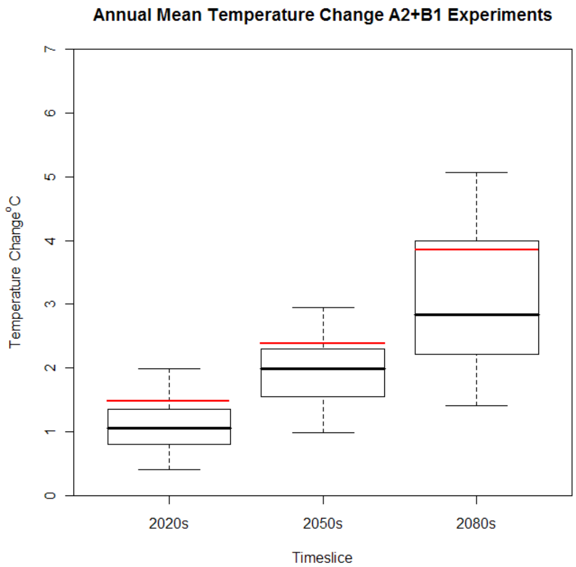
Table 4-1: Future projections of mean annual temperature change (°C) from 1961-1990 baseline using 15 GCMs with both A2 and B1 emissions scenarios.

	Winter			Summer			Annual		
	2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
90th percentile	1.7	3.2	4.9	1.8	3.2	5.7	1.4	2.7	4.4
75th percentile	1.4	2.4	4.0	1.6	3.0	4.9	1.3	2.3	4.0
Median	1.0	1.8	2.9	1.3	2.3	3.6	1.1	2.0	2.8
25th percentile	0.7	1.4	2.2	0.8	1.9	2.6	0.8	1.6	2.2
10th percentile	0.4	1.1	1.6	0.7	1.5	2.2	0.6	1.2	1.8

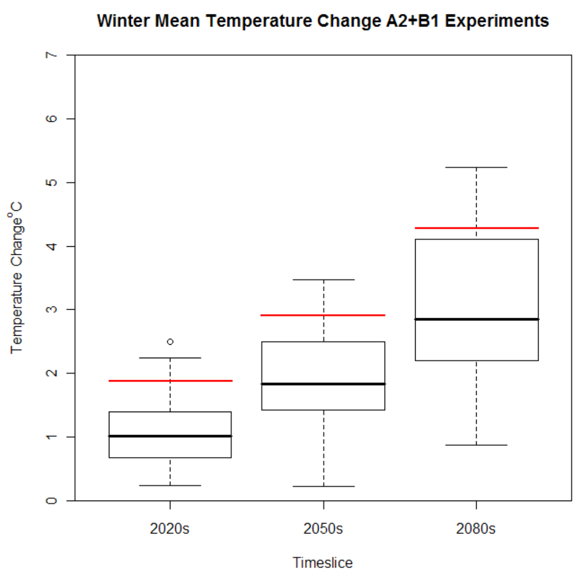
Table 4-2: Future projections of precipitation change (%) from 1961-1990 baseline using 15 GCMs with both A2 and B1 emissions scenarios.

	Winter			Summer			Annual		
	2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
90th percentile	9	15	28	3	1	1	7	9	11
75th percentile	7	13	20	0	-4	-4	5	8	10
Median	4	7	12	-3	-6	-8	4	5	6
25th percentile	1	1	6	-5	-10	-14	1	0	3
10th percentile	-2	-2	3	-7	-14	-23	-1	-2	2

a)



b)



c)

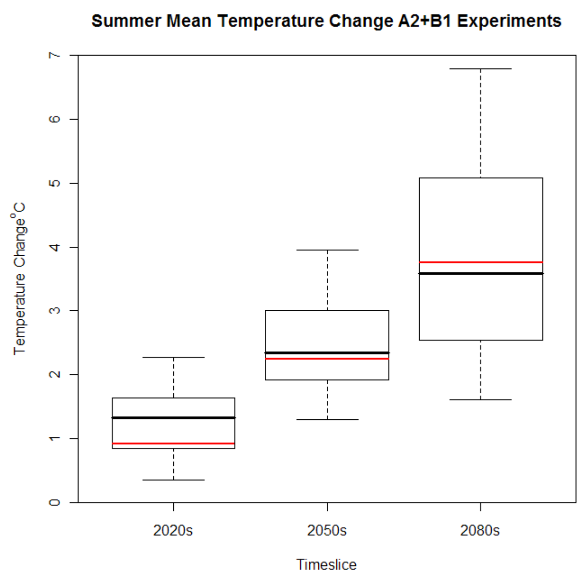
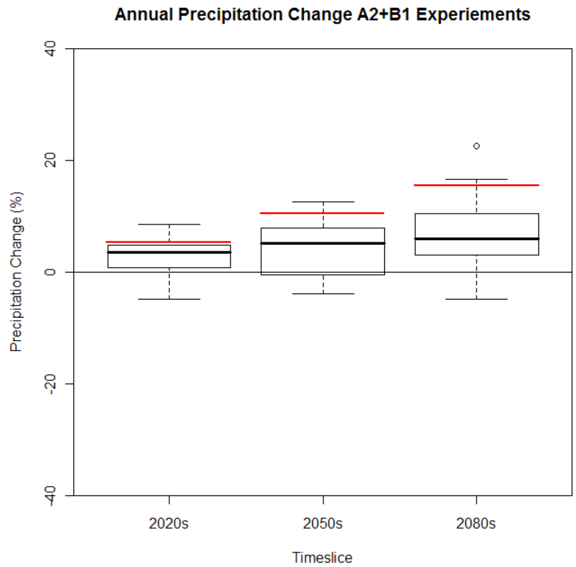
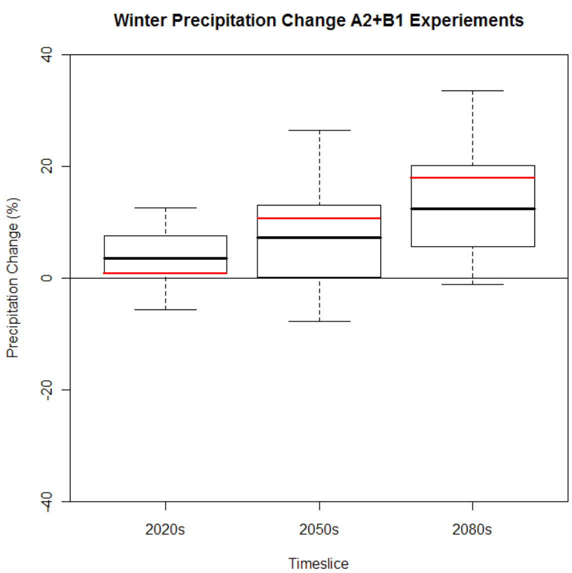


