CLIMATE EXTREMES IN THE COLUMBIA BASIN

SUMMARY REPORT

PACIFIC CLIMATE IMPACTS CONSORTIUM

INTRODUCTION

The need for regional projections of changes to climate extremes indices

Anthropogenic climate change could potentially bring with it a variety of impacts, among them, impacts due to changes in weather and climate extremes. Because of this, there is interest in projections of future climate extremes for the development of community climate adaptation strategies. Projections indicate that climate extremes will increase in their intensity and frequency in the future.

This report summarizes recent work by the Pacific Climate Impacts Consortium (PCIC) on regional future projections of climate extremes for the Columbia Basin (Figure 1). The work has been undertaken as a part of the Columbia Basin Trust's *Communities Adapting to Climate Changing Initiative* (CACCI) that seeks to increase the adaptive capacity of communities in the Basin.

PROJECTIONS INDICATE THAT CLIMATE EXTREMES WILL INCREASE IN THEIR INTENSITY AND FREQUENCY IN THE FUTURE

Summary of results

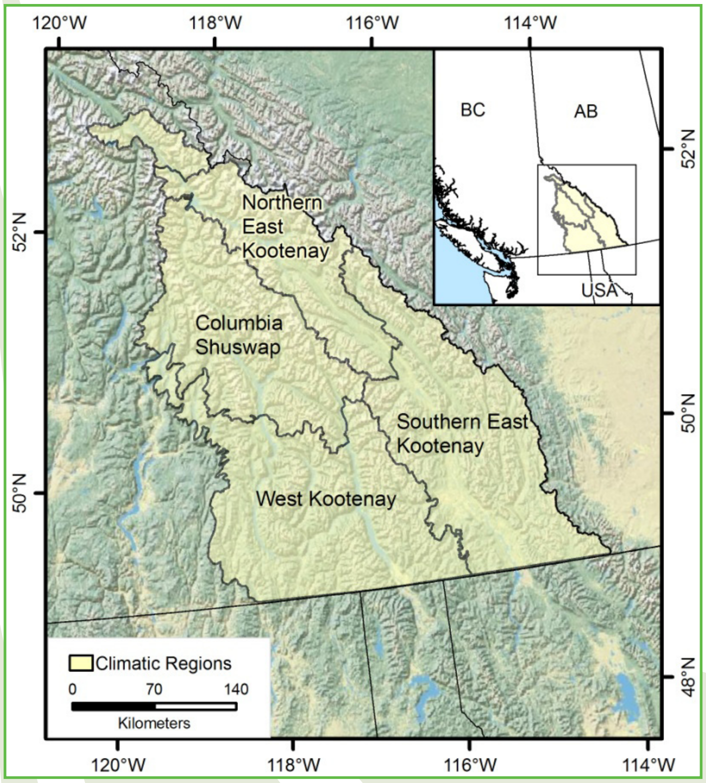
The climate projections used in this work are for the Columbia Basin for the middle of the 21st Century (2041-2070), relative to a baseline period of 1971-2000. Climate projections for this time period show a number of potential changes:

- Annual mean temperature is projected[1] to increase by between 1.8 °C and 2.7 °C
- The frequency of warm days in the summer is projected[1] to increase, occurring 1.5 to 3.3 times as often
- Extreme warm days of the type that recur only once every 25 years are projected[1] to increase in frequency, such that these events are projected to occur 1.4 to 12.5 times more often
- The frequency of cool nights in the winter is projected[1] to decrease, occurring 0.7 to 0.4 times as often
- The total number of days when the basin-average daily maximum temperature is lower than 0 °C is projected to decrease, by between 10% to 30%
- The annual total basin-averaged precipitation is projected to increase by between 1% and 9%
- Extreme wet days (precipitation events of such magnitude that they only happen, on average, once every 25 years) are projected[1] to occur between 0.3 to 4.1 times as often as in the past

THE RESULTS SHOW AN INCREASE TO AVERAGE TEMPERATURES AND WARM TEMPERATURE EXTREMES, AS WELL AS INCREASES TO AVERAGE PRECIPITATION AND EXTREME PRECIPITATION EVENTS

1. Based on 10th to 90th percentile of results for all grid boxes and all model runs. See Murdock et al., 2013: Climate change and extremes in the Canadian Columbia Basin, *Atmosphere-Ocean*, **51**, 4, 456-469.

Figure 1: **Map of the study area.** Shown is the study area for this report, the Canadian Columbia River Basin (light green) and its climatic sub-regions.



The study used the output from an ensemble of Regional Climate Models (RCMs). The RCMs were driven by observation-based data products[2] over the historical period and the output of Global Climate Models (GCMs), for future projected change. It was found that the RCMs generally reproduced the historical climate, including both temperature and precipitation, quite accurately, but that they do exhibit both cold and wet biases relative to observations. For the future, the models followed an emissions scenario[3] that assumes somewhat high greenhouse gas emissions and population growth, with slow economic and technological growth.

