Selecting and Using Climate Change Scenarios for British Columbia

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Trevor Q. Murdock
David L. Spittlehouse

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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 see http://pacificclimate.org.

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Executive Summary

The purpose of this report is to assist in the selection of projections of climate change by those who do climate change impact, vulnerability and adaptation analyses. The focus is on British Columbia but much of the content of this report is generally applicable to regional climate change scenarios anywhere, and builds upon the Intergovernmental Panel on Climate Change (IPCC) guidelines for use of scenarios. The report focuses on scenarios from the IPCC Fourth Assessment Report and describes tools for data access that are readily available in BC.

Climate change scenarios should be selected with an understanding of how they will be used. Some applications require an evaluation of the impact of specific emissions trajectories while others might consider the impact of highest and lowest case changes in climate. In sensitivity analysis, selected changes to climate variables are used to illustrate how something of interest (e.g., streamflow) is sensitive to changes in climate variables such as annual temperature or summer precipitation. A time series analysis requires monthly or daily data for a number of years and is particularly useful for an assessment of risk. Examples of using global climate model output to meet each of these tasks are included in this report.

Sources of scenario data as well as visual images of the degree of projected climate change for western North America and regions of British Columbia are described with a focus on the Pacific Climate Impacts Consortium's Regional Analysis Tool[1] and Plan2Adapt[2].

The spatial resolution of global climate model output is often too coarse to provide sufficient local detail on climate. Downscaling tools to address this difference in spatial scales are illustrated. These include empirical tools such as ClimateWNA[3] and BCSD[4], weather generators, and statistical downscaling. Scenarios with future monthly or daily time series and occurrence of extreme events are required for some impact analyses. Sources and methods of generating such data are discussed.

A large number of projections of future climate are available as a result of multiple greenhouse gas emissions scenarios and multiple climate models. A subset is adequate for most studies. Three projections are recommended as a minimal set to use for climate change studies, based on providing a wide range of future climates for much of British Columbia: HadGEM A1B run 1 (hot/dry), CGCM3 A2 run 4 (warm/very wet), and HadCM3 B1 run 1 (cool/wet)[5]. Additional combinations of climate models and emissions scenarios are recommended depending on the purpose of the study.

[1] http://pacificclimate.org/tools-and-data/regional-analysis-tool
[2] http://pacificclimate.org/tools-and-data/plan2adapt
[3] http://climatewna.com and additional projections at http://pacificclimate.org/tools-and-data/climatewna
[4] BCSD is Bias Corrected Spatial Disaggregation (see Section 2.4)
[5] "Had" indicates models from the Hadley Centre, UK, while CGCM3 is the Canadian GCM. The terms A1B, A2 and B1 refer to greenhouse gas emission scenarios, and run indicates one of the simulations done by the model for this scenario.

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1. Introduction

This report addresses a question that is often asked but is much easier to pose than to answer: "which scenarios should I use?" A climate scenario consists of a projected future climate based on a specific greenhouse gas emissions path for this century, calculated by a specific global climate model (GCM). A climate change scenario is based on the difference between the projected future and simulated present-day (baseline) climate. The combination of numerous emissions pathways and GCMs has resulted in the availability of a wide range of climate projections for the future. This report presents the rationale for selecting and using these scenarios for various purposes. In this report we address projections produced for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4; Solomon et al. 2007) and we recognize the need to consider regional variations in projections.

These guidelines and suggestions on the use of regional climate change scenarios were developed to support two major British Columbia climate change initiatives: the Future Forests and Ecosystems Scientific Council (FFESC) research program and the British Columbia Regional Adaptation Collaborative (RAC). Therefore, we focus on British Columbia, though much of the content is applicable to regional climate scenarios outside the province, and builds upon the IPCC guidelines for use of scenarios (Carter 2007). Webinars on how to use scenarios were provided in 2010 by the authors to FFESC and RAC participants. However, it became apparent that because of the many different uses of climate change scenarios there was also a need for a document to provide recommendations for best practices. Some uses of scenarios include community and land use planning and policy development, vulnerability or risk assessments, and the development of adaptation plans. There is also a need for guidance on analytical work using climate change projections as input to climate impacts models.

Climate change scenarios should be selected within the context of how they will be used. For example, is there a desire to evaluate the impact of specific emissions trajectories or is it more important to consider the high and low ends of plausible changes in climate? To ensure that recommendations for scenarios match intended use, five different purposes have been identified. Each is described in Section 3 and recommended scenarios are provided in Section 4. First, a background on the sources of climate scenarios is provided in Section 2.

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2. Obtaining Regional Climate Scenarios

Global Climate Models (GCMs) are the primary source of future climate scenarios. GCM output is either used directly or adjusted to increase spatial resolution using downscaling procedures (Table 1). Data sources developed by or in collaboration with PCIC are shown in Table 2 and are referred to directly throughout the remainder of the report.

Table 1: Tools used at PCIC for producing future regional climate projections. See Appendix B for acronyms, references, and additional sources.

Climate data source type	Tools	Finest readily available time scale	Approximate spatial scale
Global climate models (GCM)	PCIC Regional Analysis Tool	Daily (limited availability)	200–300 km (400,000–900,000 km^2)
GCM → Regional climate models (RCM)	To be added to PCIC Regional Analysis Tool	Daily	10–50 km (100–2,500 km^2)
GCM* → Elevation and bias corrected GCM/RCM projections	ClimateBC, ClimateWNA, Plan2Adapt	Climatological (30-year average) values: annual, seasonal, monthly	1–4 km (1–16 km^2)
GCM* → Station-based downscaling	EDS, TreeGen, SDSM, BCSD, Biosim, LARS-WG	Daily	Point (station)

* Optionally GCMs may be first used to drive RCMs which in turn may be used for further downscaling.

Table 2: Sources of future regional climate projections developed by or in collaboration with PCIC.

Source	Description and link
Plan2Adapt	Climate change projections for BC regional districts: illustrative maps, range of uncertainty plots, summary tables, with guidance for interpretation. http://pacificclimate.org/tools-and-data/plan2adapt
Regional Analysis Tool	The PCIC Regional Analysis Tool can be used to download and visualize all GCM projections prepared for the IPCC second, third, and fourth assessments: define a custom region and get maps, plots, data, and metadata pertaining to it. http://pacificclimate.org/tools-and-data/regional-analysis-tool
ClimateWNA	Computer program to provide selected climate variables for any point in western North America (Wang et al. 2011). http://climatewna.com/

2.1 Global Climate Models

Many GCM projections have been produced by climate modelling centers for the IPCC assessments (see Table 3 in Section 4). This document focuses on those prepared for AR4 (Solomon et al. 2007), from CMIP3: the third Coupled Model Intercomparison Project (Meehl et al. 2007). These projections incorporate model improvements over those used for the Third Assessment Report, but follow the same scenarios of greenhouse gas emissions: the SRES scenarios (Carter 2007; Nakicenovic et al. 2000). The range of projected changes in climate from the Fourth Assessment Report is similar to that from the Third Assessment Report and scenarios from the latter can still be used. However, preference is given to the more recent set. The Fifth Assessment Report scenarios (CMIP5) are now being produced using a new set of emissions scenarios, representative concentration pathways (RCPs), which are starting to become available (Moss et al. 2010). These projections for AR5, based on RCP scenarios, will gradually replace the CMIP3 projections for AR4, based on SRES scenarios. Recommendations for the use of AR5 scenarios will require additional analysis, but it is expected that the general principles outlined in this report will still apply.