Figure 4-1: Box plots of projected change in temperature in the Canadian Columbia Basin in 2020s, 2050s, and 2080s a) annual mean temperature b) summer mean temperature and c) winter mean temperature using 15 GCMs with both A2 and B1 emissions scenarios. Red line denotes change according to CGCM3 run 4 following the A2 emissions scenario.

a)



b)



c)

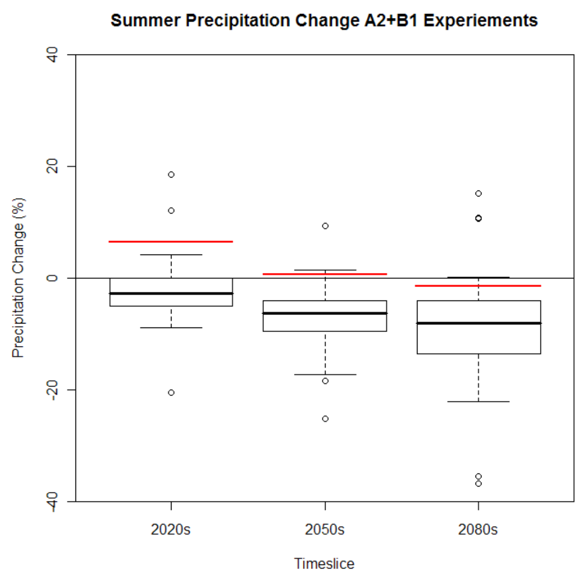


Figure 4-2: Box plots of projected change in precipitation for the Canadian Columbia Basin in 2020s, 2050s, and 2080s a) annual precipitation b) winter precipitation and c) summer precipitation using 15 GCMs with both A2 and B1 emissions scenarios. Red line denotes change according to CGCM3 run 4 following the A2 emissions scenario.

5. Regional Climate Model Projections (Higher Resolution)

Regional Climate Models (RCMs), like Global Climate Models (GCMs), are numerical representations of the climate system based on the physical, chemical, and biological properties of its components, including interactions and feedback processes. As RCMs operate at a higher resolution over a limited area, they represent elevation, physical and dynamical processes as well as land surface characteristics in more detail than GCMs.

There are fewer RCM than GCM projections available. The projections shown here are from only one RCM (Canadian Regional Climate Model CRCM version 4.1.1, driven by CGCM3) with only one emissions scenario (A2, run 4). More of the uncertainty in the projected changes by the 2050s is contributed by the various climate models than by different emissions scenarios (Rodenhuis et al. 2009). Although it would be preferable to consider multiple RCM runs for this emissions scenario, they were unavailable at the time of analysis. Additional RCM runs are now available from the North American Regional Climate Change Assessment Program (NARCCAP), which has set out to systematically investigate the uncertainties in future climate change projections at a regional level. This will be done by running multiple RCMs with multiple GCMs over North America[8]. Initial analysis of these RCM runs (including projections of extremes) is underway.

The RCM projections shown here have a resolution of 45 km. Results are presented in maps as a difference from the 1961-1990 baseline for the 2050s (2041-2070). The projected change for the region according to the GCM (CGCM3 A2 run 4) that drives the RCM is shown as a red line on each of the boxplots in Section 6. As the projection of the driving run is warmer and wetter than most other GCMs in the ensemble of 30 projections (see Figure 4-1 and Figure 4-2), it is possible that the CRCM4 results shown as maps below are also on the warmer and wetter end of a range of projections.

Interpretation of the maps in this section:

- As these maps illustrate results from a single RCM, they represent only the inter-regional difference that might be expected throughout the region and thus they should only be used to assess potential differences in future climate change across the basin. The results from the driving GCM model and emissions scenario are shown in the context of the ensemble of 30 projections in the boxplots in Section 4 as a red line, and are warmer and wetter than most.
- For more information on the RCM used see the BC *Climate Overview* (See Rodenhuis et al. 2009 Part II Introduction, Section 4.0 and Section 4.2).

Summary of results for Figure 5-1 (RCM annual temperature and precipitation):

- RCM annual temperature projections are quite consistent across the basin.
- RCM annual precipitation projections are fairly consistent across the basin, with smaller increases and some decreases projected to the east of the basin.
- The temperature projections are larger according to the RCM than the driving GCM (compare to *BC Climate Overview* (Rodenhuis et al. 2009) Figures 4.1.2 and 4.2.1).

Summary of results for Figure 5-2 (RCM seasonal temperature change):

- For winter and fall, the RCM projects more warming in the northern portion of the basin than in the south.
- For spring and summer, the RCM projections are very consistent across the region.

