Environment and Climate Change Canada
Environnement et Changement climatique Canada

# Climate data and scenarios for Canada: Synthesis of recent observation and modelling results

ISBN: 978-0-660-04262-6
Cat. No.: En84-132/2016E-PDF



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# 1. Introduction

Many aspects of Canada's infrastructure, economy, and ecology are directly affected by climate variability and change. Observations provide information about historical climate and therefore the 'baseline' against which future change is compared. Future climate change information, needed to assess future impacts, plan adaptation measures, and develop mitigation policy, cannot be reliably obtained by extrapolation of observed historical changes. Quantitative longer-term applications of climate information require model-based projections driven by a range of greenhouse gas emission scenarios. This document provides a brief overview of the most up-to-date analysis of historical climate observations and future climate projections focusing specifically on Canada. The information presented here builds upon, and is fully consistent with, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Working Group I (IPCC, 2013). The current document is intended as a resource for dissemination of climate information with a specific focus on historical and future climate change across Canada. It is not intended to serve as a definitive reference or complete characterization, and readers are directed to the underlying data sources for more detailed and quantitative analyses specific to their climate impact, adaptation, or environmental assessment context.

Given the range of natural climate variability and uncertainties regarding future greenhouse gas emission pathways and climate response, changes projected by one climate model, or one individual emission scenario, should not be used in isolation. Rather, it is good practice to consider a range of projections from multiple climate models (ensembles) and emission scenarios. Although this does not allow one to estimate the probability of a particular climate change scenario, it does convey to users some of the uncertainties involved.

Along the same lines, one should not rely on an individual study or publication to inform on the potential impacts of climate change in Canada. Rather, it is the synthesis of information from a range of valid sources that forms the foundation for understanding climate change and quantitative impact assessment. Information presented in this document is based upon the peer reviewed scientific literature and major climate assessments available to date. The underlying data is publicly available and sources are noted.

Additional information on the use of climate scenarios has been produced for the Canadian adaptation community by the Ouranos Consortium on Regional Climatology and Adaptation to Climate Change (Charron, 2014). This publication may be valuable to those looking for further technical details and guidance on the use of climate scenarios.

# 2. Historical climate change and variability in Canada

Climate everywhere varies from season to season, year to year, and decade to decade. This is a natural consequence of the complex interactions between processes in the atmosphere, ocean, and on land. Superimposed on this natural variability is the long-term shift or change in the mean state of the climate (what is commonly referred to as "climate change"). Long-term climate change is driven by both natural and human-caused, or anthropogenic, factors. The key anthropogenic contributors to long-term climate change are changes in atmospheric greenhouse gas concentrations and aerosol loadings. The Earth's climate has experienced long-term changes in the past. However, it is "*extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20$^{th}$ century" (IPCC, 2013).

Averaged globally, temperature has increased by approximately 0.85°C, over the period 1880 to 2012 (IPCC, 2013), although the warming has not been uniform in time or in space. Of particular note is that warming has been greater over high latitudes including Canada and Eurasia. Globally, as climate has warmed, extreme temperatures have also changed with increases in the frequency of hot days and heat waves and decreases in cold days (IPCC, 2013).

Because of natural variations on different time scales, historical changes in the climate need to be assessed over a long period of time. Changes in measurement techniques and instruments, in observing procedures, and in siting of the instruments do occur from time to time and can be reflected in the original climate records. As a result, the proper characterization of past climate change requires the use of homogenized climate data which have been adjusted to address artificial discontinuities which may be present in original historical records. Homogenized climate data sets account for possible artificial shifts imposed by non-climatic factors. For Canada, the adjusted data for some climate variables, including temperature and precipitation, are updated annually and are available publicly:

> *Adjusted and Homogenized Canadian Climate Data (AHCCD) for daily and monthly temperature and precipitation*
> http://www.ec.gc.ca/dccha-ahccd/

> *Canadian Blended Precipitation, version 0 (CanBPv0)*
> http://data.gc.ca/data/en/dataset/5d49713a-fe56-48a8-887f-c0ca3e4aebfe

> *Canadian Gridded Temperature and Precipitation Anomalies (CANGRD) at 50 km resolution*
> http://data.gc.ca/data/en/dataset/3d4b68a5-13bc-48bb-ad10-801128aa6604

Additionally, Environment Canada's Climate Trends and Variations Bulletin (CTVB) summarizes recent Canadian climate data and presents it in a historical context. The CTVB makes use of the adjusted and homogenized Canadian climate datasets to present seasonal, annual, and long-term temperature and precipitation trends on the national and regional scales. The CTVB can be accessed from the climate trends and variations section of Environment Canada's website: http://www.ec.gc.ca/adsc-cmda/.

In Canada, sufficient observations to generate national temperature estimates are available from 1948 onward, and a summary is shown in Figures 1 and 2. These results, when compared with global temperature trends calculated over the same time period, indicate that the rate of warming in Canada as a whole has been more than double that of the global mean, and that warming in northern Canada (i.e., north of 60°N) has been roughly three times the global mean. Longer term trends are available for some locations, especially for southern Canada, with data records extending back more than 100 years.

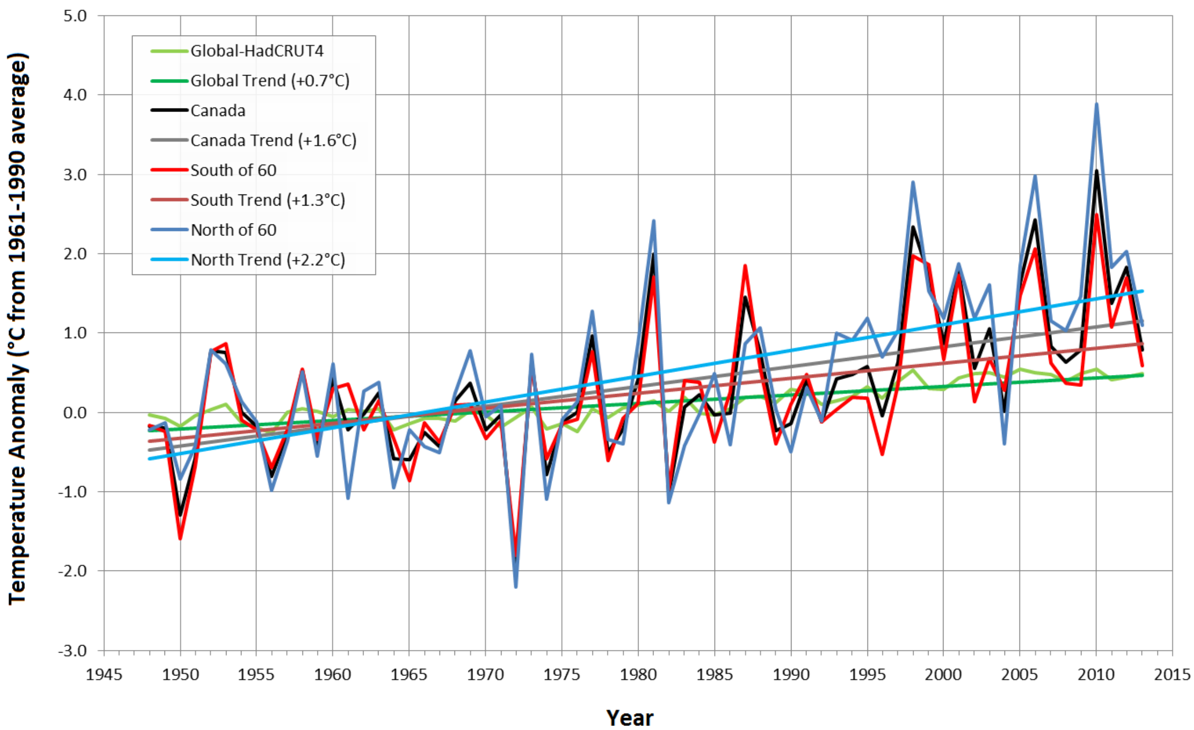


**Figure 1:** Annual mean temperature anomalies and linear trends for the globe, all of Canada, southern Canada (i.e., south of 60°N), and northern Canada (i.e., north of 60°N) over the period 1948–2013 (relative to the 1961–1990 average). See inset for colour scheme. Global temperature anomalies were computed using HadCRUTv4. Canadian mean temperatures were computed using the CANGRD data set (updated from Zhang et al., 2000), which is based on homogenized temperature data from 338 stations in Canada.

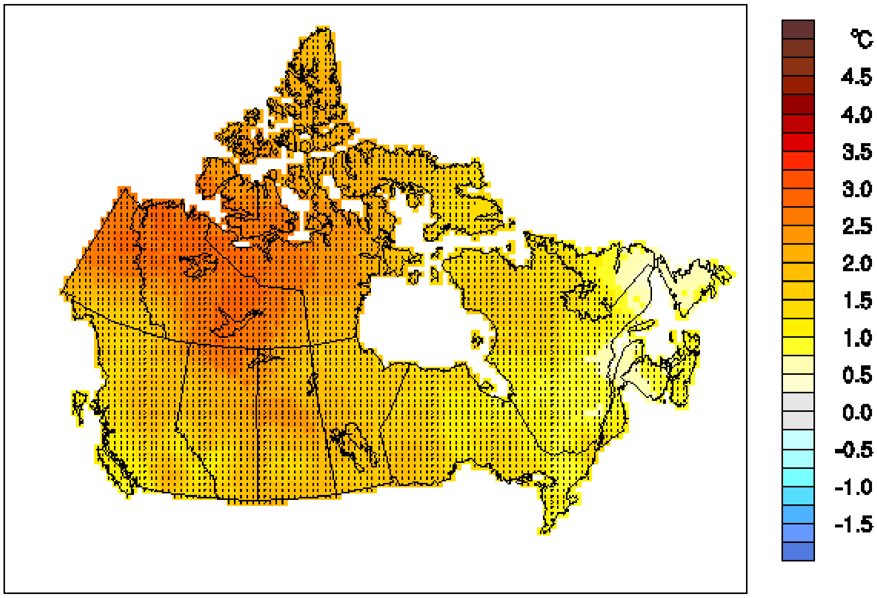


**Figure 2:** Linear trends in annual mean temperatures (°C) in Canada over the period 1948–2013, as computed from CANGRD data (updated from Zhang, et al., 2000). Note that the northern region has lower station density and as such higher uncertainty in gridded temperature anomalies.

To illustrate long-term changes in temperature at the local level, Table 1 provides estimates of linear trends in annual, summer, and winter mean temperatures for the 1900–2013 period for 16 selected Canadian cities where sufficient data is available (data is available from 1942, 1942, and 1946 for Whitehorse, Yellowknife, and Iqaluit, respectively, and trends for these cities are calculated accordingly). The cities were selected to include Canada's three largest cities, the national capital, and all provincial and territorial capitals.

**Table 1:** Trends in annual, summer (June, July, August), and winter (December, January, February) mean temperatures for 16 selected Canadian cities. Trends are calculated over the 1900–2013 period (in °C/century), except for territorial capitals where the data record is shorter (see "Calculated Trend Period" column). Trends are computed from the homogenized monthly temperature dataset, but are not corrected to remove the effects of urbanization.

| Canadian City | Calculated Trend Period | Annual Temp. Trend (°C / century) | Summer (JJA) Temp. Trend (°C / century) | Winter (DJF) Temp. Trend (°C / century) |
|---|---|---|---|---|
| Charlottetown, PE | 1900–2013 | 0.5 | 0.3 | 1.0 |
| Edmonton, AB | 1900–2013 | 2.0 | 2.3 | 3.1 |
| Fredericton, NB | 1900–2013 | 1.4 | 1.4 | 2.0 |
| Halifax, NS | 1900–2013 | 1.2 | 1.6 | 1.4 |
| Iqaluit, NU | 1946–2013 | 1.3 | 1.1 | 2.9 |
| Montreal, QC | 1900–2013 | 2.0 | 1.4 | 2.7 |
| Ottawa, ON | 1900–2013 | 1.7 | 1.0 | 2.6 |
| Quebec City, QC | 1900–2013 | 0.6 | 0.0 | 1.1 |
| Regina, SK | 1900–2013 | 1.9 | 1.5 | 3.1 |
| St. John's, NL | 1900–2013 | 0.6 | 1.2 | 0.9 |
| Toronto, ON | 1900–2013 | 1.8 | 1.8 | 2.2 |
| Vancouver, BC | 1900–2013 | 1.5 | 2.0 | 1.4 |
| Victoria, BC | 1900–2013 | 0.6 | 0.6 | 1.1 |
| Whitehorse, YT | 1942–2013 | 2.1 | 0.2 | 6.0 |
| Winnipeg, MB | 1900–2013 | 1.0 | 0.8 | 1.5 |
| Yellowknife, NT | 1942–2013 | 4.0 | 2.2 | 7.4 |

Precipitation totals have also changed in Canada as illustrated in Figure 3, with most of the country (particularly the North) having experienced an increase in precipitation over the past century. There are regional exceptions however, such as the lack of significant change over the southern Prairies and northeastern Ontario. Seasonally, total precipitation has increased mainly in the north. In winter, decreasing trends are dominant in the southwestern part of the country (British Columbia, Alberta, and Saskatchewan). There is less evidence of significant changes in the south during spring, summer, and autumn. It should be noted that changes in annual precipitation do not directly relate to changes in water availability, particularly in critical summer periods (e.g., an increase in precipitation does not necessarily translate directly to an increase in water availability, as other factors are also involved).