The models in CMIP3 are known as coupled atmosphere-ocean general circulation models (AOGCMs). These models simulate physical processes of atmospheric and ocean circulation and produce a range of weather and climate variables for grid sizes between about 1.4° to 4.0° (at mid-latitudes this means typical grid cell areas of 15,000 km^2 to 160,000 km^2). A general assessment of CMIP3 results over British Columbia can be found in Rodenhuis et al. (2009). The data represent area averages; their values are not necessarily representative of specific locations within the grid box. Consequently, it is recommended that analyses that use GCM projections be based on anomalies (i.e., differences between the projection for a future period and of the historical baseline period, typically 1961-1990). The most commonly used future time periods are the 2020s (2011-2040), the 2050s (2041-2070), and the 2080s (2071-2100). In the case of temperature, the anomaly is a difference between current and future conditions; for precipitation, a percentage change is commonly used. The anomalies are applied to the baseline climate of the location of interest to give values for the future climate. This is similar to the approach used by some downscaling methods (Section 2.3). Other baselines and time slices are also in use such as 1971-2000, 1980-1999, 1981-2000, 2031-2060, and 2080-2099.

2.2 Earth-System Models of Intermediate Complexity

Global earth-system models of intermediate complexity (EMICs) take less time and computing resources to run than AOGCMs. EMICs are often used to simulate longer time frames (multiple centuries into the future) or answer different policy questions. One EMIC (Weaver et al. 2007) has been used to explore climate change in British Columbia for emissions scenarios that are higher or lower than the standard SRES scenarios explored by AOGCMs (Section 3.2). As with AOGCMs, the data are average values for a large area and should be used as anomalies from a baseline climate.

2.3 Regional Climate Models

Regional climate models (RCMs) are used to dynamically downscale GCM results to a finer spatial resolution for specific areas of the world. For example the North American Regional Climate Change Assessment Program (NARCCAP) resolution is 50 km x 50 km, or 2,500 km^2. RCMs have an advantage over GCMs due to their higher resolution but, like GCMs, they represent each grid box as a regional average rather than a point quantity. RCM projections from Ouranos and the NARCCAP (see Appendix B) are used at PCIC (Sections 4.1 and 4.5). Although the grid size for RCMs is smaller than for AOGCMs, the data still represent average values for a relatively large area and also inherit biases from coarse-scale driving GCMs. For this reason, RCM projections are also best applied as anomalies from a baseline climate.

2.4 Elevation-Corrected Projections and Statistical Downscaling

As noted above, climate model output is often too spatially coarse to provide sufficient local detail. Resolution can be increased (and biases in simulating the past climate corrected) by applying statistical or empirical downscaling. Some of the downscaling tools used in BC are described briefly below.

ClimateWNA (Wang et al. 2011) is a stand-alone software package that provides monthly historic and climate change data for western North America, downscaled to any scale or to points through a combination of bilinear interpolation, elevation adjustment, and application of the PRISM high-resolution 1961-1990 baseline climatology. Originally called ClimateBC and covering a smaller area (Wang et al. 2006), the program can be used to produce gridded data for mapping and other applications. It comes with a range of climate change projections and more are available for download (http://pacificclimate.org/tools-and-data/climatewna). Although convenient, it has limitations. It is dependent on the accuracy of its baseline climatology and although it performs well in simulating the historic climate for areas with climate data, there is no way to assess accuracy for areas that lack station coverage (Wang et al. 2011; Jarosch et al. 2010).

PCIC has used the Bias Corrected Spatial Disaggregation downscaling technique and applied it to all of BC at a spatial resolution of 1/16° and daily temporal resolution for a set of 23 scenarios (see Section 4.5; Werner, 2011). The dataset includes daytime high and nighttime low temperatures, precipitation, and wind speed for the period 1950 to 2098. The primary application so far has been analysis of hydrological impacts (Schnorbus et al. 2011). The data are currently available directly from PCIC by special request only but will be available in future on a PCIC data portal in development.

Weather generators statistically simulate monthly or daily time series of weather data at a point. The statistical information (probability distributions, means etc.) can be adjusted based on changes in mean conditions indicated by GCMs and used to create a time series of weather data under a changing climate (Semenov 2007; Semenov 2008). Methods for interpolating to create climate surfaces have been developed. PCIC is investigating the application in British Columbia of the LarsWG5 weather generator (Semenov and Stratonovitch 2010).

Statistical downscaling starts with an analysis of present climatic conditions for an area, as represented by large-scale and local observations (e.g., station data). From this analysis a statistical "model" is derived that relates large-scale information (predictors) to the local scales (predictands) (Maurer et al. 2007; Bürger et al. 2009). The derivation of such a model requires the identification of empirical relationships between large scale and local climate variables, and the estimation of fitting parameters, means and variables from historical data. Statistical downscaling thus cannot be performed in the absence of this historical data because it is needed for training (calibration).

A statistical downscaling intercomparison project for British Columbia is currently underway for specific locations across the province using several of the techniques listed in Appendix B. The approach follows that of the European Stardex project (http://www.cru.eua.ac.uk/projects/stardex/) in that indices of extremes are produced.

The accuracy of downscaled climate change projections cannot be directly evaluated. It is possible that climate change may fundamentally alter local weather patterns at small scales (Fyfe and Flato 1999; Fowler et al. 2007; Daly et al. 2009), thus questioning the assumption that the predictor-predictand relationships of the various downscaling methods remain valid. The climate produced by these downscaling methods is that for a standard weather station (e.g., temperature at 1.5 m height in open areas) or for gridded area averages, depending upon the type of observational dataset used to train the downscaling scheme. Consequently, the microclimate driven by small-scale topography such as aspect, slope, frost pockets, and geographic features such as rivers and lakes are not captured directly.

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3. Uses of Regional Scenarios

To help select scenarios within the context of how they will be used, we have defined five common uses of regional climate change scenarios. The five categories defined here are based on our experiences working with many different applications:

1. *illustrative* purposes
2. *sensitivity* analysis
3. differences between *emissions* scenarios
4. *range* of regional change
5. *time series and extremes*

There is some overlap between these five uses of regional scenarios and there are certainly different ways to categorize them. However, it is important to understand the distinctions we have made, as described in detail in Sections 3.1 through 3.5, because the set of recommended scenarios differs between types (Sections 4.1 through 4.5). Following the detailed descriptions below, a summary and visual depiction of the five types is given in Section 3.6 as a reference for readers.

In addition to becoming familiar with the distinctions between the five uses of scenarios defined below, there are several other considerations to address before selecting scenarios:

- What is the location or region of interest? (e.g., Prince George, Columbia Basin)
- What is the purpose for considering climate projections? (e.g., water supply, tree species suitability, storm water management)
- What climate variables[6] are of interest? (e.g., summer daytime high temperature, spring snowpack)
- What spatial resolution is required? Is high resolution necessary or is a coarser scale adequate?
- What temporal resolution is required? (e.g., climatological 30-year annual/seasonal/monthly averages, monthly time series, daily time series)
- What is the time period of interest? (e.g., 2050s, 2080s)
- What output format is required for the climate projections? (e.g., descriptive, maps, plots, data)
- How much access do you have to sources of projections and what is your capacity for analysis?

Ultimately, users of regional climate change scenarios will need to be prepared to repeat the process of scenario selection, the assessment of potential impacts or sensitivities, and the analysis of adaptation options several times. This is because learning about future climate change and the different ways in which impacts and adaptation options may present themselves, is an iterative process. The questions that you pose to yourself, and the scenarios that you consequently use, will change as you learn.

[6] Although most studies focus on changes in temperature and precipitation, a wide range of variables such as solar radiation, wind speed and humidity are available for most climate projections described in this report. Data are available as monthly normals, monthly time series or daily time series (Section 3.5), though not necessarily for all projections.