[8] http://www.narccap.ucar.edu

Summary of results for Figure 5-3 (RCM seasonal precipitation change):

- RCM seasonal precipitation projections show considerable variation between the seasons as well as more variation within the region than may be expected from the annual projection.
- The greatest precipitation increases across the basin are projected in spring.
- Winter RCM precipitation projections range from small decreases to modest increases for most of the region, with larger projected increases on the eastern edge of the region and east of the basin.
- Summer RCM precipitation projections show increases for most of the basin, with decreases projected for areas on the eastern edge of the basin, These results are in contrast to the basin average results from GCM projections, most of which project decreased precipitation in summer (see Figure 4-2b) and the GCM that drives the RCM which projects a very slight increase in precipitation (see red line on Figure 4-2b for 2050s).
- Fall RCM precipitation projections are the most spatially consistent compared to other seasons, with modest increases in precipitation projected across the basin.

a) **b)**

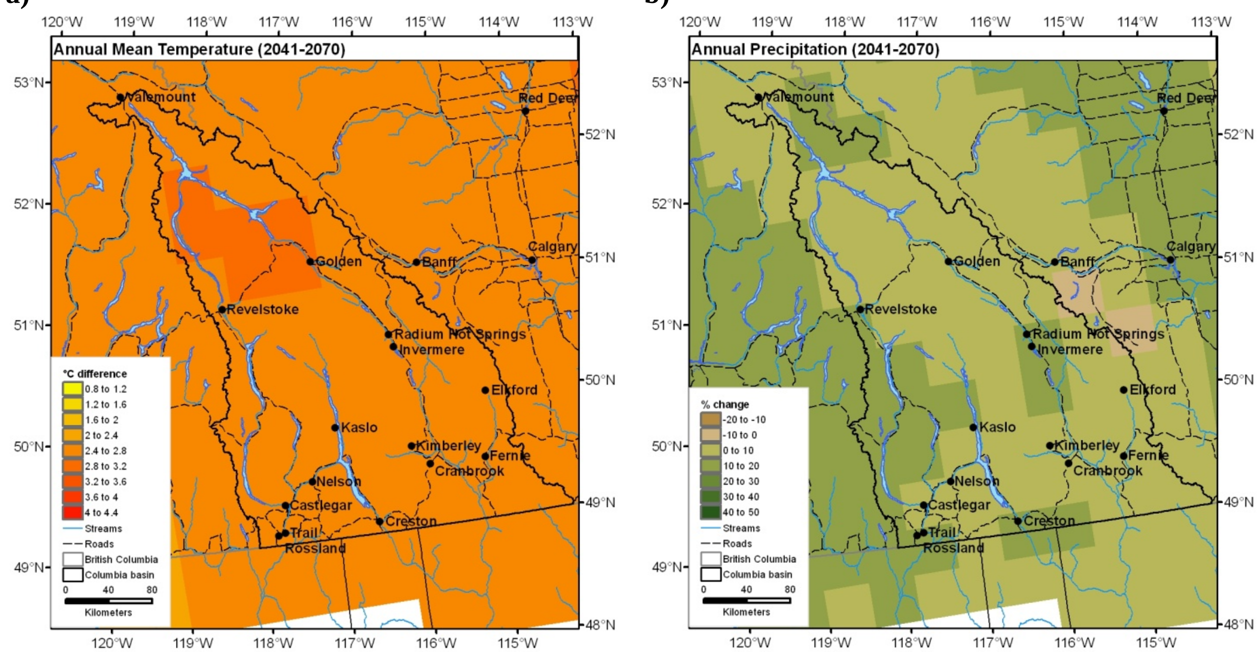
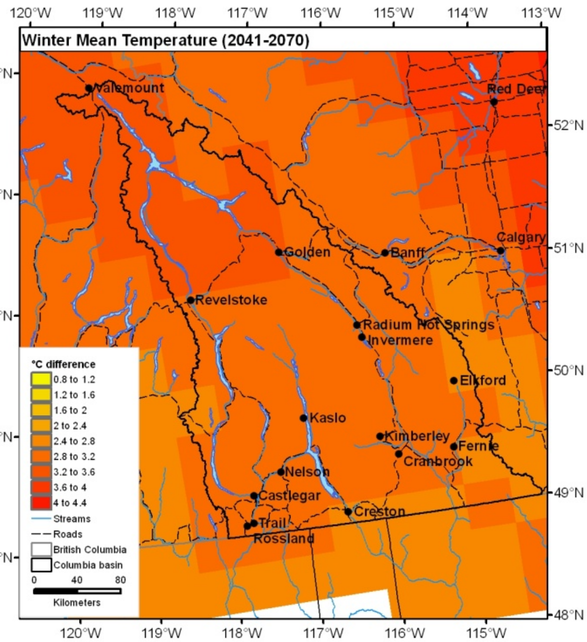
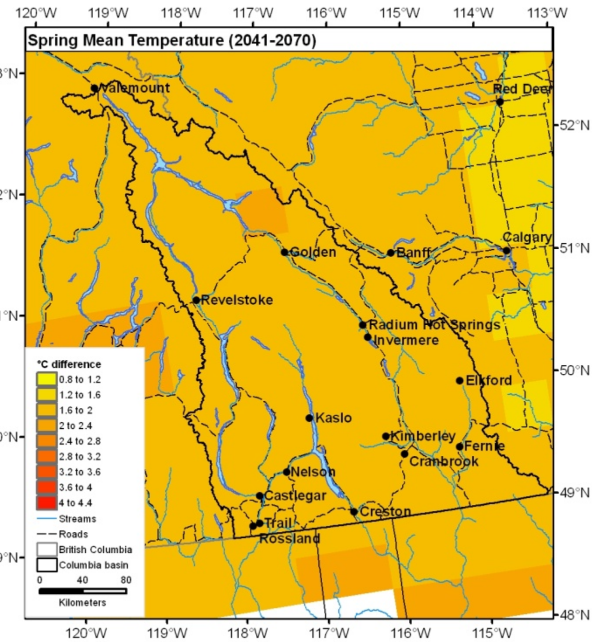


Figure 5-1: RCM projected change for the Canadian Columbia Basin (2041-2070) climate as compared to the 1961-1990 baseline for a) annual mean temperature and b) annual precipitation.