THE PAST CLIMATE

How the model output compares against historical climate observations

THE MODELS WERE FIRST TESTED TO DETERMINE THEIR SKILL AT SIMULATING PAST CLIMATE

To assess the historical skill of the RCMs, they were driven using observation-based reanalysis data products. The resulting RCM output was then compared to independent observational data from the same region to determine how the model-simulated climate compares to the observed climate.

2. These data products, known as reanalyses, are constructed from observational data with the assistance of weather forecasting models, and allow values of meteorological data to be determined between locations where observations have been made.

3. The scenario used was the A2 emissions scenario, developed by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES). For more information on emissions scenarios, see: http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains3.html.

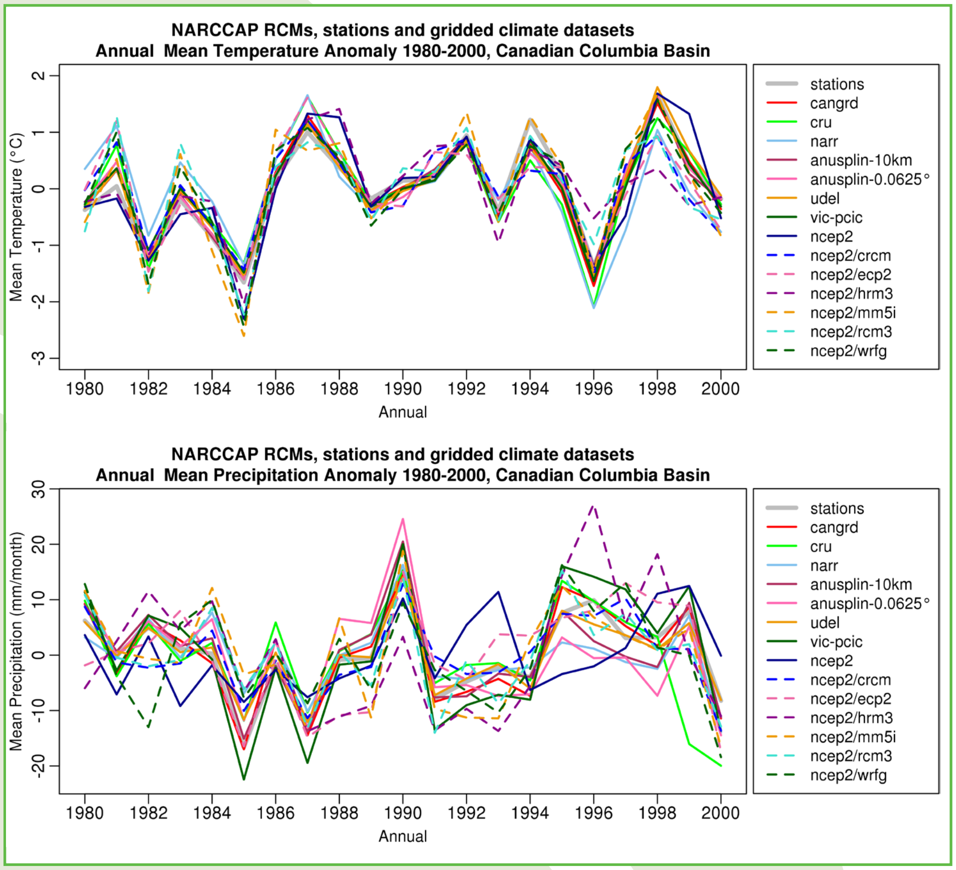


Figure2: Simulated and observed annual temperature and precipitation.
The time series graph on the right shows annual temperature (upper panel) and precipitation (lower panel) for the Basin as simulated by RCMs (dashed lines) driven by reanalysis data, and from both gridded and station observations (solid lines) as anomalies from each record's 1980-2000 period average.

The annual temperature and precipitation anomalies (differences of each year from normal) in Figure 2 show close agreement between observations and reanalysis-driven RCM output. This is an indication of each model's skill at reproducing historical climate. The simulated historical annual temperature and precipitation record from the RCMs generally matched observations more closely than the reanalysis data that were used to drive them, which gives confidence in the use of RCM projections for the region.

THE SIMULATED TEMPERATURE AND PRECIPITATION FROM THE REGIONAL CLIMATE MODELS WAS CLOSER TO THE OBSERVATIONS THAN THE REANALYSIS DATA USED TO DRIVE THEM

The performance of the reanalysis-driven RCMs varies by season and some biases in temperature and precipitation relative to observations are present. For example, the simulated historical average temperature of the basin is slightly colder than observed for most models and RCMs tend to show somewhat more precipitation than is observed. The simulated historical average precipitation of the basin agrees with observations roughly to the same degree to which different observational estimates agree with each other. The overall reductions in bias for the RCM runs, when compared with the coarse-resolution data that is used to drive the simulations, is part of the value added by using the higher-resolution RCMs.