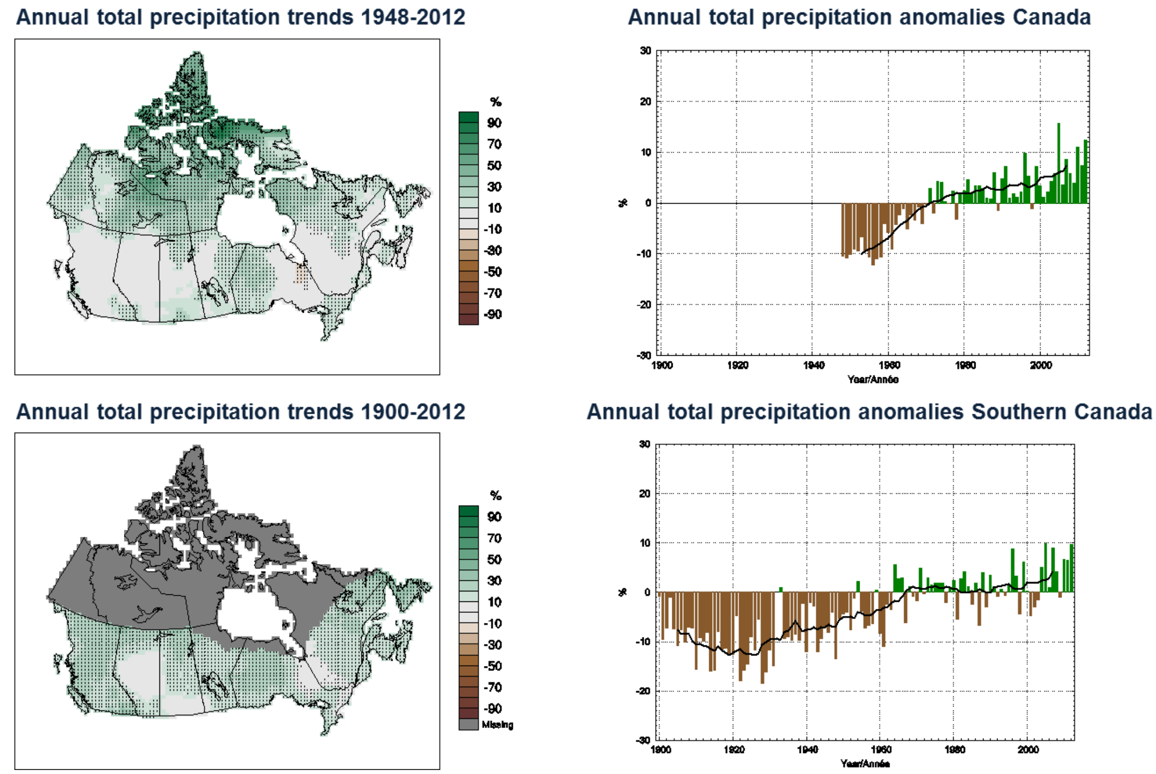


**Figure 3:** Linear trends in annual total precipitation (expressed as percent change relative to the 1961–1990 climatology) for the period 1948–2012 for all of Canada (upper left) and for the period 1900–2012 for southern Canada (lower left). Trends are computed based on CANGRD datasets (updated from Zhang, et al., 2000). Note that the northern region has lower station density and as such higher uncertainty in gridded precipitation anomalies. Also note that precipitation climatology in the north is much smaller than in the south (i.e., the north receives much less precipitation, on average, than the south). As such, a large percentage increase in the north may only represent a small change in total precipitation amounts. The right panels show time series and their 11-year moving averages for Canada (upper right) and for southern Canada (lower right).

The role of anthropogenic forcing in observed warming at global and continental scales has been a subject of intense study for many years. The most recent findings indicate that *"it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century"*, that *"it is now very likely that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century"*, and that there is medium confidence that *"anthropogenic influences have contributed to… intensification of heavy precipitation over land regions where data are sufficient"* (IPCC, 2013).

## 3. Future climate

The climate of the future will continue to experience natural variability, much as it has in the past. However, the background change in mean climate, already being driven by human activities, will continue at a rate that is determined primarily by current and future emissions of greenhouse gases and aerosols. Because future emissions are difficult to predict, it is necessary to use plausible scenarios, ranging from low to high emission pathways, to project future climate change. Global Earth System Models—which produce comprehensive computer simulations of the global climate system and the related carbon-cycle processes (see: Flato, 2011)—provide scientifically-based tools to make projections of future climate by simulating the response to atmospheric greenhouse gases and aerosols, land-use change, and other external forcings. Owing to uncertainties in the detailed representation of many complex climate processes, individual Earth System Models vary in their representation of these processes and will have biases of various kinds. Because of this, it is preferable to make use of a multi-model ensemble of projections for many applications. The average of a multi-model ensemble generally produces smaller historical errors than any individual model (Flato, et al., 2013) and the spread amongst models allows some quantification of uncertainty. The World Climate Research Programme[1] (WCRP) coordinates multi-model climate projections via its Working Group on Coupled Modelling (WGCM) and the Coupled Model Intercomparison Project (CMIP[2]). The results presented in the following sections are based on the CMIP5 results that were also featured in the Working Group I contribution to the IPCC Fifth Assessment Report (IPCC, 2013: see chapters 9, 11, and 12, and Annex I).

The CMIP5 projections make use of Representative Concentration Pathways (RCPs), which are designed to provide plausible future scenarios of anthropogenic forcing spanning a range from a low emission scenario characterized by active mitigation (RCP 2.6), through two intermediate scenarios (RCP 4.5 and RCP6), to a high emission scenario (RCP 8.5).[3] Figure 4 illustrates some of the assumptions underlying these scenarios. These scenarios make use of various combinations of projected population growth, economic activity, energy intensity, and socio-economic development. These, in turn, lead to calculations of energy consumption and related emissions and finally atmospheric concentrations of greenhouse gases and other climate forcings. These RCP scenarios serve as input to the Earth System Models, which simulate the climate system response and resulting climate conditions.

[1] The WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.
[2] Each new cycle of CMIP is referred to as a "phase". Results from phase 5, or CMIP5, supported the IPCC Fifth Assessment Report. At the time of publication of this document, planning had begun for CMIP6.
[3] The description of the Representative Concentration Pathway and their development can be found in Moss, et al., 2010 and van Vuuren, et al., 2011.

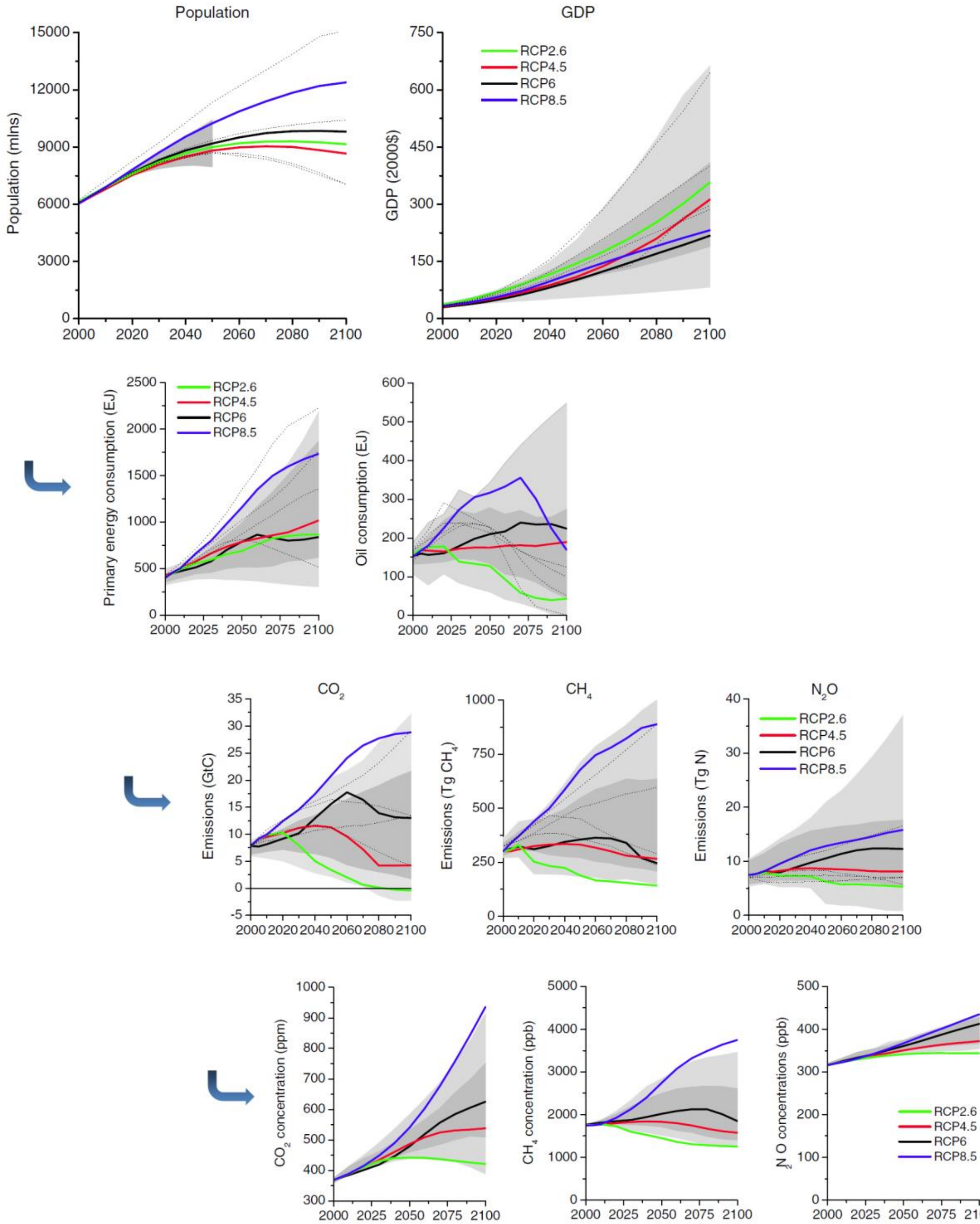


**Figure 4:** Socioeconomic (top row), energy intensity (second row), greenhouse gas emission (third row), and ultimately greenhouse gas concentration (bottom row) assumptions underlying the representative concentration pathways (RCPs) used to drive future climate projections. From van Vuuren, et al., 2011, reproduced with permission.

A new feature of the IPCC Fifth Assessment Report (AR5) is the Atlas of Global and Regional Climate Projections (Annex 1—IPCC, 2013), which provides a synthesis of results from the CMIP5 multi-model ensemble. For application to Canadian impact studies and adaptation planning, the regional boundaries of the Atlas are less than optimal: western Canada is combined with the western United States and Alaska, and eastern Canada is combined with Greenland and Iceland (but separated from western Canada). We have therefore generated multi-model ensemble results specific to Canada, using output from 29 CMIP5 models from which results were available for historical simulations, RCP2.6, RCP4.5, and RCP8.5 (results for RCP6.0 are also available, but from fewer models; so this scenario is not illustrated here). Further details on the models used in this document are presented in Table 2.

The ensemble climate model results include output representing a broad range of climate variables. For example, model output includes temperature, precipitation, snow depth, ocean pH and salinity, soil moisture, downwelling solar radiation, and many other quantities. As an example, a full listing of results from the Canadian model (CanESM2) is available at http://www.cccma.ec.gc.ca/data/cgcm4/CanESM2/index.shtml. In this document we focus on temperature and precipitation changes in the Canadian context.