3.1 Illustrative Use

A visual image of future climates is often adequate to set the context for adaptation planning and vulnerability assessment. In this case, the purpose is to assist in framing a discussion around vulnerability or adaptation, and to make the impacts of projected climate change more tangible to participants. Figure 1 shows an example from PCIC's Plan2Adapt online tool. One scenario from one GCM is shown compared to current climatology. Elevation-corrected scenarios from ClimateBC or ClimateWNA have also been used extensively for regions larger than the regional districts available in Plan2Adapt, and for custom variables of interest in certain regions that are not included in Plan2Adapt (Dawson et al. 2008; Lane et al. 2011; Murdock et al. 2007; Picketts et al. 2009; Pike et al. 2010; Rodenhuis et al. 2009; Werner et al. 2009; Werner and Murdock 2008). Figure 2 shows an example for all of BC.

The resolution of the maps shown in Figures 1 and 2 results from the 'draping' of low resolution climate projections over high resolution interpolated climatology and does not imply high accuracy. It is important to note the range of uncertainty in climate projections when only showing a single illustrative projection of the future. The bar plot to the right of the maps in Figure 1 shows how this specific projection compares with an ensemble of 30 projections ("SRES AR4-PCIC A2+B1" – see Section 4.3), and the evolution of this range over the 21st century is shown in Figure 3. This figure displays the median of the ensemble of 30 projections as a black line, the mid-range from the ensemble (25th to 75th percentile) as dark grey and the near-full range (10th to 90th percentile) in light grey. The projected change for the region from the GCM used in Figure 1 (2.4°C) falls within the range of the 25th to 75th percentile of projections (1.2°C to 2.8°C). The median shows the mid-point of the range of projections. Note, the median is not necessarily the "best estimate" and this plot does not show a formal probabilistic analysis.

When using maps and range (or box) plots to give a general description of climate change for a region, it is also useful to provide a general overview of the projections shown in the figures. For example, the following is a general overview of projected climate change for BC in the middle of the century (2050s) based on maps such as those in Figures 1 and 2 and range/box plots such as those in Figures 3 and 5:

- Mean annual temperature increases of 1°C to 3°C
- Winter minimum (nighttime low) temperature increases of 1°C to 4°C
- Summer maximum (daytime high) temperature increases of 1°C to 3°C
- Winter precipitation increases of up to 20% across most of BC
- Summer precipitation increases of up to 10% in Northern BC and decreases of up to 15% in southern BC

In many cases it will be useful to accompany such illustrative projections with summary information on extremes, provided that the scenarios were constructed with a technique that yields information on extremes. A preliminary analysis following on from Bürger et al. (2011) for several locations around BC using RCMs and statistical downscaling indicates an increase in warm temperature extremes and wet precipitation extremes consistent with projections for North America as a whole (Kharin et al. 2007; Tebaldi et al. 2006; IPCC 2011). Changes in temperature extremes tend to follow the trend in mean temperatures with the result that current extreme warm events will occur more frequently and cold events less so. Precipitation changes are also expected to result in an increase both in the intensity of extreme precipitation across BC and an increase in the length of the dry season in southern BC.

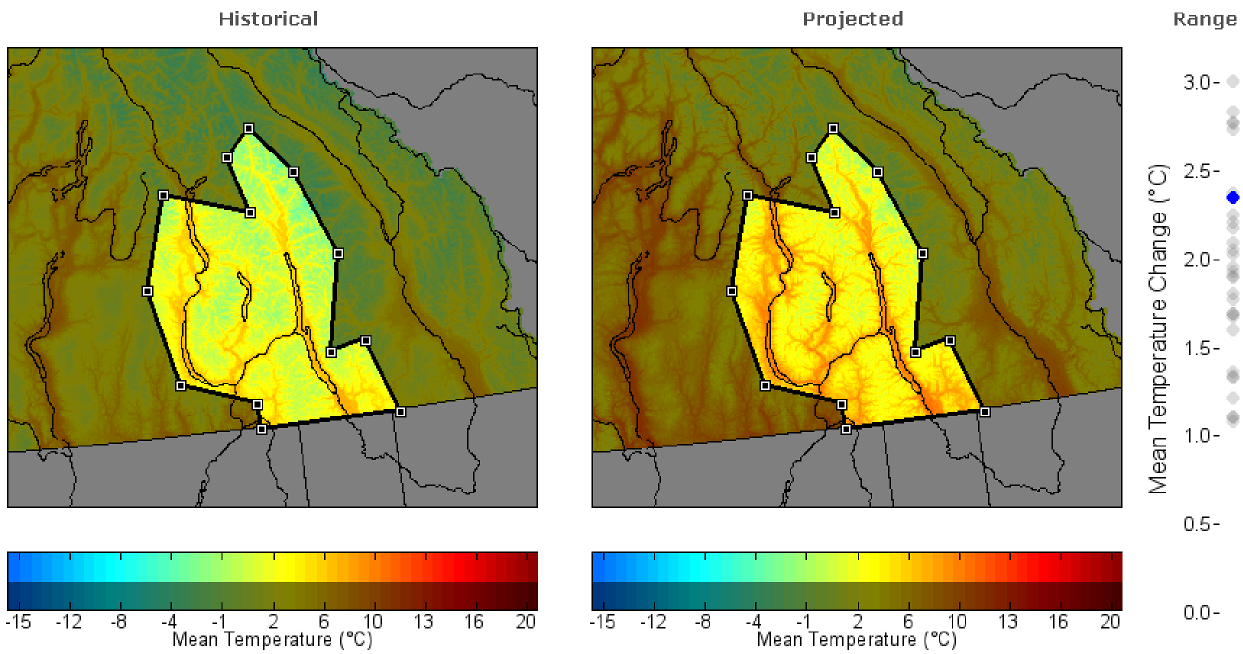

Figure 1: Maps of historical (left) and projected 2050s (right) winter temperature for the Central Kootenay regional district. The projection is for the Canadian CGCM3 model run 1 following the A2 emissions scenario. The blue dot on the right shows how this projection compares to the wide range of projections from other models and emissions scenarios. Source: www.Plan2Adapt.ca accessed 27 June 2011.

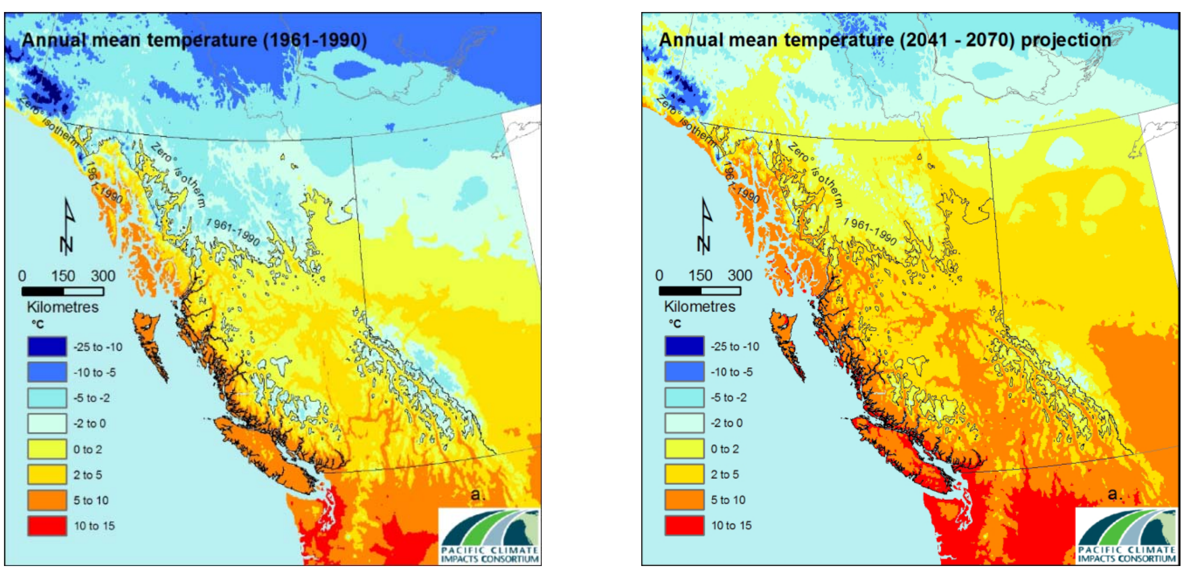

Figure 2: Annual temperature for 1961-1990 baseline (left) and 2050s (right) for BC. Future projection is CGCM3 A2 run 4. Source: PCIC, using ClimateWNA and CMIP3 data.