As can be seen in Figure 3, in which the RCMs were driven with GCM output over the historical period, the RCM simulations (bottom four panels) capture certain aspects of the observed spatial patterns of historical temperature (top left panel) and precipitation (top right panel). Notably, the simulations reproduce the cooler, wetter conditions in the Rocky Mountains and the warmer, drier conditions in the south and east of the Basin. This indicates that the RCMs perform reasonably well at representing how climate varies with the topography of the region. However, the 50-kilometre resolution of the RCMs is unable to capture finer features (top two panels),

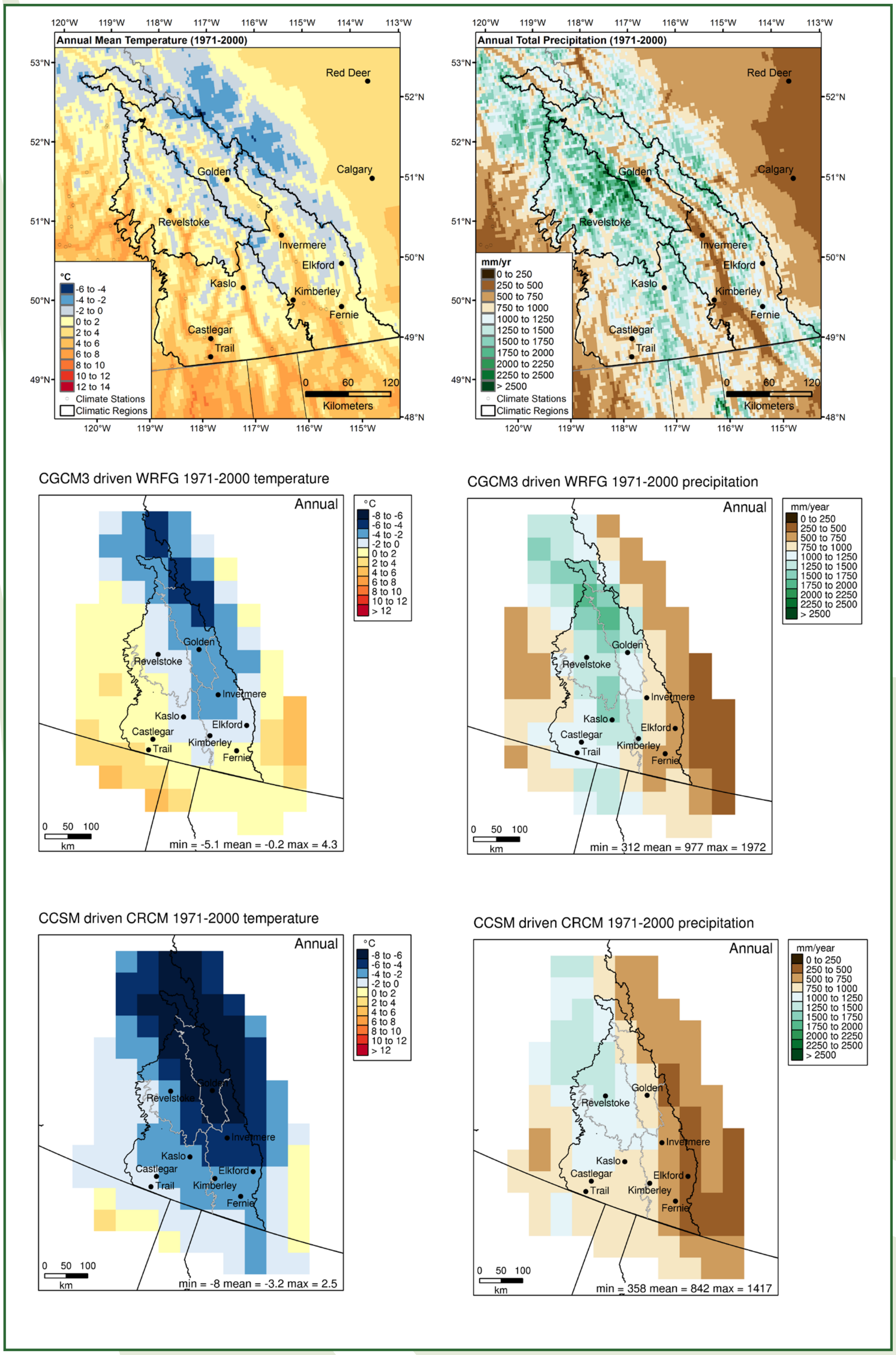


Figure 3: Observed and simulated historical annual mean temperature and annual total precipitation.
Annual mean temperature is on the left and annual total precipitation on the right. The top row displays high (~4 km) resolution climatologies based on observations from ClimateWNA (www.climatewna.com; Wang et al., 2012) while the middle and bottom rows display climatologies from two RCM historical simulations driven using GCM output.