**Table 2:** Information on the CMIP5 models whose results were used to produce the climate scenario Figures 5–10.

| Model Name | Place of Origin | Institution |
|---|---|---|
| BCC-CSM1-1<br>BCC-CSM1-1-m | China | Beijing Climate Centre, China Meteorological Administration |
| BNU-ESM | China | Beijing Normal University |
| CanESM2 | Canada | Canadian Centre for Climate Modelling and Analysis, Climate Research Division, Environment Canada |
| CCSM4<br>CESM1-CAM5<br>CESM1-WACCM | USA | National Centre for Atmospheric Research |
| CNRM-CM5 | France | Centre National de Recherches Météorologiques and Centre Européen de Recherche et Formation Avancée en Calcul Scientifique |
| CSIRO-Mk3.6.0 | Australia | Queensland Climate Change Centre of Excellence and Commonwealth Scientific and Industrial Research Organisation |
| EC-Earth | Europe | A consortium of European institutions |
| FGOALS-g2 | China | State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics |
| FIO-ESM | China | First Institute of Oceanography, State Oceanographic Administration |
| GFDL-CM3<br>GFDL-ESM2G<br>GFDL-ESM2M | USA | NOAA Geophysical Fluid Dynamics Laboratory |
| GISS-E2-H<br>GISS-E2-R | USA | NASA Goddard Institute for Space Studies |
| HadGEM2-AO<br>HadGEM2-ES | UK | UK Met Office Hadley Centre |
| IPSL-CM5A-LR<br>IPSL-CM5A-MR | France | Institut Pierre Simon Laplace |
| MIROC-ESM<br>MIROC-ESM-CHEM<br>MIROC5 | Japan | University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology |
| MPI-ESM-LR<br>MPI-ESM-MR | Germany | Max Planck Institute for Meteorology |
| MRI-CGCM3 | Japan | Meteorological Research Institute |
| NorESM1-M<br>NorESM1-ME | Norway | Norwegian Climate Centre |

### 3.1 Temperature scenarios

In the following sections, multi-model climate change projections (relative to the 1986–2005 reference period) are shown for Canada. The format of the figures presented here is as consistent as possible with the analogous figures in the IPCC AR5 Atlas (IPCC, 2013—Annex I), referred to earlier, so as to allow direct comparison.

Time series of temperature anomalies, averaged over Canada covering the historical period (as simulated by the CMIP5 models) and the future (to year 2100), are shown in Figure 5. Results for three future forcing scenarios, RCP2.6, RCP4.5, and RCP8.5 are provided. The individual thin lines are the results of the individual models listed in Table 2 and the heavy line represents the multi-model ensemble average. Temperature anomaly is defined as the temperature relative to the 1986–2005 reference period. The range of values, quantified by the box and whisker plots to the right of each panel, results from both natural climate variability (as simulated by the models) and the differences in the detailed representation of physical processes in each model. As can be seen by comparing these plots to the global mean plots in the IPCC Atlas (IPCC, 2013—Annex I, pp. 1318–1319), the historical and projected changes for Canada are considerably larger (roughly 50 %) than for the *global* land area.

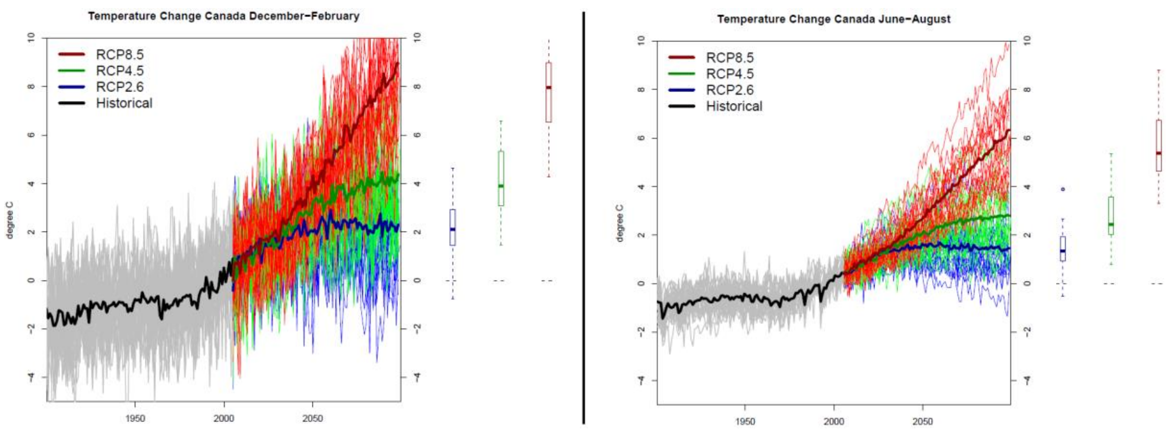


**Figure 5:** Time series of historical and projected temperature change for the December, January, and February (left) and the June, July, and August (right) averages, as simulated by the CMIP5 multi-model ensemble. As in Annex I of the IPCC AR5 (IPCC, 2013), the individual curves represent the simulation results for individual models, while the heavy lines indicate the ensemble average. Results are shown for Canadian land areas only. Change is computed relative to the 1986–2005 period. The spread amongst models, evident in the thin curves, is quantified by the box and whisker plots to the right of each panel. They show, for the 2081–2100 period, the 5$^{th}$, 25$^{th}$, 50$^{th}$ (median), 75$^{th}$, and 95$^{th}$ percentile values.

Even within Canada, climate change is not projected to be uniform, and so national average values may not be suitable for many applications. Figures 6 and 7 show maps of temperature change from the CMIP5 multi-model ensemble, based on the RCP4.5 scenario. Similar maps for the other RCP scenarios are available from the Canadian Climate Data and Scenarios website (http://www.ccds-dscc.ec.gc.ca/). RCP4.5 is used here for illustration purposes (as in the IPCC Atlas) and its use here does not imply that it is more probable than the other RCPs.

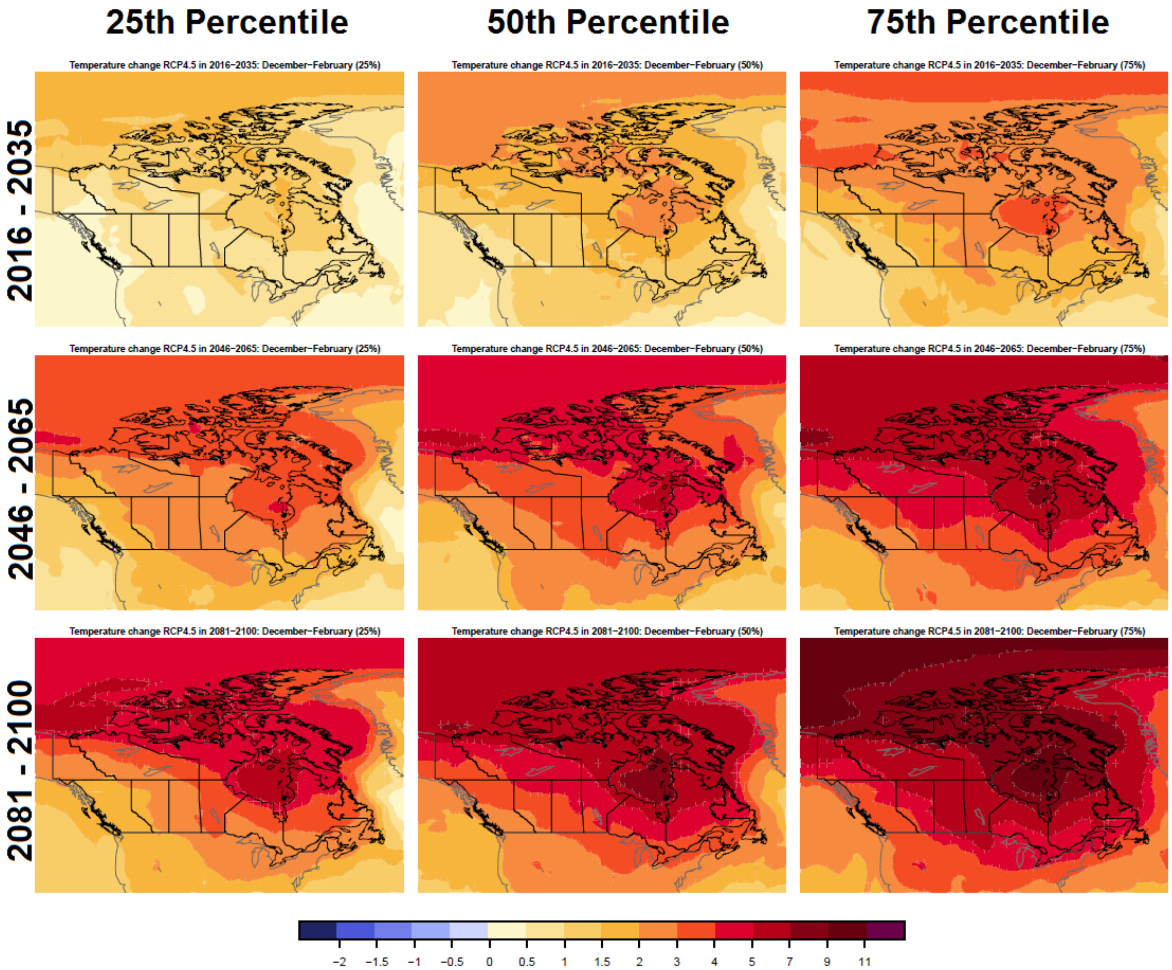


**Figure 6:** Maps of winter temperature change projected by the CMIP5 multi-model ensemble for the RCP4.5 scenario, averaged over December–February. Change is computed relative to the 1986–2005 baseline period. As in the IPCC Atlas (IPCC, 2013), the top row shows results for the period 2016–2035, the middle row for 2046–2065, and the bottom row for 2081–2100. For each row the left panel shows the 25$^{th}$ percentile of simulated temperature change (25% of individual simulations show warming less than this), the middle panel the 50$^{th}$ percentile (median), and the right panel the 75$^{th}$ percentile. The color scale indicates temperature change in °C with positive change (warming) indicated by yellow through red colors and cooling by blue colors, consistent with the color scale used in the IPCC AR5 Annex I (IPCC, 2013).

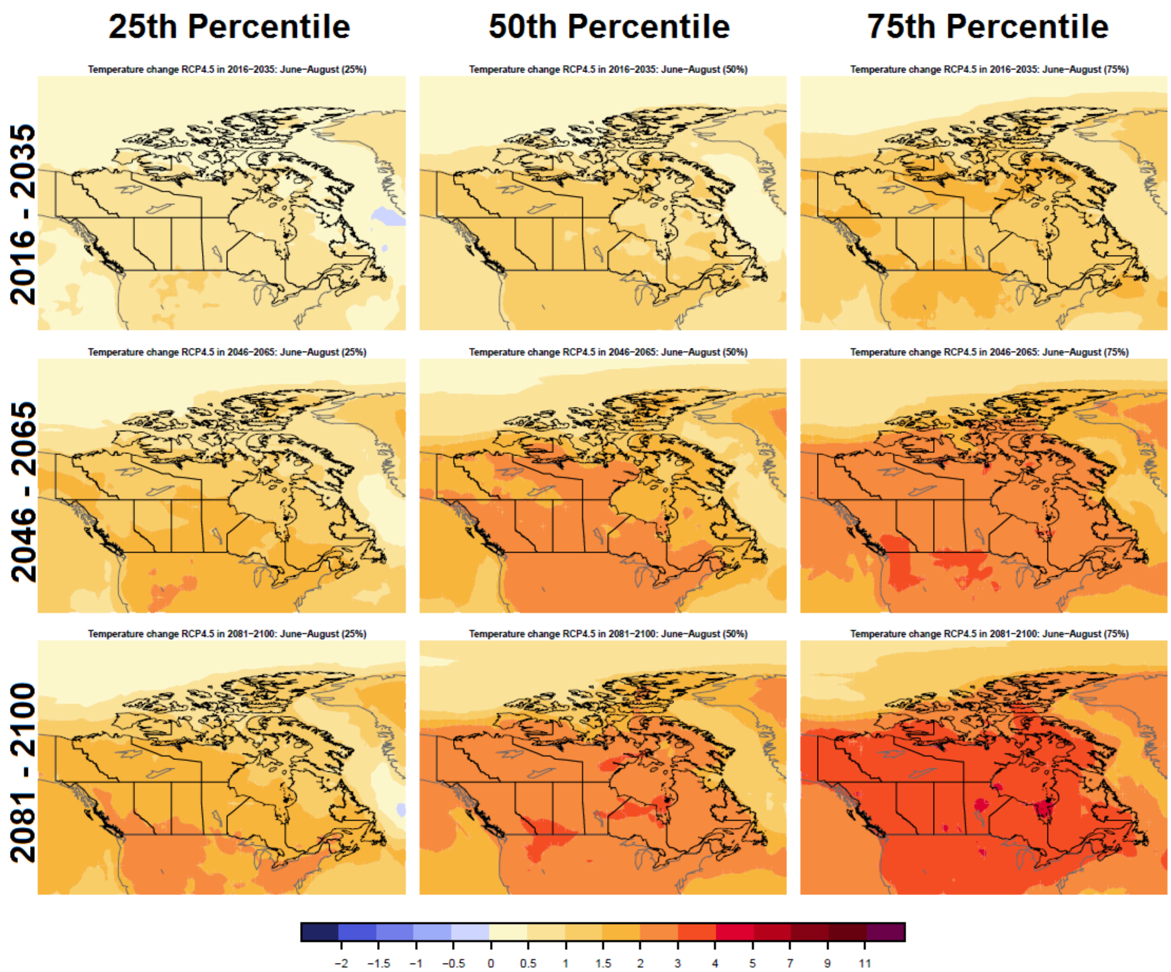


**Figure 7:** Maps of summer temperature change projected by the CMIP5 multi-model ensemble for the RCP4.5 scenario, averaged over June–August. Change is computed relative to the 1986–2005 baseline period. As in the IPCC Atlas (IPCC, 2013), the top row shows results for the period 2016–2035, the middle row for 2046–2065, and the bottom row for 2081–2100. For each row the left panel shows the 25th percentile, the middle panel the 50th percentile (median), and the right panel the 75th percentile. The color scale indicates temperature change in °C with positive change (warming) indicated by yellow through red colors and cooling by blue colors, consistent with the color scale used in the IPCC AR5 Annex I (IPCC, 2013).