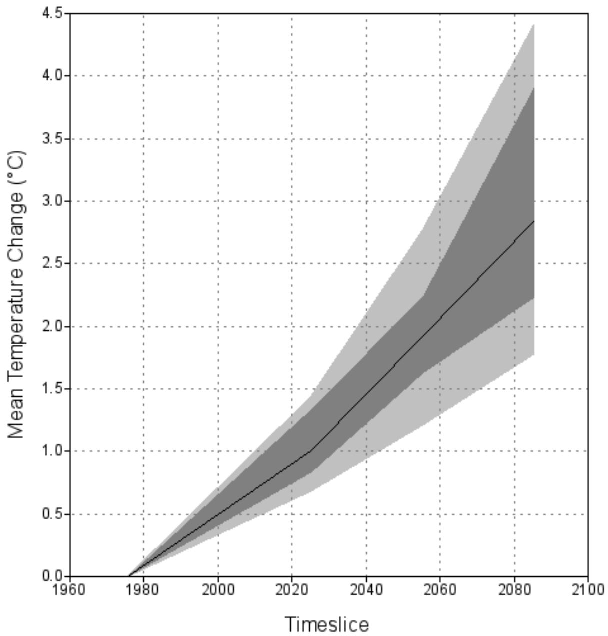

Figure 3: Range of winter temperature change from the same ensemble used for the bar to the right of Figure 1. The lines show the change for 2020s, 2050s, and 2080s periods based on the ensemble: black line is the median, dark grey indicates 25th to 75th percentile (middle half of projections), and the light grey the 10th to 90th percentiles. Source: www.Plan2Adapt.ca accessed 27 June 2011.

3.2 Dependence of Climate Change on Emissions

Planning for climate change at the local and regional scales often blurs the line between adaptation and mitigation. Thus, in some cases, it becomes important to show the difference in impact between higher and lower emissions futures. Examples of how the different climates resulting from high and low emissions trajectories might impact tree species suitability in BC are presented in Flower et al. (2011) and Locatelli et al. (2010).

Scenarios of greenhouse gas emissions over the 21st century are based on assumptions about possible future economic growth, population change, technology, and societal development. The SRES scenarios, used for the third and fourth IPCC assessment reports (IPCC 2001; IPCC 2007) were developed by the IPCC through a Special Report on Emissions Scenarios, and consist of four storylines (Nakicenovic et al. 2000). The A1 storyline describes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The A2 storyline describes a heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The B1 and B2 family of scenarios parallel the A1 and A2 scenarios but the emphasis is on global solutions to economic, social and environmental sustainability, environmental protection and social equity. GCM climate projections (Section 2.1) produced for AR4 are available mainly for the B1, A1B, and A2 emissions scenarios.

Replacements for the SRES emissions scenarios, called representative concentration pathways (RCPs), have been developed for the next IPCC assessment (Moss et al. 2010). These new greenhouse gas scenarios specify concentrations rather than emissions because of the ability of the newest generation of GCMs to include climate-carbon feedbacks. The range of equivalent emissions covered by the set of RCPs is similar to the range covered by SRES, except on the lower end where RCP2.6 represents aggressive greenhouse gas emissions reductions.

None of the SRES emissions scenarios include intentional societal reductions to greenhouse gas emissions, such as might be expected to occur under a successfully implemented international treaty. Hypothetically, success of global treaties could result in greenhouse gas concentrations lower than B1. It is even possible that climate change could stabilize if greenhouse gas emissions cease (Matthews and Weaver 2010). However, recent emissions appear to have been larger than any of the IPCC emissions scenarios (Le Quere et al. 2009). For these reasons, it is recommended that climate projections based on SRES scenarios be considered a reasonable range for impacts and adaptation analyses and the possibility of higher or lower concentrations than those based on SRES emissions should be kept in mind. For example, projections for British Columbia from an EMIC (Pike et al. 2010; Weaver et al. 2007) show considerable climate change even when emissions are reduced by 2050 to 50% or even 100% below 2006 levels and then held constant, as in Figure 4. This model has a magnitude of climate change for BC similar to that of the median from an ensemble of all 140 projections from 22 GCMs for AR4.

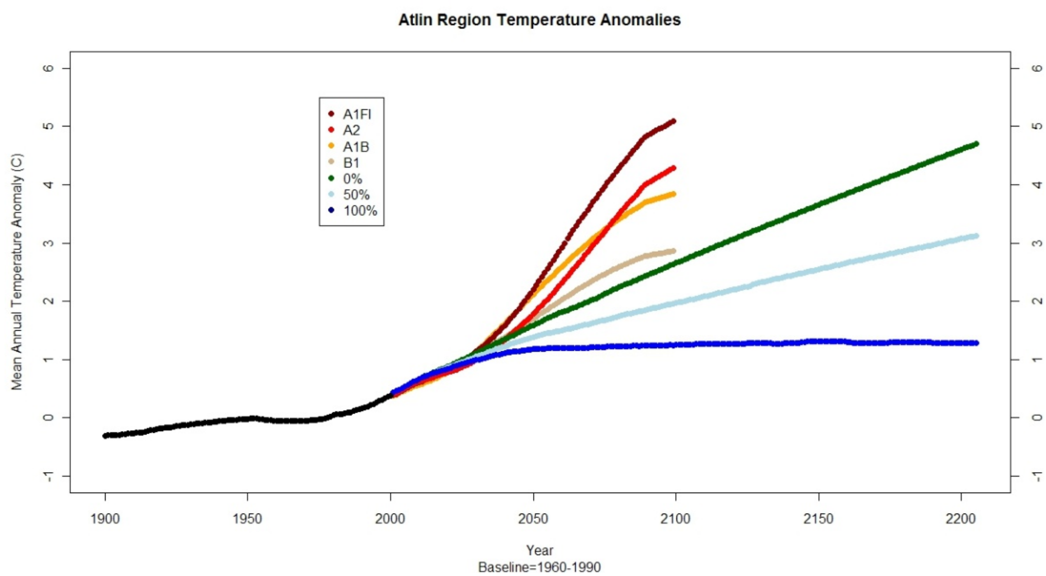

Figure 4: UVic Earth System Climate Model projected change for the Atlin region in Northwest BC for the three standard SRES scenarios, as well as a higher emissions scenario (A1FI), and three lower emissions scenarios (0% - no reduction and future emissions constant at 2006 levels, 50% - linear reduction to 50% below 2006 emissions by 2050 and constant afterwards, 100% - linear reduction to zero emissions by 2050 and no emissions afterwards). Source: Pacific Climate Impacts Consortium – using the UVic ESCM (see also Pike et al. 2010).

3.3 Range of Regional Change

Although it is generally desirable to use as many scenarios as possible to quantify uncertainty, it is not always practical—there were about 140 for CMIP3 (used for AR4). For most purposes, including a range of plausible changes in climate is more important than selecting certain models or certain emissions scenarios. When the focus is on selecting a subset of scenarios that still contain most of the range of conditions projected by the full set of scenarios, individual projections should primarily be viewed as providing spatially and temporally consistent sets of future climate change.

It is important to check the actual range of expected climate change for the region and seasons of interest. One way to do this is through box plots and scatter plots of changes in precipitation and temperature (and other variables) for specific seasons of interest. An example is shown in Figure 5 for winter conditions in the Central Kootenay region obtained from the PCIC Regional Analysis Tool. The left panel shows that projected winter temperature change is positive (warming) in all cases with increasing magnitude and range throughout the 21st century. The right panel shows projected change in temperature vs. projected change in precipitation for the winter season by the 2050s for the Central Kootenay region. There appears to be a relationship in this area between the amount of warming and the amount of precipitation change that is projected (note that such a relationship, while not seen universally in all regions, is also seen when considering projections of change in the global mean). Also, although the majority of models project modest increased winter precipitation, some project decreases and a few project large increases.