THE REGIONAL CLIMATE MODELS REPRESENT THE EFFECTS OF THE TOPOGRAPHY OF THE REGION ON ITS CLIMATE FAIRLY WELL

such as the warm, dry Rocky Mountain Trench, a valley that extends from Kimberly to Golden. When compared to the driving GCMs, the RCM-simulated climate is generally colder, with more precipitation, and this is consistent with higher elevation terrain being better represented in the RCMs than in the driving GCMs. There are also large differences between runs, the main source of these differences being the driving GCM run.

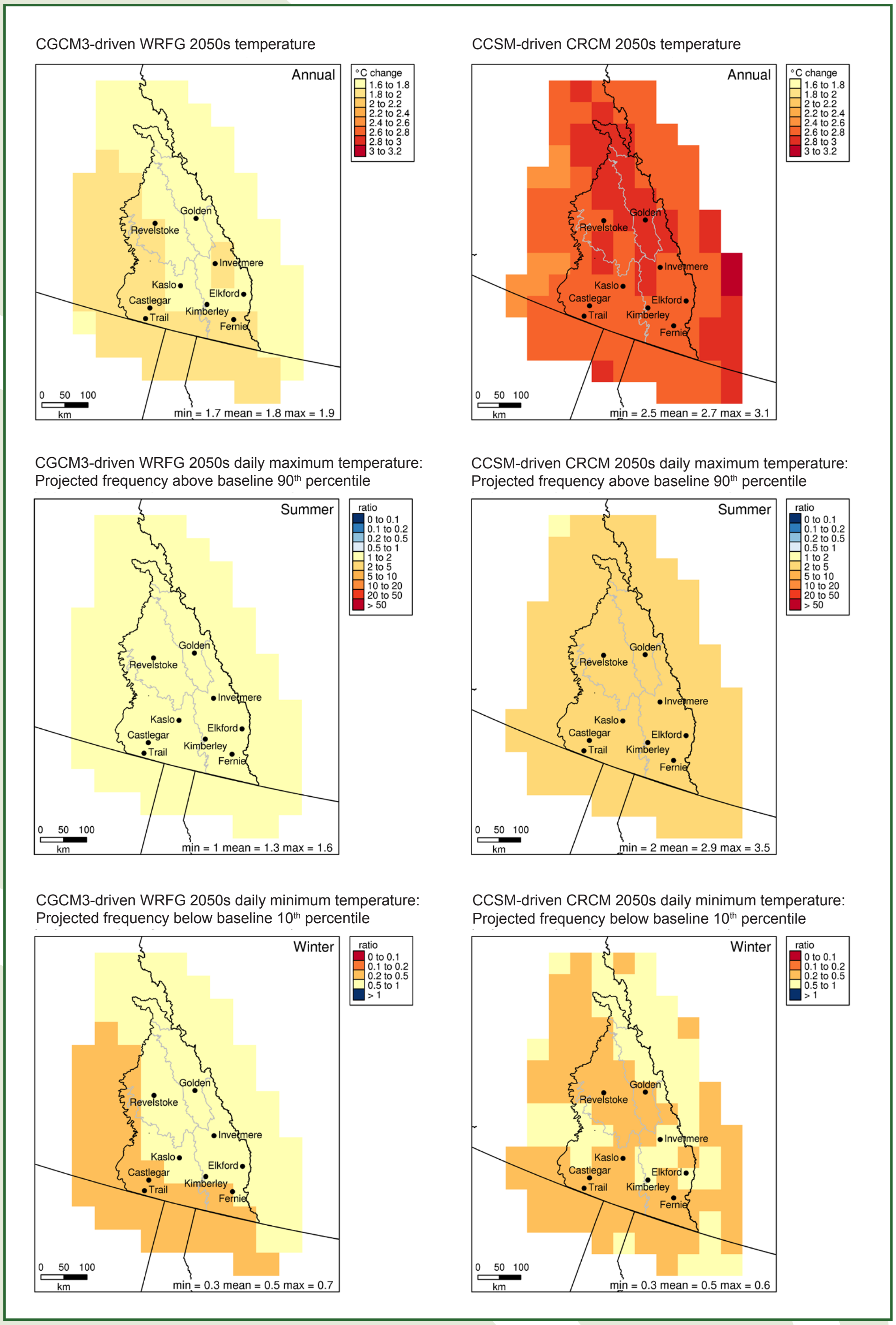


Figure 4: RCM-projected changes in temperature and temperature extremes indices.
This figure shows changes in projected annual mean temperature (top row), the frequency of warm days in summer (TX90p – middle row) and the frequency of cool nights in winter (TN10p – bottom row) for the 2050s, from two RCM simulations.