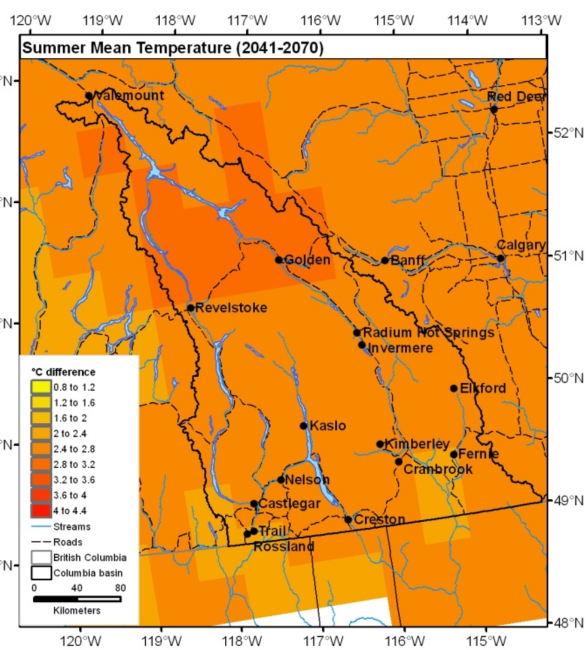
a)



b)



c)



d)

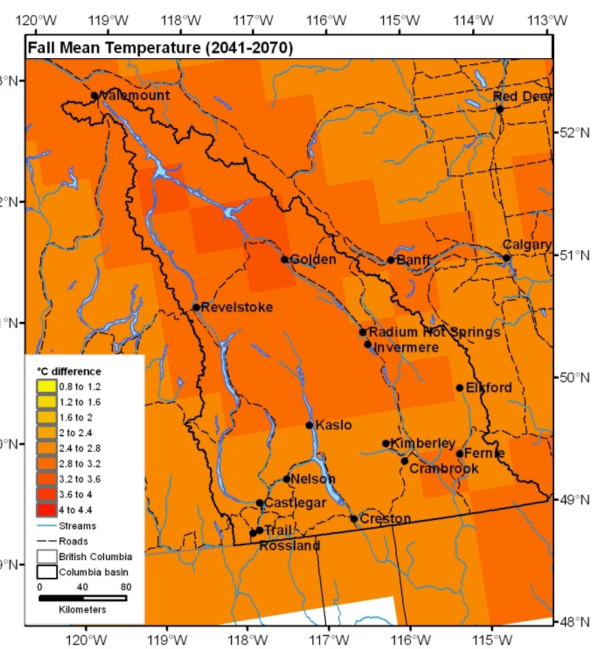


Figure 5-2: RCM projected change in the Canadian Columbia Basin (2041-2070) climate as compared to the 1961-1990 baseline a) winter mean temperature, b) spring mean temperature, c) summer mean temperature and d) fall mean temperature.