Geographical patterns of individual projections can also be investigated with maps. For example, Figure 6 shows projected total summer precipitation change for two models with quite different projections over much of BC for the same emissions scenario. The blocky nature of the figures indicates the size of the grid boxes. The large difference in projected precipitation produced by two GCMs indicates the large uncertainty in future climate at the local scale.

One reason that is often given for avoiding the use of more than a few scenarios is the difficulty in visually presenting information for a larger number of them. In other words, if a dozen different maps of future conditions are produced, how is the viewer meant to take in all the differences? One solution is to create a map of the percent agreement in projected climate change or impacts across the projections. This gives a much more coherent picture than for example 10 individual maps. This approach has been taken for global precipitation (Figure 11.12 in Christensen et al. 2007) and for assessing climate change impacts on Douglas fir and spruce suitability in BC (Flower et al. 2011; Locatelli et al. 2010).

3.4 Sensitivity Analysis

In some cases, it is less important that projected changes in different variables are physically and temporally consistent, and more important to investigate the sensitivity of an impact to specified changes in one or more variables at a time. In this case, it is important to ensure that the projected changes correspond to (or at least include) amounts of change projected by climate models for the region, season, and variables in question.

An example of a sensitivity analysis is shown in Figure 7. A snow accumulation and melt model (Spittlehouse and Winkler 2004) was used to determine the evolution of the snowpack under a forest for a high elevation site in the southern interior of BC. The model was run for each of 19 years of historic weather data and then with the daily temperature increased by 2°C and then by 4°C. Other variables such as solar radiation and precipitation were kept constant at their historic values. Under current conditions the length of the snow season (continuous snowpack) averaged 209 days but varied from 172 days in a warm winter to over 236 days in a cold snowy winter. (This agreed well with measured data, RMSE=5 d, R^2=0.898). Warming by 2°C reduced the length of the continuous snowpack season by about 20 days, mainly at the end of the season. A 4°C warming affected both ends of the snow season, resulting in it averaging 60 days shorter than at present. Increasing precipitation by 10% (not shown) resulted in only a minor increase in the length of the snow season.

Recommended changes in temperature and winter and summer precipitation (Section 4.4) for sensitivity analyses were chosen by investigating the range of change projected by many models around most of BC in the same way as in the preceding section, using the PCIC Regional Analysis Tool. Changes used for sensitivity analysis have the benefit of not being tied to a specific climate model, emissions scenario or time frame but they do not necessarily match the climate produced by any one specific scenario because variables are adjusted in a manner that is not necessarily physically consistent and other variables are left constant at historic values. More than one variable can be adjusted to assess interactions.

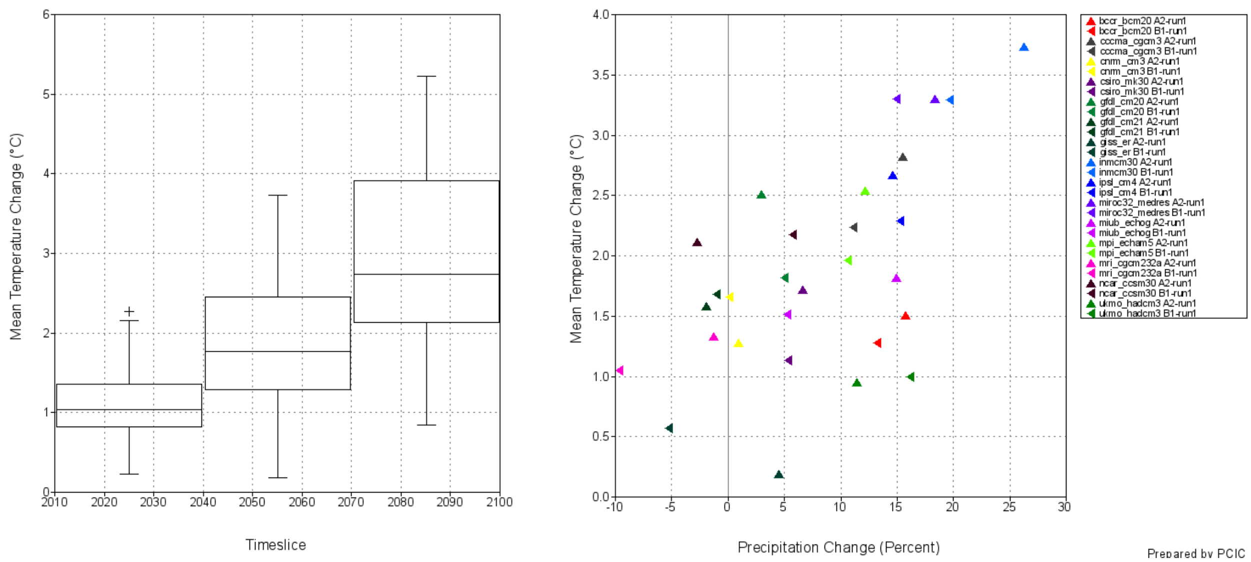

Figure 5: PCIC Regional Analysis Tool plots for the Central Kootenay region of BC: box plot of winter temperature change (left), and scatter plot of 2050s winter temperature change vs. precipitation change (right). Source: PCIC Regional Analysis Tool accessed 27 June 2011.

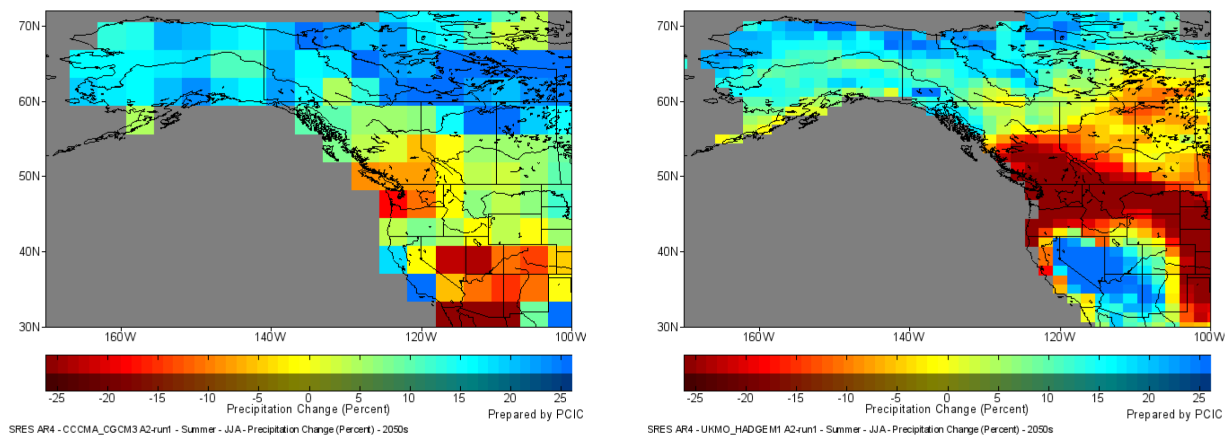

Figure 6: Projected change in summer (June, July, August) precipitation for the A2 scenario (run 1 in both cases) for the 2050s from the Canadian model CGCM3 (left) and the United Kingdom model HADGEM1 (right). Source: PCIC Regional Analysis Tool accessed 27 June 2011.