THE MODELS PROJECT AN INCREASE TO MEAN TEMPERATURE AND THE FREQUENCY OF WARM DAYS AND A DECREASE IN THE FREQUENCY OF EXTREMELY COLD WINTER NIGHTS

PROJECTIONS OF FUTURE CLIMATE

Future temperature projections

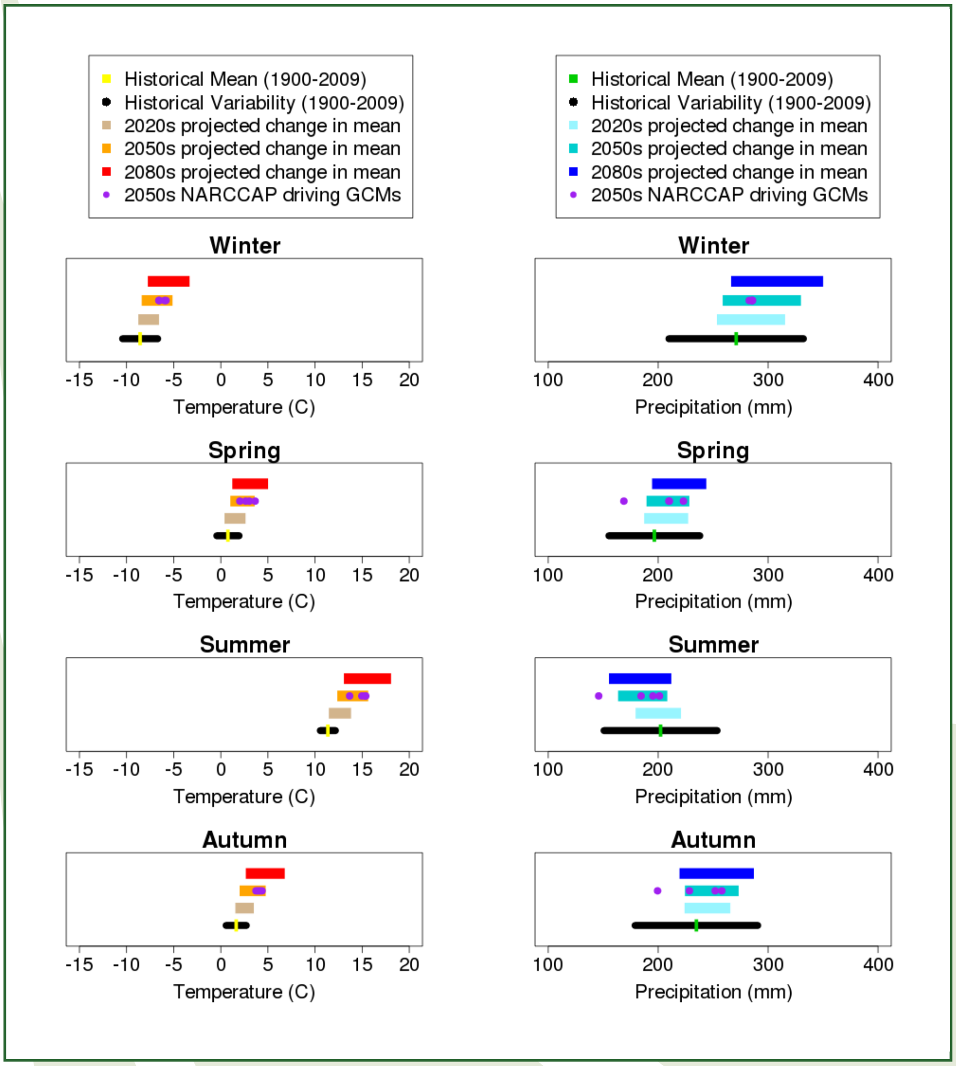
The ensemble of eight RCMs project a basin-average, annual mean warming of between 1.8 °C and 2.7 °C for the 2050s compared to the 1971-2000 period. The model projections indicate warming in each of the four climatic regions of the Columbia Basin (Figure 4, upper panel). The RCM results also show an increase in the frequency of warm days[4] in summer (Table 1, Figure 4, middle panel), which are projected to increase in frequency by 1.5 to 3.3 times at most locations[1]. The projections further indicate a decrease in the frequency of cold nights in winter (Table 1, Figure 4, lower panel)

4. For definitions of indices used, see Tables 1 and 2.

Table 1: Temperature Indices

Index	Description
Cool Nights in Winter (TN10p)	Frequency of winter nights cold enough to fall in the bottom ten percent of cool nights over the 1971-2000 period.
Warm Days in Summer (TX90p)	Frequency of summer days hot enough to fall in the top ten percent of warm days over the 1971-2000 period.
Warm Spells (WSDI)	Annual count of days in spells of at least 6 consecutive days having high temperatures in the top 10 % of the 1971-2000 baseline.
Cold Spells (CSDI)	Annual count of days in spells of at least 6 consecutive days having low temperatures in the bottom 10 % of the 1971-2000 baseline.