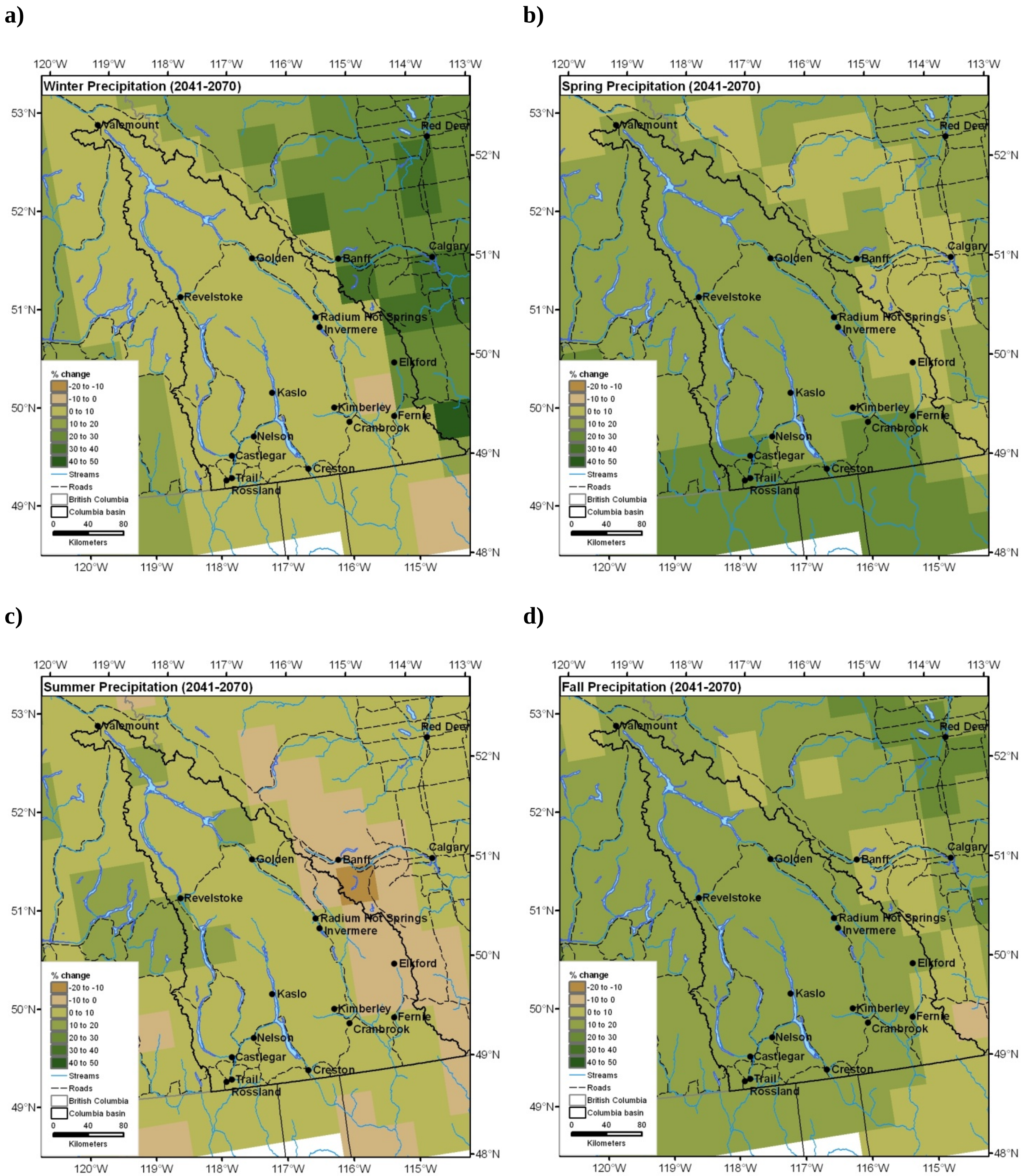


Figure 5-3: RCM projected change for the Canadian Columbia Basin (2041-2070) climate as compared to the 1961-1990 baseline a) winter precipitation, b) spring precipitation, c) summer precipitation and d) fall precipitation.

6. Empirical Downscaling Projections (High Resolution)

The projected climate change from a Regional Climate Model at 45 km (Section 5) is an improvement in resolution over the coarse GCM projections, but remains too coarse to illustrate the regional micro-climates in the basin that result from complex topography. The maps in this section show projections for the 2050s (2041-2070) from the Canadian Global Climate Model (CGCM3 run 4 following the A2 emissions scenario), when placed in the context of a high resolution (4 km) 1961-1990 climatology.

Interpretation of the maps in this section:

- The high resolution maps are constructed by "draping" the projected coarse resolution GCM change over the high resolution (interpolated) baseline[9]. This method ignores possible feedbacks between local micro-climate and climate change, which could be considerable in complex terrain, particularly at high elevation. Thus, these should be used only as an illustration of how the projected regional average change may look in the context of the basin's complex terrain.
- The 2050s maps are based on the same single GCM and emissions scenario (CGCM3 A2 run 4) used to drive the RCM projections in Section 5.
- For additional information on the methods used to create these maps see the *BC Climate Overview* (Rodenhuis et al. 2009, Part II Introduction, Section 4.0 and Section 4.3).

Summary of results for Figure 6-1 (annual temperature and precipitation):

- Locations with a mean annual temperature less than 0°C are projected to virtually disappear from the Canadian Columbia Basin by the 2050s. This isotherm is a rough indicator of conditions that can support glaciers.[10]
- Although considerable annual precipitation increases are projected in some locations (see Sections 4 and 5), these changes are small compared with large regional differences in precipitation.

Summary of results for Figures 6-2 to 6-4 (seasonal temperature and precipitation):

- The summer and winter temperature projections illustrate how mean seasonal temperature regimes could move upslope in response to the GCM projected regional warming.
- Although considerable winter precipitation increases are projected in some locations (see Sections 4 and 5), these changes are small compared with large regional differences in precipitation.

Summary of results for Figure 6-5 (growing degree days):

- A projected increase in growing degree days by the 2050s indicates a potential change in productivity and the suitability of potential agricultural crops.

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[9] See Section 1 for more information on the PRISM technique that provides a high resolution baseline.
[10] Dr. Shawn Marshall, pers. comm.