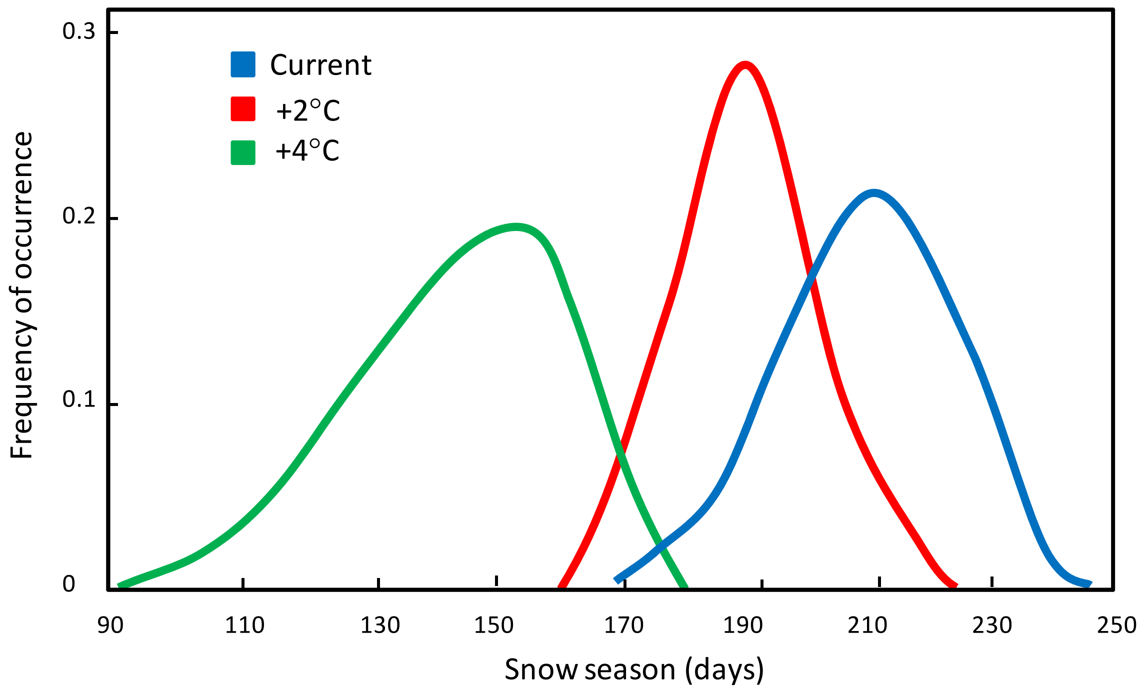

Figure 7: Sensitivity analysis of the influence of increasing winter temperature on the length of snow season under a lodgepole pine forest at Upper Penticton Creek under current conditions (blue) and 2°C (red) and 4°C warming of winter temperature. Measured data (not shown) follow the blue line. Source: (Pike et al. 2010).

3.5 Monthly and Daily Time Series

Scenarios with future monthly or daily data are required for some impact analyses (e.g., forest growth, river flow, fire risk). Until recently, only a relatively small number of modelling centres provided access to simulated daily values (see Section 4.5), although all GCMs simulate daily and sub-daily variability. Using daily GCM data requires some form of spatial downscaling that makes use of the coarse spatial scale projections and relationships between coarse and local scale (see list in Appendix B). Figure 8 shows the projected Peace River flow under current and future climate for the 2050s (Schnorbus et al. 2011). Daily output from eight GCMs was downscaled with Bias Corrected Spatial Disaggregation (BCSD) and used to drive a semi-distributed hydrologic model applied to the Peace River Basin (Werner 2011). Although there is variability in predicted flow between models, most show a shift to earlier and larger peak flow as well as decreased low flow.

Synthetic future daily time series can also be created using computationally inexpensive methods. One approach is to use a weather generator to statistically simulate historic monthly or daily time series. The statistical information (probability distributions, means, etc.) can then be adjusted based on changes projected by GCMs and used to create (multiple) plausible projected future time series under a changing climate (Semenov 2007; Semenov 2008).

Another approach is similar to that described in the previous section for sensitivity analysis but uses the climate change projected by various scenarios directly (Spittlehouse 2003). Historic data are used to generate a trend in the anomalies from the mean climate of the historic period. The anomalies are then added to the trend in the mean of a climate projection. This approach is even simpler than using a weather generator because only the mean changes while the variability around the mean and the temporal pattern stays the same as in the past. Although there are obviously limitations with this approach it does provide a way to get a first approximation of the sensitivity to change.

Finally, methods that rely on the existence of statistical relationships between large scale aspects of climate variability that are well simulated by climate models and the local scale that is of interest for impacts and adaptation research, may require observations and simulated values of climate parameters beyond those being downscaled such as surface pressure, 500 mb geopotential height, and upper level winds. Examples of such methods include Expanded Downscaling (Bürger 1996; Burger et al. 2009), TreeGen (Stahl et al. 2008), and Automated Statistical Downscaling (Hessami et al. 2008; Wilby et al. 2002) These data requirements have until recently reduced the ability to choose from the full set of available climate change projections.