Figure 5: Projected changes to seasonal mean temperature and precipitation. Seasonal ranges in the projected change of temperature (left) and precipitation (right) over four time intervals, from 30 global climate model projections are shown. Historical mean and variability (represented by +/- 1 standard deviation of historical values) were obtained from gridded observations (CANGRID), while the GCM projections were obtained from 15 models using both the A2 and B1 scenarios from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios. Also shown for reference (purple dots) are the four GCM projections that were used to drive the eight North American Regional Climate Change Assessment Program RCM simulations of the 2050s.



throughout the region, with historical cold temperatures only occurring 0.4 to 0.7 times as often[1]. Warm nights in summer (Table 1) are projected to increase in frequency, occurring two to four times as often for the region as a whole. Also, warm spells (Table 1) are expected to last about 1.5 to 5.5 times as long at most locations and cold spells (Table 1) are expected to decrease in length by between about 40% to 80% at most locations.

For comparison, Figure 5 shows the coarser resolution, GCM runs that provided the RCMs' driving conditions (purple dots) and a larger ensemble consisting of 30 simulations from 15 GCMs, each driven by both the A2 and B1 emissions scenarios (PCIC30 in Murdock and Spittlehouse 2011[5]).

The projections show increased temperatures for all seasons for the 21st century and an increase in mean summer temperatures, such that they lie outside of the range of natural variability by the end of the century. As can be seen in Figure 5, the four GCMs that drive the RCM ensemble do not span the range of uncertainty from the overall ensemble of GCM projections, and thus the RCM-based projections analysed in this report do not cover the full range of plausible changes for the future in the Columbia Basin region.

5. Murdock, T.Q. and D.L. Spittlehouse, 2011: *Selecting and Using Climate Change Scenarios for British Columbia.* Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 39 pp.

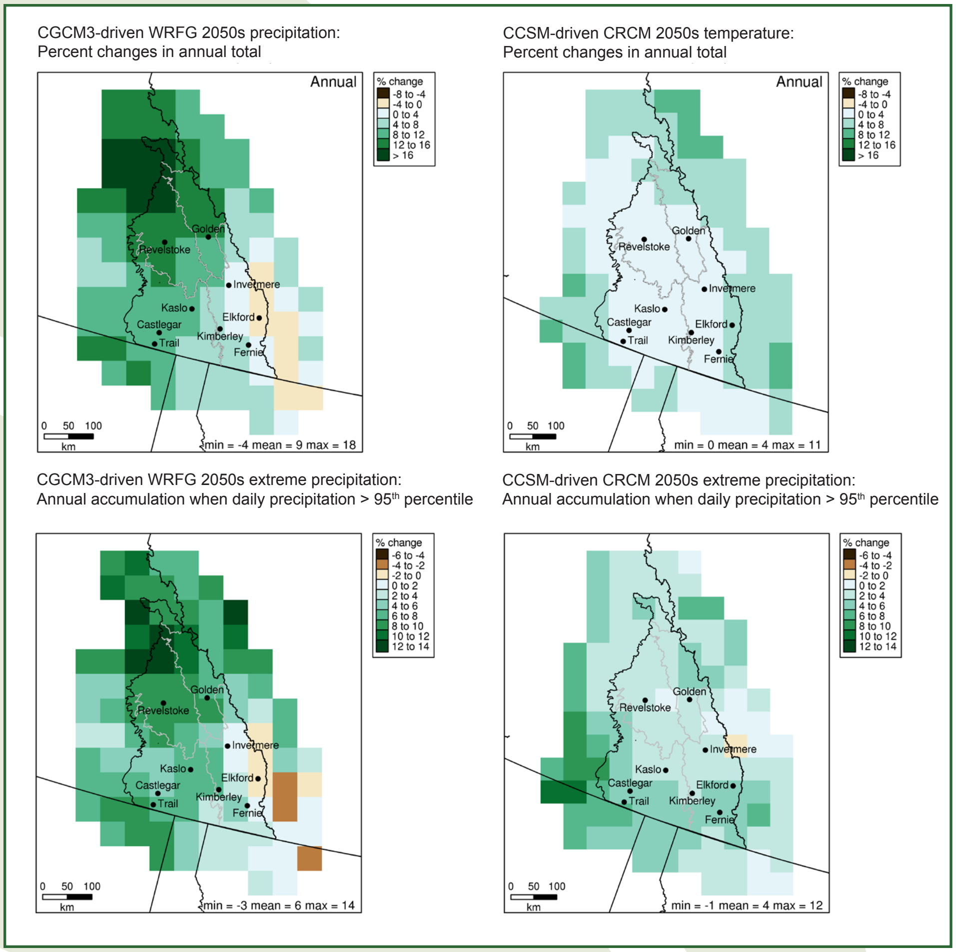


Figure 6: Precipitation projections for the 2050s.
These figures show projected changes in precipitation from two of the eight NARCCAP RCM simulations for the 2050s. The top row displays percent changes in annual mean precipitation totals, while the bottom row displays percent changes in moderately extreme precipitation.