### 3.1.1 Summary tables for temperature

Tables 3 and 4 provide values averaged over Canada and over each province and territory for the 50th (median), 25th and 75th percentiles of temperature change for the three future periods illustrated in the previous figures. These tables also provide the corresponding projections under RCP2.6 and RCP8.5. As Figures 6 and 7 clearly show, projected temperature changes are not constant across a province or territory, but the tables are provided to inform province- or territory-wide assessment activities that may need area-averaged information.

**Table 3:** Summary information for projected winter temperature change (in °C, relative to the 1986–2005 baseline period), averaged over December–February for three future periods and three RCPs. The table shows values for the 50th percentile (a), 25th percentile (b), and 75th percentile (c).

| (a) 50th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 1.5 | 2.3 | 2.4 | 1.5 | 3.3 | 4.4 | 1.8 | 4.7 | 8.9 |
| *Alberta* | 1.2 | 1.9 | 2.2 | 1.2 | 2.9 | 3.6 | 1.8 | 3.7 | 6.9 |
| *British Columbia* | 1.1 | 1.7 | 1.8 | 1.1 | 2.4 | 3.1 | 1.5 | 3.1 | 5.7 |
| *Manitoba* | 1.5 | 2.4 | 2.7 | 1.7 | 3.6 | 4.8 | 2.2 | 5.0 | 9.5 |
| *New Brunswick* | 1.1 | 1.7 | 2.1 | 1.3 | 2.7 | 3.5 | 1.4 | 3.6 | 6.4 |
| *Newfoundland and Labrador* | 1.3 | 2.2 | 2.3 | 1.3 | 2.9 | 4.1 | 1.5 | 4.3 | 7.7 |
| *Northwest Territories* | 2.1 | 2.8 | 3.1 | 1.9 | 4.3 | 5.4 | 2.2 | 6.1 | 12.3 |
| *Nova Scotia* | 1.0 | 1.5 | 1.9 | 1.2 | 2.3 | 2.9 | 1.3 | 3.0 | 5.4 |
| *Nunavut* | 1.9 | 3.1 | 3.0 | 2.0 | 4.4 | 5.9 | 2.2 | 6.5 | 12.9 |
| *Ontario* | 1.4 | 2.2 | 2.4 | 1.6 | 3.2 | 4.4 | 1.9 | 4.6 | 8.2 |
| *Prince Edward Island* | 1.1 | 1.7 | 2.1 | 1.3 | 2.7 | 3.4 | 1.4 | 3.4 | 6.0 |
| *Quebec* | 1.6 | 2.5 | 2.7 | 1.6 | 3.4 | 4.8 | 1.8 | 5.2 | 9.1 |
| *Saskatchewan* | 1.3 | 2.2 | 2.5 | 1.4 | 3.3 | 4.2 | 2.0 | 4.3 | 8.1 |
| *Yukon* | 1.8 | 2.1 | 2.3 | 1.5 | 3.3 | 4.1 | 1.9 | 4.4 | 8.1 |

| (b) 25th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 0.9 | 1.6 | 1.5 | 1.0 | 2.5 | 3.2 | 1.2 | 3.7 | 7.2 |
| *Alberta* | 0.6 | 1.3 | 1.3 | 0.7 | 2.2 | 2.1 | 1.0 | 2.7 | 5.5 |
| *British Columbia* | 0.5 | 1.1 | 1.2 | 0.5 | 1.7 | 1.9 | 0.9 | 2.2 | 4.5 |
| *Manitoba* | 0.9 | 1.8 | 1.5 | 1.0 | 2.8 | 3.5 | 1.3 | 3.7 | 7.4 |
| *New Brunswick* | 0.8 | 1.3 | 1.4 | 0.7 | 2.0 | 2.9 | 1.0 | 3.0 | 5.6 |
| *Newfoundland and Labrador* | 0.8 | 1.4 | 1.3 | 0.8 | 2.2 | 3.1 | 1.0 | 3.4 | 6.5 |
| *Northwest Territories* | 1.3 | 2.0 | 1.8 | 1.2 | 3.1 | 4.1 | 1.7 | 4.8 | 9.4 |
| *Nova Scotia* | 0.7 | 1.1 | 1.0 | 0.7 | 1.7 | 2.4 | 0.9 | 2.5 | 4.7 |
| *Nunavut* | 1.4 | 2.2 | 2.0 | 1.4 | 3.4 | 4.7 | 1.7 | 5.4 | 10.5 |
| *Ontario* | 0.8 | 1.5 | 1.4 | 0.9 | 2.4 | 3.1 | 1.2 | 3.4 | 6.9 |
| *Prince Edward Island* | 0.8 | 1.3 | 1.3 | 0.8 | 1.8 | 2.7 | 1.0 | 2.7 | 5.3 |
| *Quebec* | 0.9 | 1.6 | 1.5 | 1.0 | 2.6 | 3.6 | 1.3 | 4.0 | 8.0 |
| *Saskatchewan* | 0.7 | 1.6 | 1.5 | 0.9 | 2.6 | 2.8 | 1.4 | 3.1 | 6.5 |
| *Yukon* | 0.8 | 1.3 | 1.6 | 0.7 | 2.0 | 2.8 | 1.3 | 3.2 | 6.1 |

| (c) 75th Percentile | RCP2.6 2016–2035 | RCP2.6 2046–2065 | RCP2.6 2081–2100 | RCP4.5 2016–2035 | RCP4.5 2046–2065 | RCP4.5 2081–2100 | RCP8.5 2016–2035 | RCP8.5 2046–2065 | RCP8.5 2081–2100 |
|---|---|---|---|---|---|---|---|---|---|
| ***Canada*** | 2.1 | 3.1 | 3.4 | 2.2 | 4.3 | 5.7 | 2.4 | 5.7 | 10.8 |
| *Alberta* | 1.9 | 2.8 | 2.8 | 1.9 | 3.9 | 4.7 | 2.3 | 4.8 | 7.8 |
| *British Columbia* | 1.7 | 2.4 | 2.5 | 1.5 | 3.1 | 3.7 | 2.0 | 3.9 | 6.6 |
| *Manitoba* | 2.1 | 3.3 | 3.4 | 2.4 | 4.4 | 6.1 | 2.7 | 6.1 | 10.9 |
| *New Brunswick* | 1.4 | 2.3 | 2.7 | 1.8 | 3.3 | 4.3 | 1.9 | 4.4 | 7.3 |
| *Newfoundland and Labrador* | 1.8 | 3.0 | 3.3 | 2.0 | 3.7 | 4.9 | 2.2 | 5.2 | 9.0 |
| *Northwest Territories* | 2.7 | 3.8 | 4.1 | 2.7 | 5.5 | 7.4 | 3.1 | 7.3 | 14.4 |
| *Nova Scotia* | 1.3 | 2.1 | 2.5 | 1.6 | 2.9 | 3.7 | 1.6 | 3.6 | 6.2 |
| *Nunavut* | 2.7 | 4.2 | 4.6 | 2.8 | 5.7 | 7.9 | 3.0 | 7.7 | 16.1 |
| *Ontario* | 1.9 | 2.8 | 3.0 | 2.0 | 4.1 | 5.3 | 2.2 | 5.4 | 9.7 |
| *Prince Edward Island* | 1.6 | 2.5 | 2.9 | 1.8 | 3.2 | 4.1 | 1.8 | 4.1 | 6.7 |
| *Quebec* | 2.1 | 3.4 | 3.8 | 2.2 | 4.6 | 6.1 | 2.5 | 6.1 | 10.8 |
| *Saskatchewan* | 2.0 | 3.0 | 3.1 | 2.1 | 4.1 | 5.5 | 2.4 | 5.5 | 9.1 |
| *Yukon* | 2.5 | 3.0 | 3.1 | 2.0 | 4.3 | 5.1 | 2.4 | 5.3 | 10.0 |

**Table 4:** Summary information for projected summer temperature change (in °C, relative to the 1986–2005 baseline period), averaged over June–August for three future periods and three RCPs. The table shows values for the 50th percentile (a), 25th percentile (b), and 75th percentile (c).

| (a) 50th Percentile | RCP2.6 2016–2035 | RCP2.6 2046–2065 | RCP2.6 2081–2100 | RCP4.5 2016–2035 | RCP4.5 2046–2065 | RCP4.5 2081–2100 | RCP8.5 2016–2035 | RCP8.5 2046–2065 | RCP8.5 2081–2100 |
|---|---|---|---|---|---|---|---|---|---|
| ***Canada*** | 1.1 | 1.4 | 1.3 | 1.1 | 2.0 | 2.5 | 1.2 | 2.9 | 5.3 |
| *Alberta* | 1.1 | 1.5 | 1.4 | 1.1 | 2.2 | 2.7 | 1.4 | 3.2 | 5.9 |
| *British Columbia* | 1.1 | 1.5 | 1.5 | 1.2 | 2.2 | 2.7 | 1.3 | 3.0 | 5.6 |
| *Manitoba* | 1.2 | 1.5 | 1.5 | 1.2 | 2.2 | 3.0 | 1.4 | 3.4 | 6.3 |
| *New Brunswick* | 1.0 | 1.5 | 1.4 | 1.1 | 2.1 | 2.5 | 1.2 | 3.0 | 5.4 |
| *Newfoundland and Labrador* | 0.8 | 1.2 | 1.2 | 0.8 | 1.7 | 2.2 | 1.0 | 2.5 | 4.6 |
| *Northwest Territories* | 1.1 | 1.5 | 1.4 | 1.1 | 2.1 | 2.4 | 1.2 | 2.9 | 5.1 |
| *Nova Scotia* | 0.9 | 1.5 | 1.3 | 1.0 | 1.9 | 2.4 | 1.1 | 2.7 | 4.9 |
| *Nunavut* | 1.0 | 1.4 | 1.2 | 0.9 | 1.8 | 2.4 | 1.1 | 2.6 | 4.8 |
| *Ontario* | 1.1 | 1.4 | 1.3 | 1.1 | 2.1 | 2.9 | 1.3 | 3.1 | 6.0 |
| *Prince Edward Island* | 0.9 | 1.6 | 1.4 | 1.1 | 2.0 | 2.5 | 1.2 | 2.9 | 5.1 |
| *Quebec* | 0.9 | 1.4 | 1.3 | 1.0 | 1.9 | 2.6 | 1.2 | 2.8 | 5.3 |
| *Saskatchewan* | 1.2 | 1.5 | 1.5 | 1.2 | 2.3 | 2.8 | 1.4 | 3.4 | 6.3 |
| *Yukon* | 1.1 | 1.4 | 1.3 | 1.1 | 1.9 | 2.4 | 1.1 | 2.6 | 4.9 |