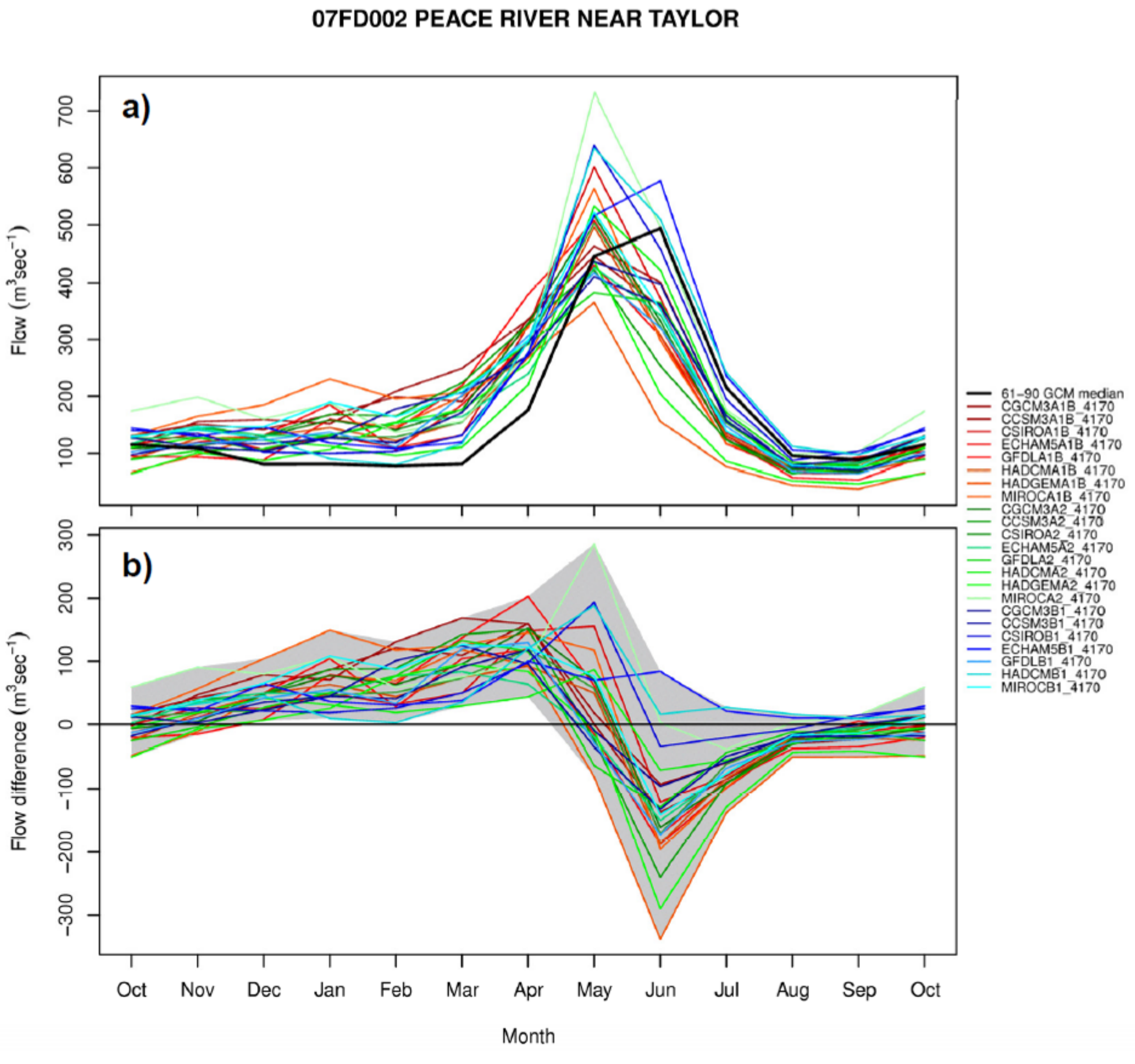

Figure 8: Median monthly discharge for the Peace River at Taylor showing: a) historic (1961 to 1990) and future (2041 to 2070) discharge, and b) the 2050s anomaly. Historic discharge (black line) is presented as the full ensemble median (23 runs x 30 years) and each future discharge value is the median of each GCM run (1 run x 30 years). Anomalies represent the future monthly median minus the historic ensemble monthly median. (Source: Schnorbus et al. 2011).

3.6 Summary

The five uses of scenarios described in detail in Sections 3.1 through 3.5 are summarized below and in Figure 9.

1. *illustrative* purposes

   If scenarios are being selected for use in a report or a vulnerability or risk assessment workshop where the role is to provide context, then a small number of *illustrative* scenarios accompanied by some indication of the range from a larger ensemble is likely adequate.

2. *sensitivity* analysis

   For a more technical application, such as addressing specific impacts in a particular sector like hydrology or forestry, illustrative scenarios may be useful but probably insufficient. If the potential response of a particular impact to different amounts of climate change is being explored, consider *sensitivity* analysis. This may be an alternative to scenario uses 3, 4, and 5 or as a complement to them. Although not necessarily tied directly to GCM projections, the magnitude of change for sensitivity analysis can be guided by the range of regional change projected by models.

3. differences between *emissions* scenarios

   If sensitivity analysis is not sufficient (on its own), the next distinguishing factor is whether or not to treat the effect of different *emissions* scenarios separately. For cases where both adaptation and mitigation are of interest explicitly and the time frame being considered is the end of the 21st century (e.g., 2080s) or later, ensembles that allow for consideration of change according to different emissions scenarios separately are recommended.

4. *range* of regional change

   For cases where the focus is primarily adaptation or the time frame of interest is 2050s or earlier, then the *range* of projected change with projections from different emissions scenarios combined is probably more relevant. This is the case even for impacts that require high temporal resolution (e.g., daily time series) as long as (bias-corrected) projected changes in climatological means can be applied to historical time series.

5. *time series and extremes*

   In some cases that require future projected change in (sub-)daily *time series* because, for example, changes in the timing and/or distribution of events are important, some additional considerations are required, such as the constraints of data availability. This may be important in cases involving further process-based modelling, further downscaling, assessment of GCM skill, and/or projections of future change in indices of climate *extremes*.

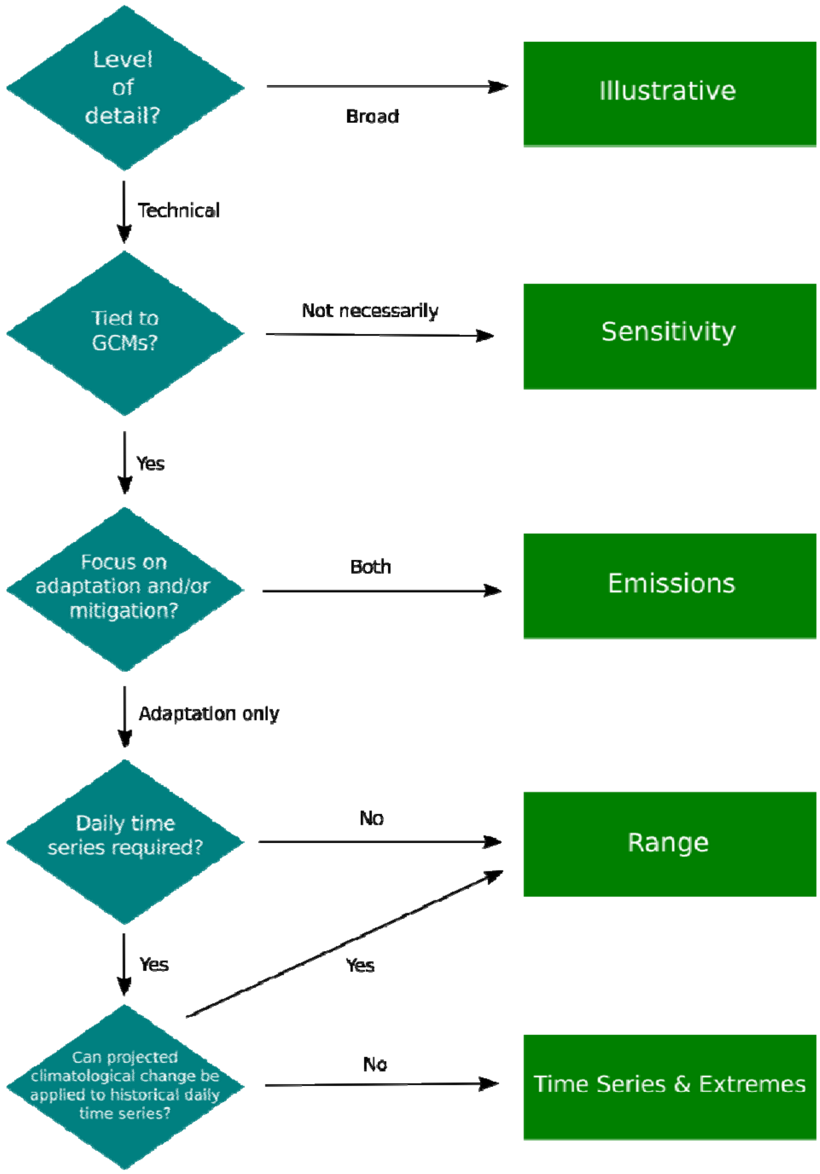

Figure 9: An illustration of the five uses of regional scenarios. The series of questions at the left can be used to help determine the corresponding use in green boxes at right. This figure is intended to summarize the five scenario uses only – please see Sections 3.1 through 3.5 for full descriptions and Sections 4.1 through 4.5 for corresponding recommended scenarios.

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4. Recommended Scenarios

Descriptions of the sources of climate scenarios have been provided (Section 2) and the different types of uses of scenarios have been defined (Section 3). With that background, lists of recommended scenarios are provided in this section. Each sub-section follows the five types of scenarios defined in Section 3 and illustrated in Figure 9. Projections from each CMIP3 model in Table 3 are considered for inclusion in the sets of recommended scenarios that follow. Most of the tables of recommended scenarios use only the second part of the IPCC ID (the GCM abbreviation) although some use the full ID (GCM preceded by the institution abbreviation).

Some brief comments on the rationale behind the selections are provided preceding each table of recommended scenarios. Two considerations that apply in general include differences between emissions scenarios and climate models.

Differences between projections from the same model that result from different greenhouse gas emissions scenarios are relatively small until the middle of the century, after which they become considerable (Pike et al. 2010; Rodenhuis et al. 2009).

Even when run for the same emissions scenario, climate projections differ between models in part because they simulate different, but statistically equivalent, sequences of weather when started from different initial conditions, demonstrating the effect of chaotic variability that is present in the real climate system (Barnett et al. 2000; Lorenz 1965). When this internal variability is accounted for, different GCMs can still project different scenarios of climate change due mainly to differences in which components are included and in parameterizations of processes that are not included directly, or occur at scales too fine to be resolved directly (Barnett et al. 2000).