FUTURE PROJECTIONS FROM THE REGIONAL CLIMATE MODELS INDICATE A POTENTIAL INCREASE IN PRECIPITATION AND PRECIPITATION EXTREMES

Future precipitation projections

While the projected changes to temperature in the GCM and RCM runs were large compared to historical temperature variability, the projected changes to precipitation (Figure 5) are small relative to the variability of historical precipitation for all seasons. Although the observed precipitation has a large associated uncertainty, given that the RCM simulations match observations well over the historical period, the projections can provide some idea of how precipitation may change in the future. There are also large differences in the spatial patterns of change between RCM runs (Figure 6, top panel). Basin-averaged annual precipitation is projected to increase between 1% and 9% compared to the historical average. The amount of precipitation on very wet days (Table 2) is projected to increase between 2% and 8%, and most runs project an increase of between 0% and 4% in the amount of precipitation accumulated annually on extremely wet days (Table 2). The number of days with precipitation of more than 10 millimetres is projected to increase by between 5% and 15% in most areas.

Future return period projections

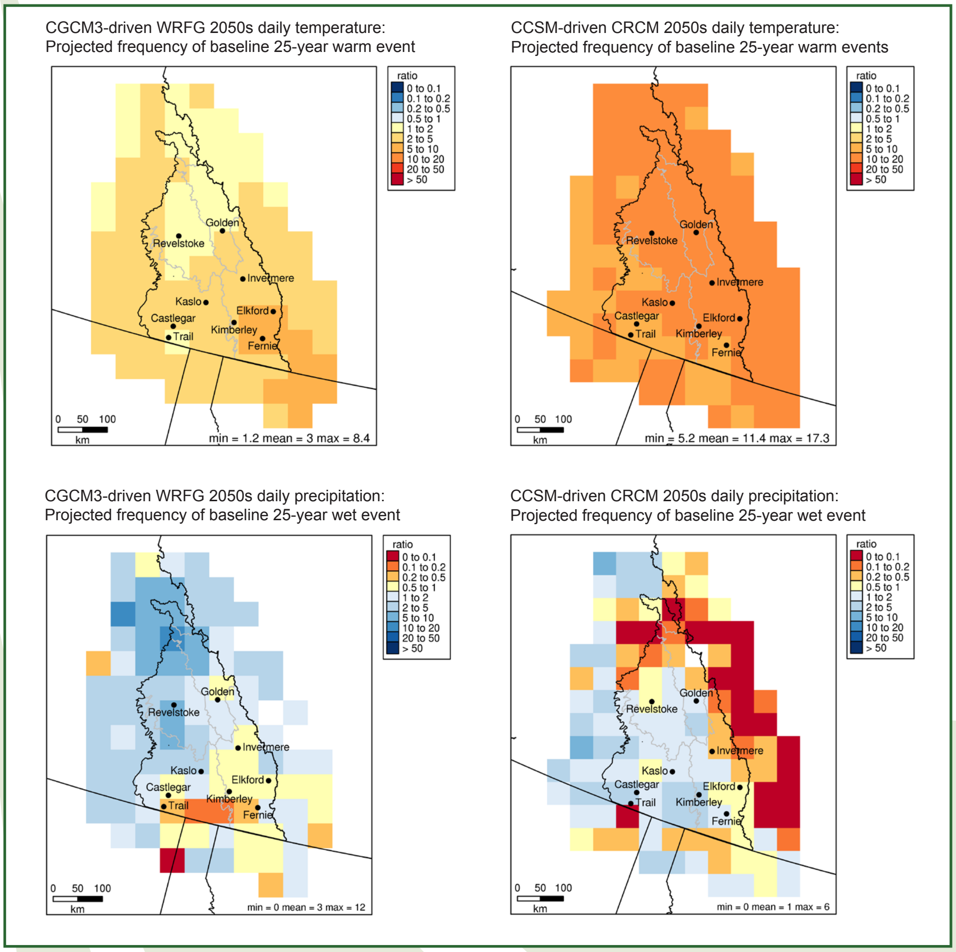
Return periods reflect the average length of time between the occurrence of rare events. This project considered 25-year events, that is, extremes of such a magnitude that they would have only a 4% chance of occurrence in any given year during the historical baseline period.

Table 2: Precipitation Indices

Index	Description
Very Wet Days (R95pTOT)	Amount of precipitation accumulated on days as wet as the 5% of wettest days in the historical reference period.
Extremely Wet Days (R99pTOT)	Amount of precipitation accumulated on days as wet as the 1% of wettest days in the historical reference period.

Figure 7: Projected changes in the frequency of baseline 25-year extreme events for the 2050s.

Projected changes in frequency from two of the eight NARCCAP RCM simulations for the 2050s are shown. The top row displays frequency changes for extreme temperatures, while the bottom row displays those for extreme precipitation.



Six of the eight RCM runs project increases in the frequency of occurrence of 25-year return period warm events at all locations, while the remaining two runs project increases only in some areas. These events are projected to occur between 1.4 and 12.5 times as often at most locations in the future (Figure 7, top panel), with the largest increase generally projected to occur in the southern and eastern portions of the Basin. Averaged over the basin, they are projected to occur about five times as often. Warm events with return periods of five years and ten years are projected to occur about two to four times as often and two to six times as often, respectively. While the frequency of warm events is projected to increase, the frequency of cold events is projected to decrease, with historical 25-year return period cold events occurring only about one-half to one-tenth as often, or less.