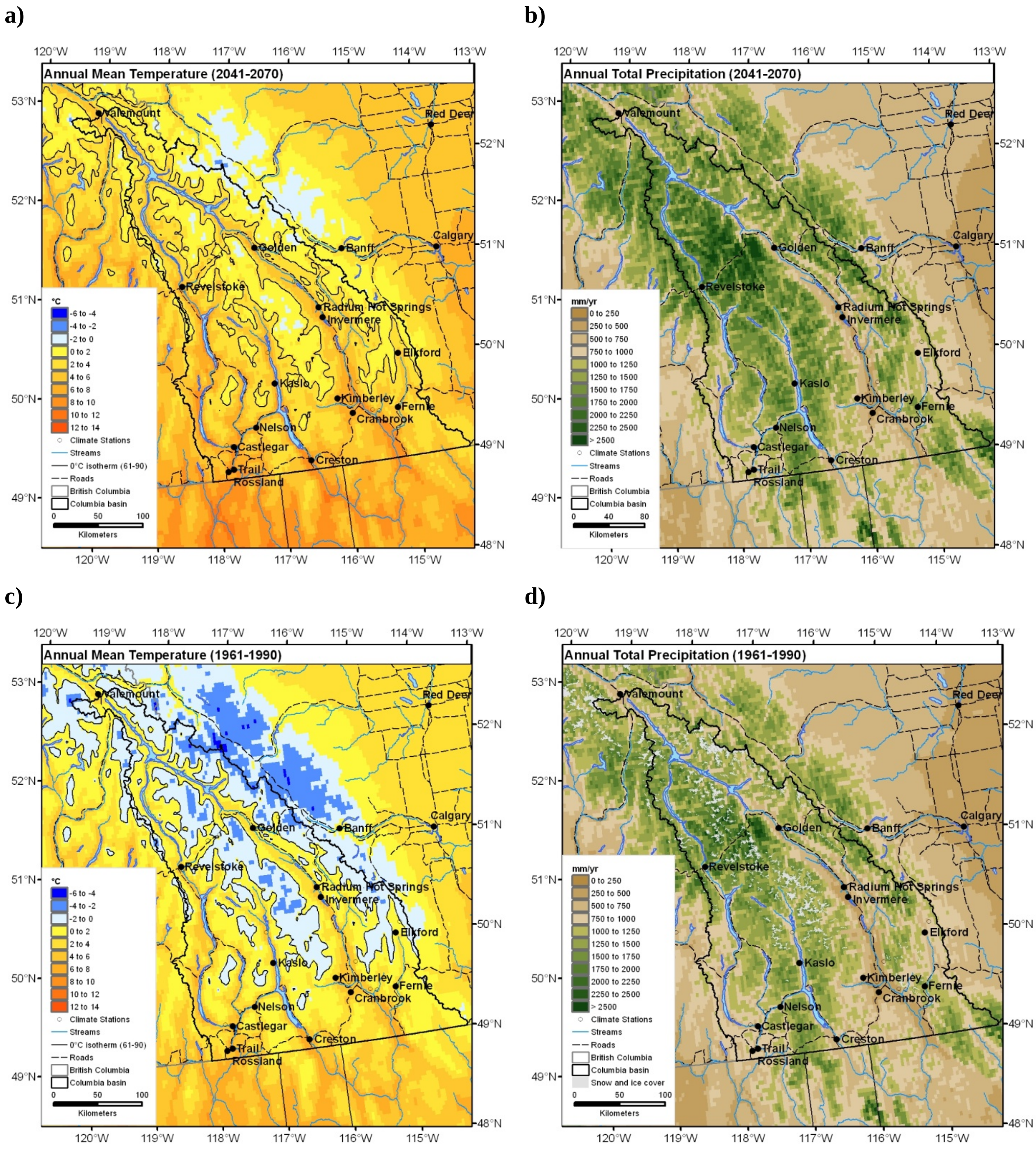

Figure 6-1: Projected change for the Canadian Columbia Basin (2041-2070) climate for a) annual mean temperature and b) annual total precipitation. Baseline maps of c) annual mean temperature and d) annual total precipitation for Columbia Basin (1961-1990) from Figure 1-1 are reprinted here for comparison. Source: ClimateWNA.

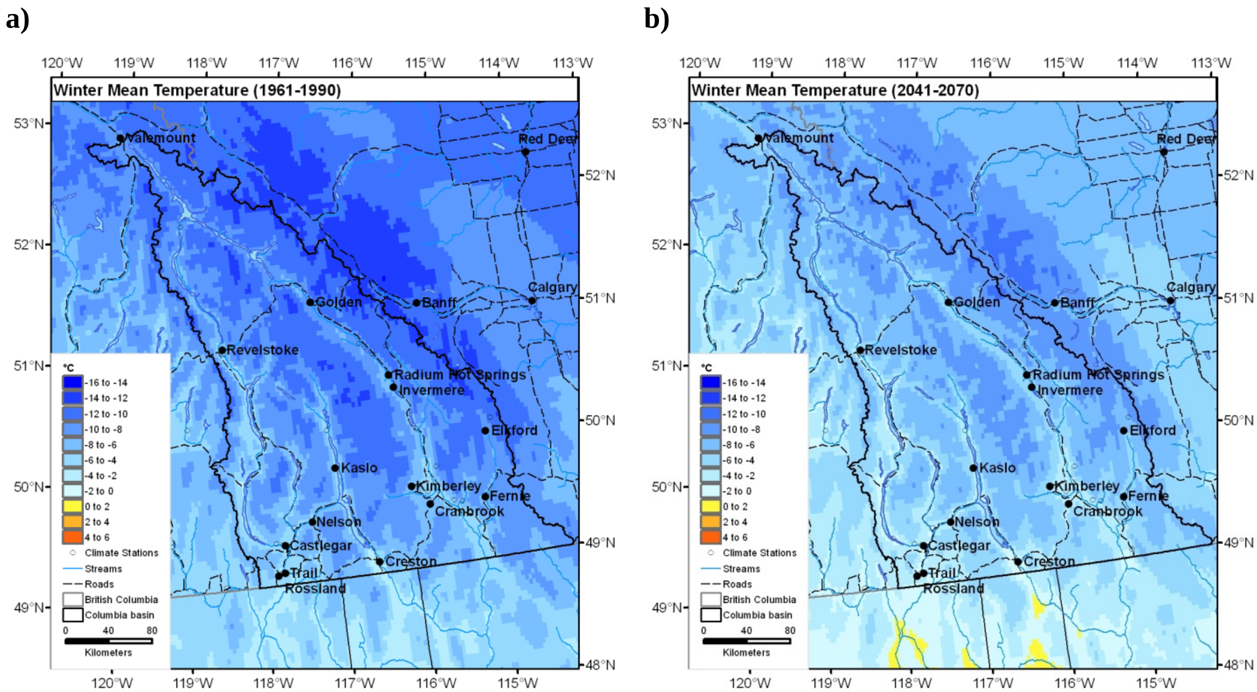

Figure 6-2: Winter mean temperature for the Canadian Columbia Basin climate for a) the historical period 1961-1990 and b) the 2050s (2041-2070). Source: ClimateWNA.