| (b) 25th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 0.7 | 0.9 | 0.8 | 0.7 | 1.4 | 1.7 | 0.9 | 2.2 | 4.2 |
| *Alberta* | 0.8 | 0.9 | 0.8 | 0.9 | 1.5 | 1.8 | 1.1 | 2.3 | 4.4 |
| *British Columbia* | 0.8 | 1.0 | 0.9 | 0.9 | 1.5 | 2.0 | 0.9 | 2.3 | 4.3 |
| *Manitoba* | 0.8 | 1.0 | 0.9 | 0.9 | 1.7 | 1.9 | 1.0 | 2.7 | 4.9 |
| *New Brunswick* | 0.8 | 1.0 | 0.8 | 0.7 | 1.5 | 2.0 | 1.0 | 2.4 | 4.4 |
| *Newfoundland and Labrador* | 0.5 | 0.7 | 0.6 | 0.5 | 1.2 | 1.5 | 0.8 | 1.9 | 3.9 |
| *Northwest Territories* | 0.7 | 0.9 | 0.9 | 0.8 | 1.4 | 1.7 | 0.9 | 2.1 | 4.0 |
| *Nova Scotia* | 0.7 | 1.0 | 0.9 | 0.7 | 1.5 | 1.9 | 0.9 | 2.2 | 4.2 |
| *Nunavut* | 0.5 | 0.7 | 0.6 | 0.5 | 1.1 | 1.3 | 0.6 | 1.8 | 3.4 |
| *Ontario* | 0.8 | 1.0 | 0.9 | 0.8 | 1.6 | 1.8 | 1.0 | 2.6 | 4.7 |
| *Prince Edward Island* | 0.7 | 1.0 | 0.8 | 0.7 | 1.6 | 2.0 | 1.0 | 2.4 | 4.2 |
| *Quebec* | 0.6 | 0.9 | 0.8 | 0.6 | 1.4 | 1.7 | 0.9 | 2.2 | 4.1 |
| *Saskatchewan* | 0.9 | 1.0 | 0.8 | 0.9 | 1.7 | 1.9 | 1.1 | 2.6 | 4.9 |
| *Yukon* | 0.7 | 0.9 | 0.8 | 0.7 | 1.5 | 1.7 | 0.7 | 1.9 | 3.8 |

| (c) 75th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 1.5 | 2.0 | 2.0 | 1.4 | 2.6 | 3.4 | 1.6 | 3.6 | 6.6 |
| *Alberta* | 1.4 | 2.1 | 2.1 | 1.4 | 2.6 | 3.5 | 1.6 | 3.8 | 6.8 |
| *British Columbia* | 1.4 | 2.1 | 2.2 | 1.5 | 2.8 | 3.6 | 1.6 | 3.8 | 6.8 |
| *Manitoba* | 1.7 | 2.4 | 2.2 | 1.5 | 2.9 | 4.1 | 1.8 | 4.2 | 7.8 |
| *New Brunswick* | 1.4 | 2.1 | 1.8 | 1.4 | 2.6 | 3.5 | 1.6 | 3.7 | 6.3 |
| *Newfoundland and Labrador* | 1.2 | 1.8 | 1.7 | 1.3 | 2.3 | 3.0 | 1.3 | 3.2 | 5.9 |
| *Northwest Territories* | 1.6 | 2.2 | 2.1 | 1.5 | 2.7 | 3.4 | 1.6 | 3.7 | 6.8 |
| *Nova Scotia* | 1.2 | 1.8 | 1.8 | 1.5 | 2.4 | 3.2 | 1.5 | 3.4 | 5.9 |
| *Nunavut* | 1.5 | 2.0 | 2.1 | 1.4 | 2.5 | 3.2 | 1.5 | 3.4 | 6.6 |
| *Ontario* | 1.5 | 2.2 | 2.0 | 1.4 | 2.8 | 3.6 | 1.6 | 3.9 | 6.9 |
| *Prince Edward Island* | 1.3 | 2.1 | 1.9 | 1.4 | 2.5 | 3.3 | 1.6 | 3.4 | 6.0 |
| *Quebec* | 1.3 | 2.0 | 1.9 | 1.3 | 2.6 | 3.3 | 1.5 | 3.5 | 6.3 |
| *Saskatchewan* | 1.6 | 2.3 | 2.2 | 1.5 | 2.7 | 3.9 | 1.7 | 4.0 | 7.5 |
| *Yukon* | 1.5 | 2.0 | 2.0 | 1.5 | 2.6 | 3.4 | 1.5 | 3.7 | 6.4 |

## 3.2 Precipitation

In this section, multi-model climate change projections (relative to the 1986–2005 reference period) are shown for precipitation in Canada. The format of these figures is as consistent as possible with the analogous figures in the IPCC AR5 Atlas (IPCC, 2013—Annex I) referred to earlier so as to allow direct comparison.

Time series of precipitation anomaly (as a percentage relative to the 1986–2005 mean), averaged over Canada and covering the historical period (as simulated by the CMIP5 models) and the future (to year 2100), are shown in Figure 8. Results for three future forcing scenarios, RCP2.6, RCP4.5, and RCP8.5, are provided. The individual thin lines are the results of the individual models listed in Table 2, and the heavy line represents the multi-model ensemble average. The range of values, quantified by the box and whisker plots to the right of each panel, results from both natural climate variability (as simulated by the models) and the differences in the detailed representation of physical processes in each model.

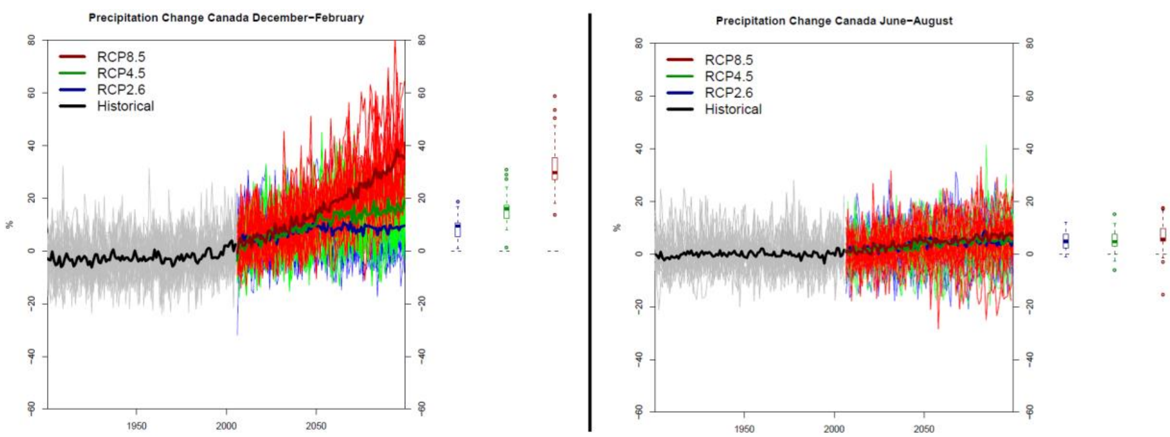


**Figure 8:** Time series of historical and projected precipitation change for December–February (left) and June–August (right) average, as simulated by the CMIP5 multi-model ensemble. As in Annex I of the IPCC AR5 (IPCC, 2013), the individual curves represent the simulation results for individual models, while the heavy lines indicate the ensemble average. Results are shown for Canadian land areas only. Change is computed as a percentage relative to the 1986–2005 period. The spread amongst models, evident in the thin curves, is quantified by the box and whisker plots to the right of each panel. They show, for the 2081–2100 period, the 5$^{th}$, 25$^{th}$, 50$^{th}$ (median), 75$^{th}$ and 95$^{th}$ percentile values.

As was shown for temperature in Figures 6 and 7, Figures 9 and 10 show maps of precipitation change from the CMIP5 multi-model ensemble, based on the RCP4.5 scenario. Similar maps for the other RCP scenarios are available from the Canadian Climate Data and Scenarios website (http://www.ccds-dscc.ec.gc.ca/). RCP4.5 is used here for illustration purposes (as in the IPCC Atlas) and its use here does not imply that it is more probable than the other RCPs.

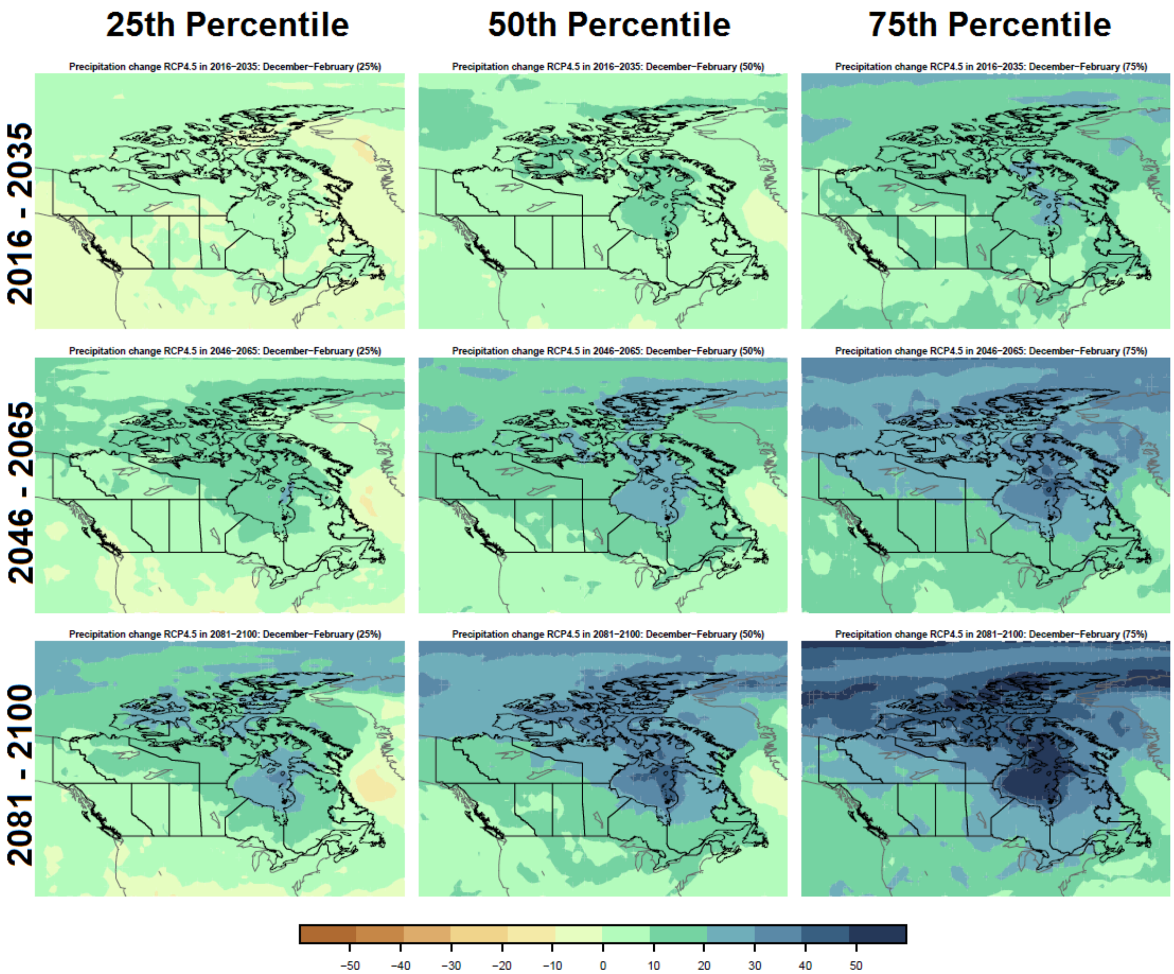


**Figure 9:** Maps of winter precipitation change projected by the CMIP5 multi-model ensemble for the RCP4.5 scenario, averaged over December–February. Change is computed relative to the 1986–2005 baseline period. As in the IPCC Atlas (IPCC, 2013), the top row shows results for the period 2016–2035, the middle row for 2046–2065, and the bottom row for 2081–2100. For each row the left panel shows the 25$^{th}$ percentile, the middle panel the 50$^{th}$ percentile (median), and the right panel the 75$^{th}$ percentile. The colour scale indicates precipitation change in % with positive change (increased precipitation) indicated by green colours and decrease by yellow to brown colours, consistent with the colour scale used in the IPCC AR5 Annex I (IPCC, 2013).