As with the temperature findings above, the projections of changes in the frequency of 25-year return period precipitation events (Figure 7, bottom panel) show a large spatial variance, with the minimum and maximum change in frequency varying from zero to 12 times as often. The median projection for the region is that these events will increase in frequency, occurring about 1.5 times as often, with the largest increases in frequency occurring in the northern and western parts of the Basin. Snow-depth projections, available for two RCMs, indicated a reduction in the frequency of baseline 5-, 10- and 25-year return period events.

For all future return period projections, the differences between models are indicative of large uncertainties and thus these findings must be interpreted cautiously.

CONTEXT AND METHODS

Using RCMs to investigate the climate of the Columbia Basin

The Canadian Columbia River Basin is located in the south-western corner of British Columbia. It is bordered by the Rocky Mountains on the north and east and by the Monashee mountains on the west. The Basin has extremely complex topography, with elevation varying greatly over distances of only tens of kilometres. It has an average elevation of 1160 metres and and annual average temperature of 1.6 °C. The region has a large seasonal variation in temperature, with December averaging -14.5 °C and July averaging 19.1 °C. Precipitation in the region ranges from 16 millimetres in March to 417 millimetres in December, with an annual total of 1160 millimetres.

The study used eight runs from six RCMs, taken from the North American Regional Climate Change Assessment Program (NARCCAP)[6]. These cover most of North America for the historical period of 1971-2000 and the future period of 2041-2070. Over the historical period, the models were first driven with gridded reanalysis data to assess their performance. The IPCC SRES emissions scenario A2 was used to drive the models for future projections. The projections were compared with additional runs for the historical period that were driven with the same GCMs as for the future projections. Over the historical period, the GCMs and RCMs used historical emissions rather than an emissions scenario. The CLIMDEX[7] indices of climate extremes were used in this report and evaluated using the climdex.pcic[8] software package.

Return periods were evaluated using statistical extreme value theory. This predicts that the maximum and minimum values in large blocks of observations will follow the Generalized Extreme Value probability distribution[9].

RCM RESULTS MATCHED OBSERVATIONS RELATIVELY CLOSELY AND ADDED VALUE TO THE REANALYSIS DATA USED TO DRIVE THEM

6. For more information on NARCCAP, see: http://narccap.ucar.edu.

7. For more information on the CLIMDEX indices, see: Klein Tank, A.M.G., F.W. Zwiers, and X. Zhang, 2009: Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation, Climate data and monitoring *WCDMP-No. 72*, WMO-TD No. 1500, 56pp.

Zhang, Xuebin, Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C., and Zwiers, F. W., 2011: Indices for monitoring changes in extremes based on daily temperature and precipitation data. *Wiley Interdisciplinary Reviews: Climate Change,* **2**, 6, 851–870. doi:10.1002/wcc.147

8. Climdex.pcic is a software package written in the R language and used for the calculation of climate extremes indices. For more information, see the PCIC software library: http://pacificclimate.org/resources/software-library.

9. This distribution describes large sets of independent, identically-distributed, random variables. See: Zwiers, F.W., L.V. Alexander, G.C. Hegerl, T.R. Knutson, J. Kossin, P. Naveau, N. Nicholls, C. Schär, S.I. Seneviratne and X. Zhang, 2013: Challenges in Estimating and Understanding Recent Changes in the Frequency and Intensity of Extreme Climate and Weather Events. In (Climate Science for Serving Society: Research, Modelling and Prediction Priorities, G. Asrar and J. Hurrell, eds.), 339-389.

GOING FORWARD

Summary of changes to the Columbia Basin

When compared to observations, RCM results showed some biases for both temperature and precipitation, but matched observations relatively closely. RCM simulations were also shown to add value to the coarser-scale reanalysis data used to drive the RCMs. This is due, in part, to their ability to better represent the topography of the region due to their higher resolution.

RCM future projections for the Columbia Basin show increases to the average temperature of the region and an increase in the frequency of extreme warm temperatures. Though there is greater uncertainty in the projections of precipitation, the RCMs project wetter conditions on average, with increased precipitation extremes. At the same time, the models project a decrease in summer precipitation and an increase in summer dry spells.

Owing to the increase in dry spells, decreased summer precipitation and increases to warm extremes, drought and extreme fire weather may increase. Extreme low-streamflow events may also be more likely. Late spring frosts and ground-penetrating frost is projected to decrease.

PCIC gratefully acknowledges the financial support of the Columbia Basin Trust.

The Pacific Climate Impacts Consortium

University House 1, University of Victoria
PO Box 1700 STN CSC, Victoria, British Columbia
Canada V8W 3R4

Phone: 250-721-6236
Fax: 250-721-7217

pacificclimate.org