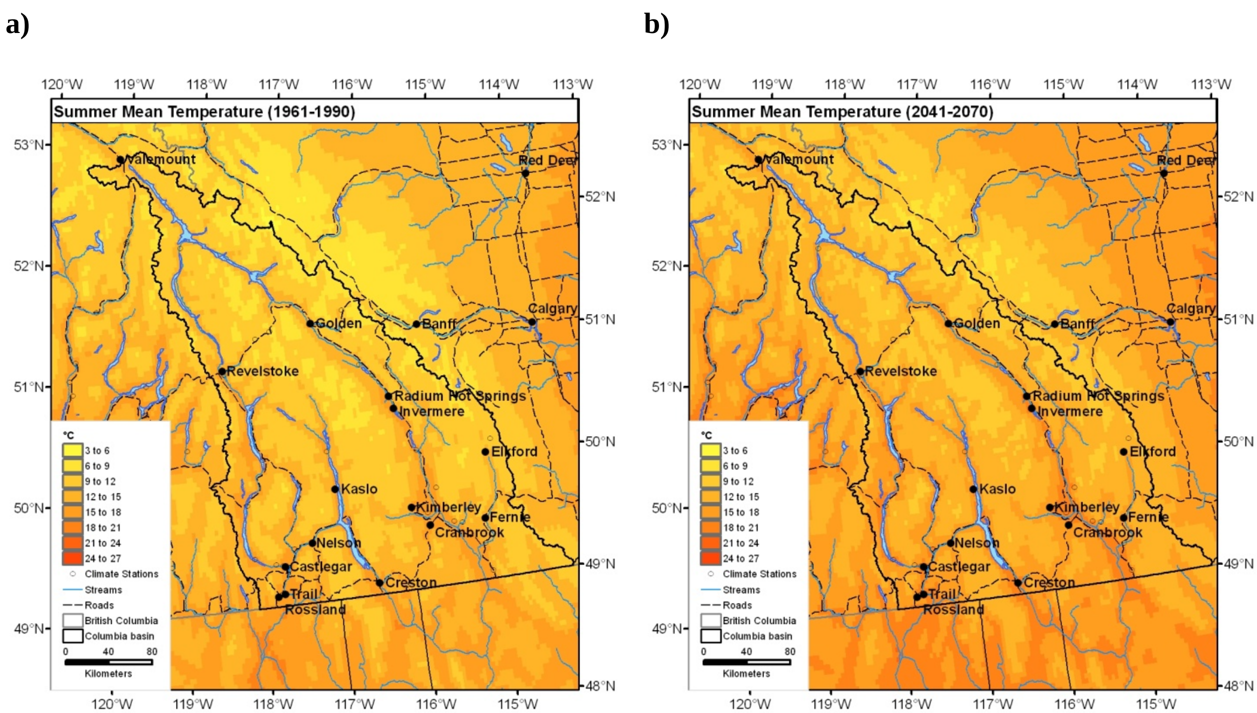

Figure 6-3: Summer mean temperature for the Canadian Columbia Basin climate for a) the historical period 1961-1990 and b) the 2050s (2041-2070). Source: ClimateWNA.

a) b)

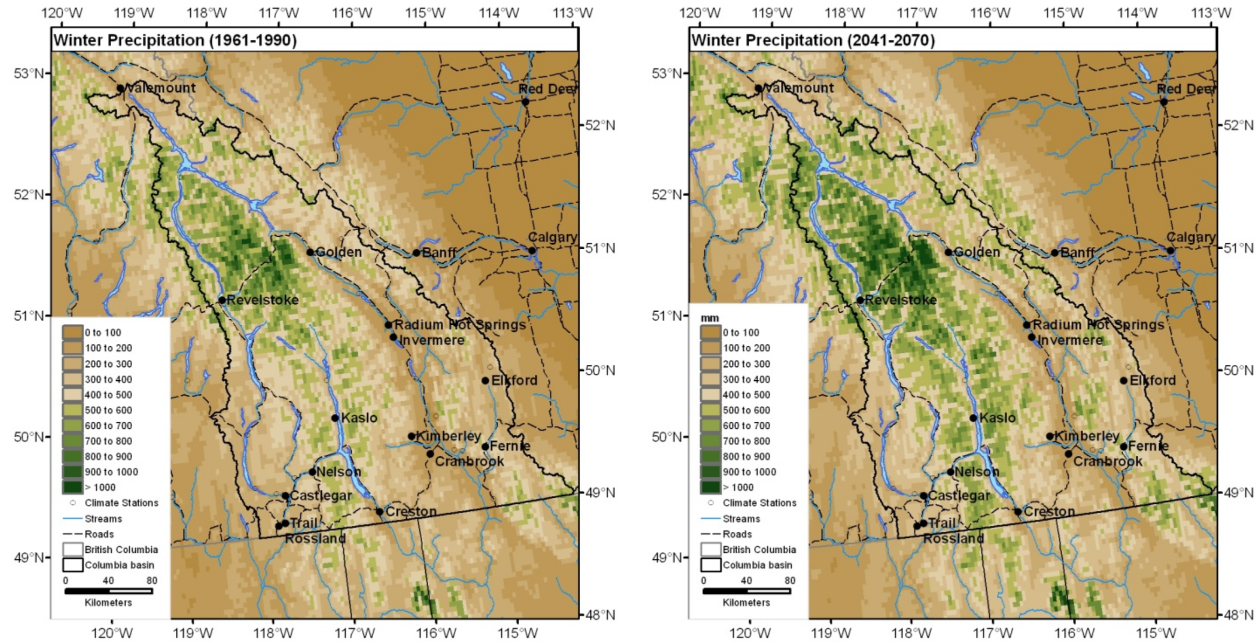

Figure 6-4: Winter precipitation for the Canadian Columbia Basin climate for a) the historical period 1961-1990 and b) the 2050s (2041-2070). Source: ClimateWNA.