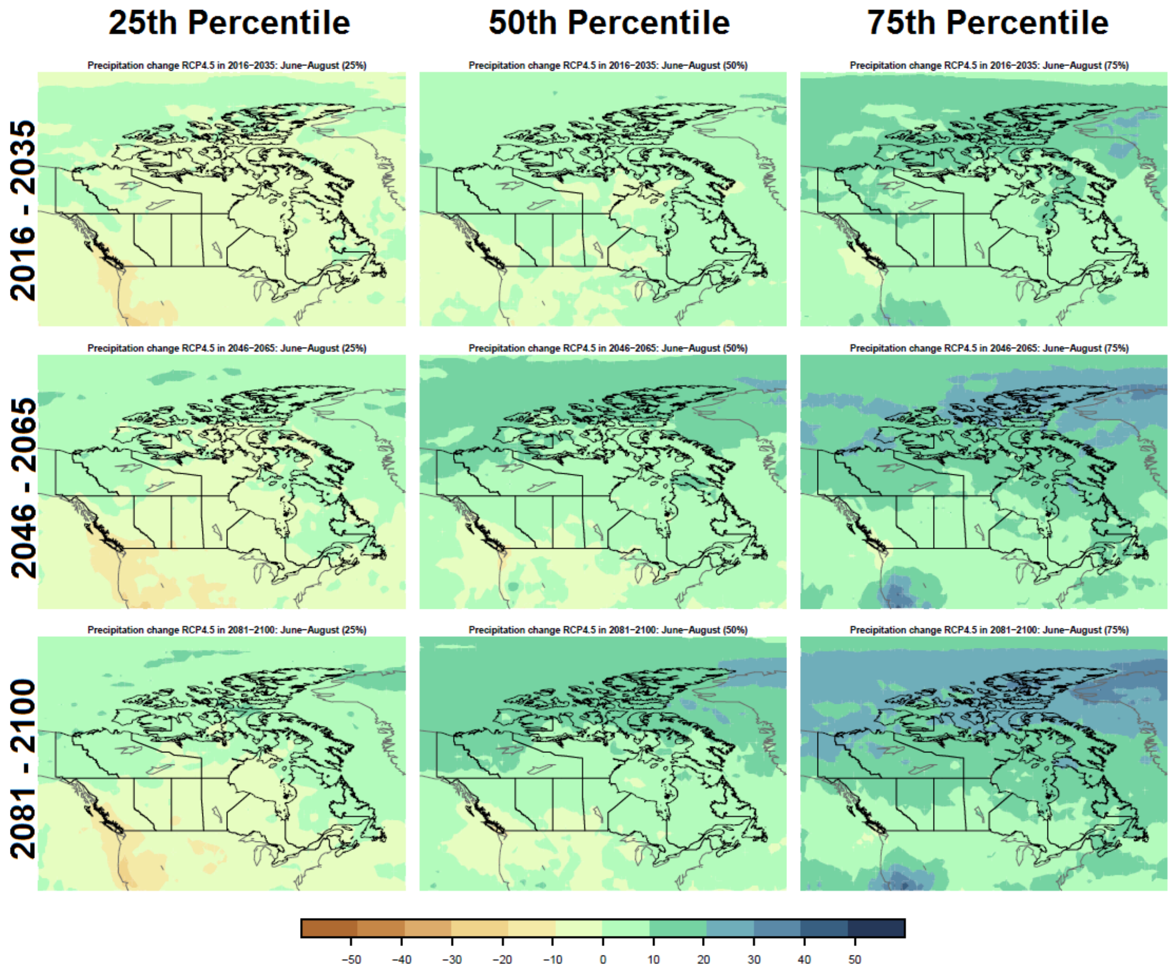


**Figure 10:** Maps of summer precipitation change projected by the CMIP5 multi-model ensemble for the RCP4.5 scenario, averaged over June–August. Change is computed relative to the 1986–2005 baseline period. As in the IPCC Atlas (IPCC, 2013), the top row shows results for the period 2016–2035, the middle row for 2046–2065, and the bottom row for 2081–2100. For each row the left panel shows the 25th percentile, the middle panel the 50th percentile (median), and the right panel the 75th percentile. The colour scale indicates precipitation change in % with positive change (increased precipitation) indicated by green colours and decrease by yellow to brown colours, consistent with the colour scale used in the IPCC AR5 Annex I (IPCC, 2013).

### 3.2.1 Summary tables for precipitation

Tables 5 and 6 provide values averaged over Canada and over each province and territory for the 50th (median), 25th, and 75th percentiles of precipitation change for the three future periods illustrated in Figures 9 and 10. These tables also provide the corresponding projections under RCP2.6 and RCP8.5. As the figures clearly show, projected precipitation changes are not constant across a province or territory, but the tables are provided to inform province- or territory-wide assessment activities that may need area-averaged information.

**Table 5:** Summary information for projected winter precipitation change (in % change from the 1986–2005 baseline period), averaged over December–February for three future periods and three RCPs. The table shows values for the 50th percentile (a), 25th percentile (b), and 75th percentile (c).

| (a) 50th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 5.4 | 9.1 | 9.1 | 5.9 | 12.9 | 17.6 | 7.2 | 18.1 | 37.8 |
| *Alberta* | 3.1 | 6.7 | 7.9 | 5.9 | 10.8 | 11.6 | 4.3 | 10.8 | 20.4 |
| *British Columbia* | 1.6 | 6.4 | 7.5 | 4.3 | 8.7 | 10.8 | 3.4 | 10.0 | 17.9 |
| *Manitoba* | 5.3 | 10.7 | 9.0 | 6.4 | 12.7 | 16.5 | 6.6 | 16.2 | 28.9 |
| *New Brunswick* | 4.8 | 6.7 | 3.5 | 5.2 | 8.9 | 11.9 | 5.8 | 11.4 | 19.0 |
| *Newfoundland and Labrador* | 3.2 | 5.8 | 6.3 | 5.0 | 9.5 | 14.5 | 4.8 | 12.0 | 23.2 |
| *Northwest Territories* | 7.1 | 11.9 | 10.9 | 6.8 | 15.4 | 19.5 | 8.2 | 19.7 | 42.9 |
| *Nova Scotia* | 2.8 | 2.5 | 3.0 | 2.8 | 5.4 | 8.7 | 3.7 | 8.3 | 13.9 |
| *Nunavut* | 7.2 | 13.6 | 15.4 | 8.8 | 19.0 | 28.7 | 10.9 | 29.1 | 66.4 |
| *Ontario* | 5.3 | 8.9 | 7.9 | 5.7 | 12.9 | 16.4 | 6.6 | 17.5 | 31.8 |
| *Prince Edward Island* | 3.0 | 5.2 | 5.3 | 5.3 | 7.5 | 10.8 | 5.3 | 10.7 | 17.1 |
| *Quebec* | 6.2 | 10.2 | 9.9 | 6.5 | 14.9 | 21.2 | 7.5 | 20.7 | 39.8 |
| *Saskatchewan* | 4.1 | 8.1 | 8.4 | 5.7 | 11.0 | 11.7 | 5.3 | 12.1 | 22.2 |
| *Yukon* | 7.3 | 9.7 | 11.0 | 5.9 | 14.1 | 14.7 | 5.9 | 15.8 | 29.9 |

| (b) 25th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | -0.5 | 1.9 | 2.0 | 0.1 | 6.2 | 9.1 | 0.4 | 10.5 | 24.8 |
| *Alberta* | -1.8 | 2.5 | 2.0 | 0.6 | 5.7 | 5.7 | 0.2 | 5.2 | 12.2 |
| *British Columbia* | -2.6 | 1.5 | 1.7 | -0.6 | 2.7 | 3.4 | -1.4 | 2.6 | 9.0 |
| *Manitoba* | 0.4 | 3.5 | 3.6 | 0.6 | 7.8 | 9.2 | 1.2 | 10.0 | 17.0 |
| *New Brunswick* | 1.1 | 1.0 | 0.9 | -0.7 | 3.6 | 7.0 | -0.2 | 6.0 | 13.1 |
| *Newfoundland and Labrador* | -2.4 | -0.1 | 1.0 | -0.3 | 2.9 | 6.5 | 0.6 | 6.5 | 14.2 |
| *Northwest Territories* | 1.2 | 5.2 | 5.1 | 2.0 | 9.7 | 12.4 | 2.5 | 12.9 | 29.7 |
| *Nova Scotia* | -0.1 | -2.2 | 0.3 | -1.8 | 2.9 | 4.1 | 1.7 | 3.0 | 7.7 |
| *Nunavut* | 1.5 | 4.5 | 6.0 | 2.2 | 12.0 | 17.1 | 2.2 | 19.7 | 47.5 |
| *Ontario* | 0.2 | 3.2 | 2.7 | 1.8 | 7.6 | 10.0 | 1.6 | 10.9 | 21.6 |
| *Prince Edward Island* | 1.2 | -2.3 | 2.1 | -1.2 | 2.5 | 5.1 | 1.4 | 3.4 | 8.3 |
| *Quebec* | 0.4 | 2.8 | 3.5 | 0.9 | 7.5 | 13.2 | 1.7 | 14.7 | 29.3 |
| *Saskatchewan* | -1.0 | 2.1 | 2.9 | 0.1 | 5.6 | 6.7 | 0.4 | 6.2 | 13.1 |
| *Yukon* | -0.8 | 3.4 | 4.7 | 0.7 | 8.5 | 8.4 | 1.0 | 9.7 | 18.9 |

| (c) 75th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 12.4 | 17.0 | 17.3 | 12.1 | 20.2 | 26.4 | 13.9 | 26.7 | 52.8 |
| *Alberta* | 9.9 | 13.1 | 12.6 | 10.8 | 15.2 | 17.6 | 8.7 | 17.9 | 28.8 |
| *British Columbia* | 7.6 | 12.7 | 14.0 | 9.5 | 14.4 | 17.4 | 8.4 | 17.8 | 27.1 |
| *Manitoba* | 10.6 | 17.0 | 15.3 | 12.2 | 18.7 | 24.5 | 12.3 | 23.6 | 41.8 |
| *New Brunswick* | 10.1 | 12.4 | 9.9 | 10.1 | 15.2 | 19.1 | 11.3 | 17.3 | 28.6 |
| *Newfoundland and Labrador* | 8.1 | 11.8 | 12.9 | 11.7 | 16.1 | 20.8 | 10.6 | 20.7 | 34.8 |
| *Northwest Territories* | 13.0 | 18.8 | 18.3 | 11.9 | 22.6 | 27.3 | 13.5 | 27.9 | 55.1 |
| *Nova Scotia* | 6.2 | 7.0 | 7.8 | 6.1 | 9.3 | 14.4 | 6.7 | 12.5 | 21.1 |
| *Nunavut* | 16.8 | 24.4 | 26.0 | 15.7 | 28.7 | 40.4 | 18.7 | 39.8 | 89.8 |
| *Ontario* | 10.8 | 14.9 | 13.4 | 11.2 | 18.2 | 23.5 | 12.1 | 23.9 | 41.7 |
| *Prince Edward Island* | 8.7 | 8.8 | 8.0 | 8.1 | 11.3 | 15.1 | 9.3 | 13.8 | 22.1 |
| *Quebec* | 11.6 | 17.2 | 16.9 | 12.2 | 21.6 | 28.7 | 13.9 | 29.5 | 52.3 |
| *Saskatchewan* | 8.1 | 14.1 | 12.7 | 9.9 | 16.7 | 17.1 | 10.6 | 18.7 | 30.6 |
| *Yukon* | 12.3 | 15.3 | 17.8 | 10.7 | 19.3 | 21.2 | 12.4 | 23.2 | 43.2 |

**Table 6:** Summary information for projected summer precipitation change (in % change from the 1986–2005 baseline period), averaged over June–August for three future periods and three RCPs. The table shows values for the 50th percentile (a), 25th percentile (b), and 75th percentile (c).

| (a) 50th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 2.8 | 5.0 | 5.2 | 2.2 | 5.1 | 6.5 | 3.0 | 6.4 | 10.6 |
| *Alberta* | 3.3 | 4.4 | 5.9 | 2.3 | 2.3 | 4.1 | 1.7 | 2.8 | 2.4 |
| *British Columbia* | 1.3 | 3.4 | 3.7 | 0.2 | 0.7 | 0.9 | 0.7 | 2.1 | 0.1 |
| *Manitoba* | 0.2 | 2.2 | 2.9 | 0.6 | 2.0 | 2.2 | 0.8 | 1.7 | -1.1 |
| *New Brunswick* | 2.8 | 1.1 | 3.9 | 3.0 | 3.9 | 4.5 | 3.2 | 4.2 | 7.8 |
| *Newfoundland and Labrador* | 3.5 | 4.8 | 4.3 | 3.3 | 5.1 | 5.9 | 3.5 | 6.6 | 11.5 |
| *Northwest Territories* | 4.5 | 7.4 | 6.8 | 3.5 | 7.8 | 10.1 | 4.5 | 11.1 | 17.8 |
| *Nova Scotia* | 2.8 | 2.2 | 3.6 | 3.0 | 4.4 | 6.4 | 1.7 | 4.3 | 6.8 |
| *Nunavut* | 4.6 | 6.2 | 5.9 | 3.1 | 8.1 | 10.8 | 5.2 | 11.3 | 22.9 |
| *Ontario* | 0.5 | 2.6 | 1.2 | 0.4 | 2.7 | 3.3 | 0.7 | 1.3 | -0.5 |
| *Prince Edward Island* | 0.6 | 1.9 | 2.7 | 3.1 | 3.9 | 6.1 | 2.5 | 5.4 | 6.3 |
| *Quebec* | 2.5 | 4.1 | 4.2 | 2.6 | 5.2 | 5.1 | 3.0 | 5.6 | 6.5 |
| *Saskatchewan* | 1.9 | 2.7 | 4.4 | 0.6 | 1.2 | 1.4 | 0.5 | 1.7 | -1.9 |
| *Yukon* | 5.0 | 7.4 | 6.8 | 4.5 | 8.9 | 12.0 | 4.5 | 13.2 | 21.1 |

| (b) 25th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | -3.2 | -1.5 | -1.4 | -3.4 | -1.7 | -0.4 | -2.9 | -0.6 | 0.7 |
| *Alberta* | -2.9 | -1.4 | -0.3 | -3.5 | -4.2 | -2.9 | -5.1 | -3.4 | -7.8 |
| *British Columbia* | -4.0 | -2.8 | -2.3 | -4.7 | -5.0 | -5.4 | -5.1 | -4.0 | -8.3 |
| *Manitoba* | -4.2 | -2.5 | -2.7 | -5.4 | -4.7 | -4.5 | -4.1 | -4.5 | -9.1 |
| *New Brunswick* | -3.4 | -2.7 | -0.6 | -2.2 | 0.2 | -0.7 | -2.3 | -1.3 | -1.1 |
| *Newfoundland and Labrador* | -0.2 | 0.8 | 0.3 | -0.6 | 0.7 | 2.2 | -1.7 | 2.2 | 5.3 |
| *Northwest Territories* | -1.0 | 1.8 | 0.4 | -1.6 | 1.8 | 3.8 | -1.7 | 4.4 | 8.9 |
| *Nova Scotia* | -3.9 | -3.8 | -2.9 | -2.2 | -3.6 | -1.3 | -4.5 | -2.2 | -3.0 |
| *Nunavut* | -2.4 | -0.8 | -0.9 | -2.7 | 0.6 | 3.7 | -1.0 | 4.0 | 12.6 |
| *Ontario* | -3.8 | -2.6 | -3.4 | -4.5 | -3.0 | -2.0 | -3.5 | -3.8 | -8.2 |
| *Prince Edward Island* | -3.7 | -4.3 | -1.4 | -3.1 | -1.4 | -2.1 | -6.0 | -2.4 | -1.8 |
| *Quebec* | -2.1 | 0.2 | -0.2 | -1.3 | 0.6 | 0.5 | -1.6 | 0.8 | 0.0 |
| *Saskatchewan* | -3.1 | -2.4 | -1.1 | -5.3 | -4.6 | -4.4 | -4.9 | -4.8 | -9.2 |
| *Yukon* | 0.9 | 2.8 | 2.0 | 1.1 | 4.0 | 6.2 | 0.2 | 7.4 | 12.0 |

| (c) 75th Percentile | RCP2.6 | | | RCP4.5 | | | RCP8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 | 2016–2035 | 2046–2065 | 2081–2100 |
| ***Canada*** | 12.4 | 17.0 | 17.3 | 12.1 | 20.2 | 26.4 | 13.9 | 26.7 | 52.8 |
| *Alberta* | 9.9 | 13.1 | 12.6 | 10.8 | 15.2 | 17.6 | 8.7 | 17.9 | 28.8 |
| *British Columbia* | 7.6 | 12.7 | 14.0 | 9.5 | 14.4 | 17.4 | 8.4 | 17.8 | 27.1 |
| *Manitoba* | 10.6 | 17.0 | 15.3 | 12.2 | 18.7 | 24.5 | 12.3 | 23.6 | 41.8 |
| *New Brunswick* | 10.1 | 12.4 | 9.9 | 10.1 | 15.2 | 19.1 | 11.3 | 17.3 | 28.6 |
| *Newfoundland and Labrador* | 8.1 | 11.8 | 12.9 | 11.7 | 16.1 | 20.8 | 10.6 | 20.7 | 34.8 |
| *Northwest Territories* | 13.0 | 18.8 | 18.3 | 11.9 | 22.6 | 27.3 | 13.5 | 27.9 | 55.1 |
| *Nova Scotia* | 6.2 | 7.0 | 7.8 | 6.1 | 9.3 | 14.4 | 6.7 | 12.5 | 21.1 |
| *Nunavut* | 16.8 | 24.4 | 26.0 | 15.7 | 28.7 | 40.4 | 18.7 | 39.8 | 89.8 |
| *Ontario* | 10.8 | 14.9 | 13.4 | 11.2 | 18.2 | 23.5 | 12.1 | 23.9 | 41.7 |
| *Prince Edward Island* | 8.7 | 8.8 | 8.0 | 8.1 | 11.3 | 15.1 | 9.3 | 13.8 | 22.1 |
| *Quebec* | 11.6 | 17.2 | 16.9 | 12.2 | 21.6 | 28.7 | 13.9 | 29.5 | 52.3 |
| *Saskatchewan* | 8.1 | 14.1 | 12.7 | 9.9 | 16.7 | 17.1 | 10.6 | 18.7 | 30.6 |
| *Yukon* | 12.3 | 15.3 | 17.8 | 10.7 | 19.3 | 21.2 | 12.4 | 23.2 | 43.2 |

## 3.3 Extremes

For many climate change impacts, changes in the frequency and magnitude of extreme events are more important than changes in mean values. There are many extremes that have been analyzed in the climate science literature, but by way of illustration we focus here on two basic quantities: changes in annual maximum temperature (i.e., the hottest temperature of the year) and changes in annual maximum 24-hour precipitation. Because global climate models operate with time steps of roughly half an hour, daily minimum, maximum, and mean values can be computed and the projected changes provide an indication of changes that might be anticipated in the future. An important caveat, especially for precipitation, is that the spatial resolution of global climate models remains relatively coarse (typically 100–250 km), and so the precipitation extremes in a model represent averages over an area of several thousand square kilometres. Additionally, climate models may not have all of the physical processes that produce local intense rainstorms. These limitations must be kept in mind when making comparisons to individual meteorological station measurements.

A common way to illustrate changes in climate extremes is to compute the 'return period' of events of a particular magnitude for different time periods. The return period is the long-term average interval between recurrences of extreme values. Figure 11 shows projected return periods for annual maximum temperature and the annual maximum amount of precipitation within a 24-hour period. These plots indicate that the recurrence time, or return period, for these extremes is projected to decrease, for both quantities, in the future. That is, extremes of a particular magnitude will become more frequent. For example, the lower right panel of Figure 11 indicates that, under the RCP8.5 forcing scenario, an annual maximum daily temperature that would currently be attained once every 10 years, on average, will become an annual event by the end of the century.

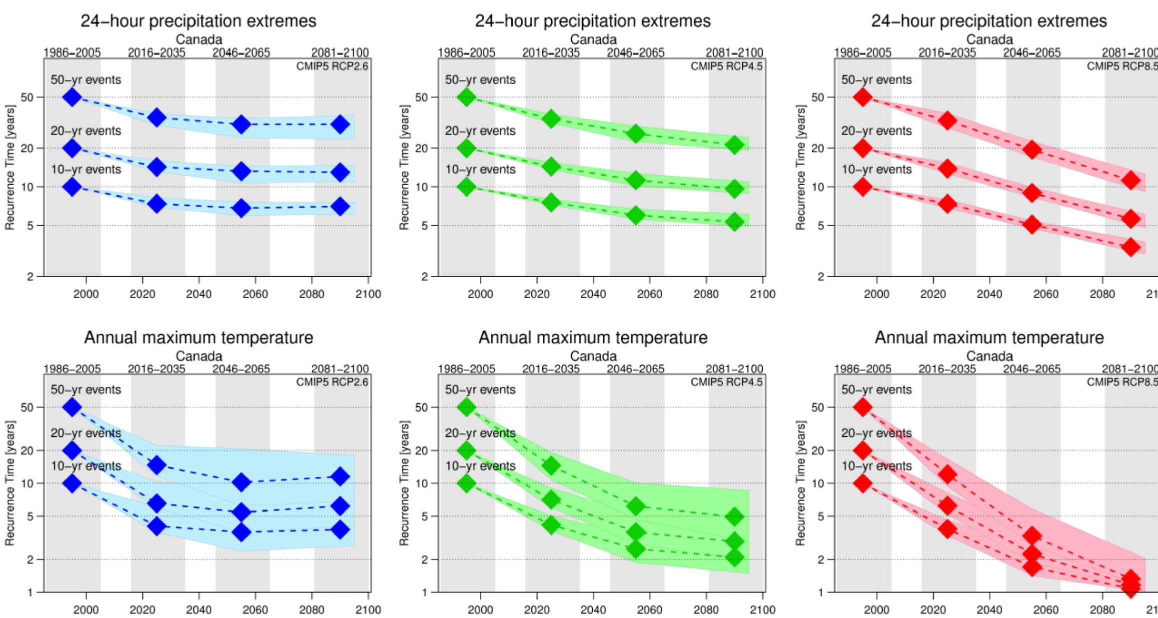


**Figure 11:** Projected return periods (in years) for -twentieth century 10-, 20-, and 50-year return values of annual maximum 24-hour precipitation (upper panel) and annual maximum temperature (lower panel) over Canada as simulated by GCMs contributing to the CMIP5 for three RCPs (RCP2.6, left; RCP4.5, middle; RCP8.5, right). Values are computed based on Kharin et al., 2013.

As with mean temperature and precipitation, changes in climate extremes are not uniform across the globe, or even across Canada. Figure 12 shows projected changes in precipitation extremes for different regions of Canada, along with estimates of the uncertainty range around the projected return periods.

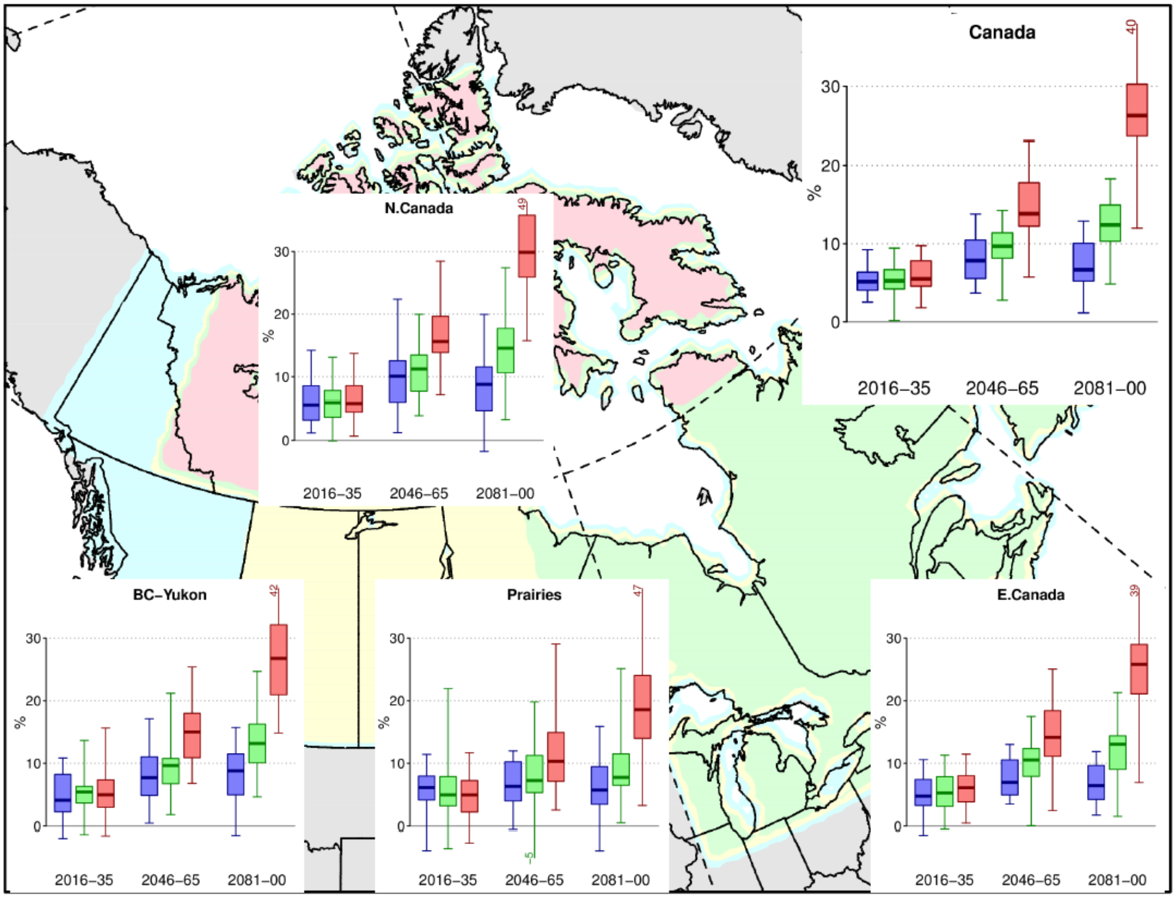


**Figure 12:** Projected changes (in %) in 20-year return values of annual maximum 24-hour precipitation rates (i.e., precipitation extremes). The bar plots show results for regionally-averaged projections for three time horizons: 2016–2035, 2046–2065, and 2081–2100, as compared to the 1986–2005 baseline period. The blue, green, and red bars represent results for RCP2.6, RCP4.5, and RCP8.5, respectively. Projections are based on GCMs contributing to CMIP5 and the analysis is described in Kharin et al., 2013.