a) b)

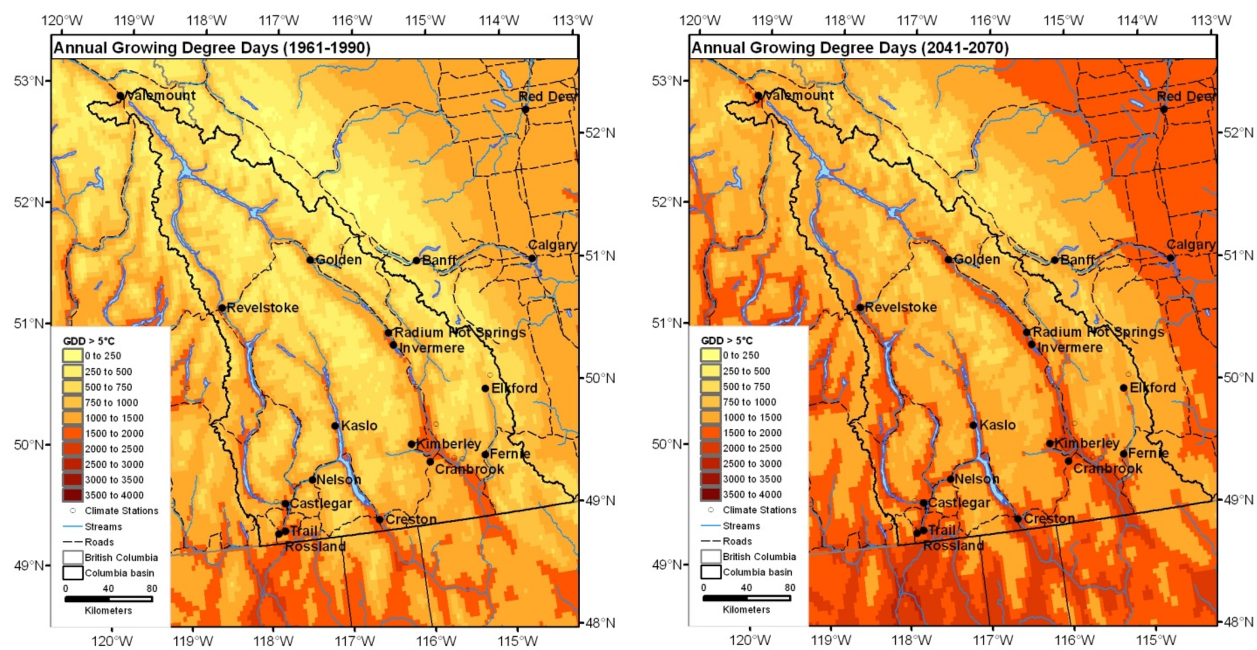

Figure 6-5: Annual growing degree days for the Canadian Columbia Basin climate for a) the historical period 1961-1990 and b) the 2050s (2041-2070). Source: ClimateWNA.

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Appendix A: Summary of IPCC Fourth Assessment on Impacts and Adaptation

Impacts relevant to the Canadian Columbia Basin are summarized below from the IPCC's Technical Summary for Working Group II (Impacts and Adaptation) from the Fourth Assessment Report Section TS.4.5 (Parry et al. 2007), which states that mountain ecosystems and water resources at mid-latitudes will be especially impacted by climate change.

Each of the following bullets are cited directly from Sections TS.4.2, TS.4.4, Box TS.6 for North America, TS.5.2, and TS.5.3. The asterisks, letters, and brackets following each point denote the section from which the statement is derived. Please see the notes following the list of findings for a key to these notations.

- Continued investment in adaptation in response to historical experience rather than projected future conditions is likely to increase vulnerability of many sectors to climate change [14.5]. Infrastructure development, with its long lead times and investments, would benefit from incorporating climate-change information. *** D [14.5.3, F14.3]
- Projected warming in the western mountains by the mid-21st century is very likely to cause large decreases in snowpack, earlier snow melt, more winter rain events, increased peak winter flows and flooding, and reduced summer flows. *** D [14.4.1]
- Reduced water supplies coupled with increases in demand are likely to exacerbate competition for over-allocated water resources. *** D [14.2.1, B14.2]
- Climate change in the first several decades of the 21st century is likely to increase forest production, but with high sensitivity to drought, storms, insects and other disturbances. ** D [14.4.2, 14.4.4]
- Moderate climate change in the early decades of the century is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warmest of their suitable range or which depend on highly utilized water resources. ** D [14.4]
- By the second half of the 21st century, the greatest impacts on forests are likely to be through changing disturbances from pests, diseases and fire. Warmer summer temperatures are projected to extend the annual window of high fire risk by 10 to 30%, and increase area burned by 74 to 118% in Canada by 2100. *** D [14.4.4, B14.1]
- Impacts are very likely to increase due to increased frequencies and intensities of extreme weather events (see Table TS.5 in IPCC AR4 WG II Technical Summary).
- Adaptation measures are seldom undertaken in response to climate change alone.
- Sustainable development can reduce vulnerability to climate change.

Key to notations:

- *** – very high confidence
- ** – high confidence
- D – further development of Third Assessment report finding
- [#] – section number of Working Group II Assessment for further details
- [F#] – figure in Working Group II Assessment
- [B#] – box in Working Group II Assessment