### 3.4 Higher resolution

For many applications, climate changes projected by fairly coarse resolution global climate models may suffice. However, there are applications for which much more spatial detail is necessary. This is particularly true for applications in which a secondary model (such as an agricultural crop model or a basin-scale hydrological model) must be driven by climate model output. In such cases, higher-resolution regional downscaling may be required.

There are two general categories of downscaling: *dynamical* downscaling, using a regional climate model; and *statistical* downscaling, using empirical relationships between larger-scale meteorological variables and the local variables of interest. It is beyond the scope of the present document to provide a comprehensive review, and more detail regarding these methods can be found in the literature (see: (Hewitson & Crane, 1996; Murphy, 1999; Wilby & Wigley, 1997; Wilby, et al., 1998; Wilby, et al., 2004; and Schmidli, et al., 2006). However, by way of example, we provide here some results from two Environment Canada resources.

### 3.4.1 Canadian regional climate model

A new regional climate model, CanRCM4, has been developed based on the ‘physics’ used in the Canadian Earth System Model (CanESM2). This model has been used to produce downscaled climate information at 50 km and 25 km resolution for domains covering North America, the Arctic, Africa, and Europe as part of an international downscaling effort. A wide array of daily and monthly output from this model is available here:

http://www.cccma.ec.gc.ca/data/canrcm/CanRCM4/index_cordex.shtml

Figure 13 compares precipitation simulated by CanRCM4 (at 25 km resolution) to that simulated by the Canadian global model, CanESM2. The spatial detail provided by dynamical downscaling is readily apparent.

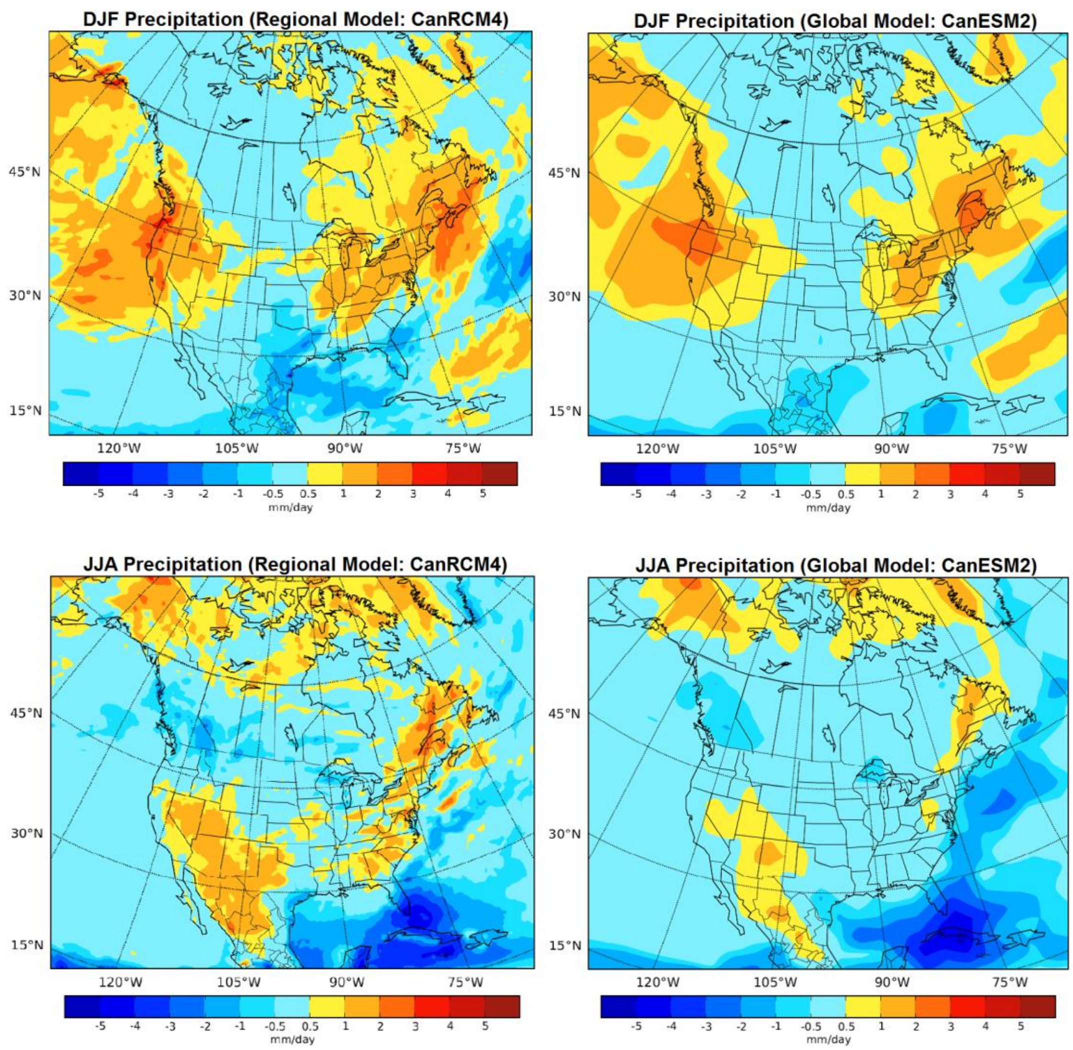


**Figure 13:** Comparison of regional climate model (CanRCM4, left) with global climate model (CanESM2, right) simulation of precipitation for the RCP8.5 forcing scenario. Upper row shows results for December–February, lower row shows results for June–August. The results show a change in precipitation as the difference between the 2096-2100 and the 2006-2010 averages. The spatial detail afforded by the high-resolution (25 km) regional model may be useful for many applications.

### 3.4.2 Statistically downscaled results from CMIP5 models

Statistical downscaling makes use of empirically-derived relationships between large and small scales, and allows for a range of relevant climate quantities to be estimated. An important underlying assumption is that the empirical relationships are unaltered by a changing climate. While this may be a limiting assumption, it is offset to some degree by the fact that these approaches reduce the effect of systematic biases that may be present in global and regional climate models. The reduction of systematic biases is essential for the projection of some extreme indicators that are based on threshold crossing, for example, heating or cooling degree days. Environment Canada has worked with the Pacific Climate Impacts Consortium (PCIC) to develop statistically downscaled climate scenarios based on the CMIP5 global climate projections and regional climate projections (NARCAPP and CorDEX[4]). The projections for Canada are available via the PCIC Data Portal (http://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios). Figure 14 shows the potential utility of statistical downscaling for projecting climate extremes. Projected changes in heating degree-days and cooling degree-days in Canada are shown for three future periods (see figure caption for further details).

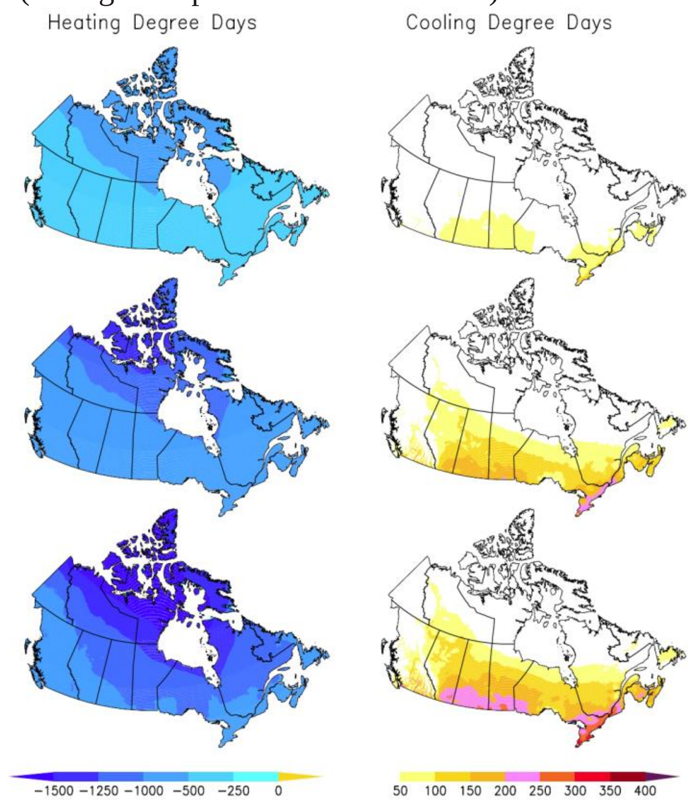


**Figure 14:** Illustration of potential utility of statistically downscaled projections of extremes. Projected changes in cooling (left panel) and heating (right panel) degree days (in degree-days) are shown for the 2016–2035 (top), 2046–2065 (middle), and 2081–2100 (bottom) periods. Projected changes are relative to

[4] NARCCAP is the North American Regional Climate Change Assessment Program: an international project in which various regional climate models are used to produce projections focussed on North America (the contiguous United States, most of Canada, and northern Mexico). CORDEX is the Coordinated Regional Climate Downscaling Experiment: a project of the World Climate Research Programme to coordinate regional downscaling experiments globally.

the 1986–2005 mean estimated from the multi-model ensemble shown in Table 7 and downscaled using BCCAQ.

**Table 7:** Information on the CMIP5 models whose results were used to produce Figure 14.

| Model Name | Place of Origin | Institution |
|---|---|---|
| ACCESS1.0 | Australia | Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology |
| CanESM2 | Canada | Canadian Centre for Climate Modelling and Analysis, Climate Research Division, Environment Canada |
| CCSM4 | USA | National Centre for Atmospheric Research |
| CNRM-CM5 | France | Centre National de Recherches Météorologiques and Centre Européen de Recherche et Formation Avancée en Calcul Scientifique |
| CSIRO-Mk3.6.0 | Australia | Queensland Climate Change Centre of Excellence and Commonwealth Scientific and Industrial Research Organisation |
| GFDL-ESM2G | USA | NOAA Geophysical Fluid Dynamics Laboratory |
| HadGEM2-CC<br>HadGEM2-ES | UK | UK Met Office Hadley Centre (additional realizations contributed by Instituto Nacional de Pesquisas Espaciais, Brazil) |
| INM-CM4 | Russia | Institute for Numerical Mathematics |
| MIROC5 | Japan | University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology |
| MPI-ESM-LR | Germany | Max Planck Institute for Meteorology |
| MRI-CGCM3 | Japan | Meteorological Research Institute |

# 4. Further reading

As stated in the introduction, this document is intended as a reference to illustrate some of the key historical and projected changes in climate in Canada. This report focuses on average temperature and precipitation changes as well as some key weather extremes for Canada. This is not intended as a comprehensive analysis of all climate change indicators, nor is it meant to provide technical guidance on the use of climate change scenarios. More detailed information on climate data, projections, and scenarios for Canada are available at Environment Canada's Canadian Climate Data and Scenarios website: http://www.ccds-dscc.ec.gc.ca/

As was noted in section 1, we would direct readers looking for technical guidance with scenarios to the Ouranos Guidebook (Charron, 2014). Similarly, an in-depth analysis of a variety of climate change indicators, specific to Canada, can be found in the Natural

Resources Canada report, “Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Chapter 2: An Overview of Canada’s Changing Climate” (Bush et al., 2014). Finally, the primary literature referenced throughout this paper collectively forms an excellent resource for more in-depth information on methods, analyses, and context related to the material presented herein. The IPCC Assessment Reports are generally accepted as the most authoritative source on climate change at a global scale. At the time of publication of this document, the Fifth Assessment Report was the most recent of these reports issued by the IPCC.

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Additional information can be obtained at:

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Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800
Email: ec.enviroinfo.ec@canada.ca