To narrow down which of the numerous GCMs to use, performance measures have been devised (Gleckler et al. 2008; Moore et al. 2010; Mote and Salathe 2009; Werner 2011). These can be used to choose or assign weights to GCMs but doing so requires careful consideration (Tebaldi, pers. comm.). Furthermore, if GCM projections are viewed as spatially and temporally consistent sets of plausible future climate conditions, there is no need to favour some over others.

All recommended scenarios have been checked to ensure that they are at least not consistently poor across a wide range of metrics, seasons, and variables for northern hemisphere mid-latitudes and for western North America in particular (Gleckler et al. 2008; Werner 2011). However, only Section 4.5 considers model performance explicitly. In other cases, other factors have been given greater importance.

Table 3: Global climate models in CMIP3.

IPCC ID	Center and Location
BCCR-BCM2.0	Bjerknes Centre for Climate Research (Norway)
CCCMA-CGCM3.1 (T47 or T63)	Canadian Centre for Climate Modelling and Analysis (Canada)
CSIRO-Mk3.0	CSIRO Atmospheric Research (Australia)
CNRM-CM3	Meteo-France, Centre National de Recherches Meteorologiques (France)
MIUB-ECHO-G	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group (Germany and Korea)
GFDL-CM2.0	US Dept. of Commerce, NOAA Geophysical Fluid Dynamics Laboratory (USA)
GISS-AOM	NASA/Goddard Institute for Space Studies (USA)
FGOALS-g1.0	LASG/Institute of Atmospheric Physics (China)
INM-CM3.0	Institute for Numerical Mathematics (Russia)
IPSL-CM4	Institut Pierre Simon Laplace (France)
MIROC3.2 (medres or hires)	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (Japan)
MRI-CGCM2.3.2	Meteorological Research Institute (Japan)
MPI-ECHAM5	Max Planck Institute for Meteorology (Germany)
NCAR-CCSM3	National Center for Atmospheric Research (USA)
NCAR-PCM	
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research, Met Office (UK)
UKMO-HadGEM1	

4.1 Illustrative Use

For illustrative purposes, it is sufficient to consider only a few projections, such as those listed in Table 4a. It is useful to check where these models fit within a wider range of projections as illustrated in Figures 1 and 2 in Section 3.1. If only one scenario is used, CGCM3 A2 is recommended, run 4 in particular, because it has been most widely used in BC and will thus be the most comparable to other work. Any run of CGCM3 A2 could be substituted if more readily available (run 1 is the next most widely used), because differences between runs are normally smaller than between different models.

Table 4a: Recommended GCM projections for illustrative purposes and projected 2050s change in British Columbia.

Model	Emissions	Run	2050s change (BC average)	
			Annual Temperature (°C)	Annual Precipitation (%)
CGCM3	A2	4	2.7	14
HadCM3	B1	1	1.7	6
HadGEM	A1B	1	3.7	0

The projected climate change from one or more of these GCM runs will normally be used with some form of downscaling, typically including elevation adjustment methods as well as an estimate of the range of change projected by a wider ensemble (Section 4.3). RCMs may also be used for illustrative purposes. Only one RCM projection is recommended (Table 4b) because it has been the most widely used in BC to date (e.g., Murdock and Flower 2009; Rodenhuis et al. 2009), and is thus reasonably well understood. Also, it is driven by one of the three recommended GCM runs in Table 4a. If a different RCM projection is used, it is important to place results in the context of the driving GCM projection and of a larger ensemble of GCM projections such as the range of projections from NARCCAP.

Table 4b: Recommended RCM projection for illustrative purposes and projected 2050s change in British Columbia.

Model	Driving GCM projection	2050s change (BC average)	
		Annual Temperature (°C)	Annual Precipitation (%)
CRCM4*	CGCM3 A2 run 4	2.6	13

4.2 Dependence of Climate Change on Emissions

If the end of the 21st century is of interest, then it is important to compare differences between emissions scenarios. The recommendation is to compare B1 to A2 for the following six models (Table 5). Most available RCM simulations, including NARCCAP simulations, follow the A2 emissions scenario and provide projections for the 2050s only. Thus, RCMs have not been widely used to explore differences between emissions scenarios in North America.

Table 5: Recommended GCM projections for investigating differences between emissions scenarios and projected 2050s and 2080s change for British Columbia.

Model	2050s change (BC average)				2080s change (BC average)			
	Annual Temperature (°C) run 1		Annual Precipitation (%) run 1		Annual Temperature (°C) run 1		Annual Precipitation (%) run 1	
	B1	A2	B1	A2	B1	A2	B1	A2
CGCM3	1.8	2.4	8	12	2.5	4.0	13	22
HadCM3	1.7	1.9	6	3	2.5	3.7	8	9
GFDLCM21	1.9	2.0	7	2	2.1	3.9	7	6
ECHAM5	1.4	1.8	10	10	2.8	4.0	11	16
NCARCCSM30	1.9	2.6	8	9	2.3	4.7	6	12
CSIROMK30	1.4	1.9	5	6	1.7	3.3	7	12

* Projected change is shown for Canadian Regional Climate Model version 4.1.1 operated by Ouranos. This version was used at PCIC before NARCCAP results were available; NARCCAP uses CRCM version 4.2, which has similar results.

4.3 Range of Regional Change

The sets of projections listed in Table 6 provide a wide range of projected future change in both temperature and precipitation for most regions of BC. It is important to check the completeness of the range covered for the particular region, seasons, and time periods of interest. The PCIC Regional Analysis Tool (RAT) at http://pacificclimate.org/tools-and-data/regional-analysis-tool may be used as described in Section 3.3.

Table 6: Recommended GCM projections for investigating range of change and projected 2050s change in British Columbia.

Model	Emissions Scenario	Run	2050s change (BC average)	
			Annual Temperature (°C)	Annual Precipitation (%)
CGCM3	A2	4	2.7	14
HadCM3	B1	1	1.7	6
HadGEM	A1B	1	3.7	0
CSIROMK30	B1	1	1.4	5
MRICGCM232A	B1	5	0.8	3
ECHAM5	A1B	3	2.3	8
NCARCCSM30	A1B	5	3.4	7
GISS-EH	A1B	3	1.0	-5
CGCM3	A2	5	2.5	15
GFDLCM21	A2	1	2.0	2

This set intentionally includes two runs from the same model because this allows for some representation of the differences that can result from the internal variability of the climate system. Care has been taken to ensure that the range of climates considered has not been unduly influenced by this selection. Figure 10 shows each of the projections recommended for the set of 10, and how they compare to the full ~140 projections for BC in terms of annual average temperature and precipitation.

The range of climates projected by this recommended set can be compared to three larger sets (ensembles) of projections that are available on the RAT:

- **SRES AR4 – PCIC A2+B1** is a set of 30 projections consisting of A2 run 1 and B1 run 1 from each of the following 15 models: BCCR-BCM20, CCCMA-CGCM3, CNRM-CM3, CSIRO-MK30, GFDL-CM20, GFDL-CM21, GISS-ER, INMCM30, IPSL-CM4, MIROC32 (medres), MIUB-ECHOG, MPI-ECHAM5, MRI-CGCM232A, NCAR-CCSM30, UKMO-HADCM3. This ensemble is the one used to create range and box plots on the Plan2Adapt online tool.

- **SRES AR4 – PCIC A2+A1B+B1** also includes A1B run 1 from each of the 15 models listed in the previous ensemble.

- **SRES AR4 – All scenarios** includes all available runs (from as few as one to as many as five for each model + emissions scenario combination) listed in the above two ensembles as well as all runs from the following additional models: CCCMA-CGCM3 (T63), GISS-AOM, GISS-EH, IAP-FGOALS10G, MIROC32 (hires), NCAR-PCM1, UKMO-HADGEM1.

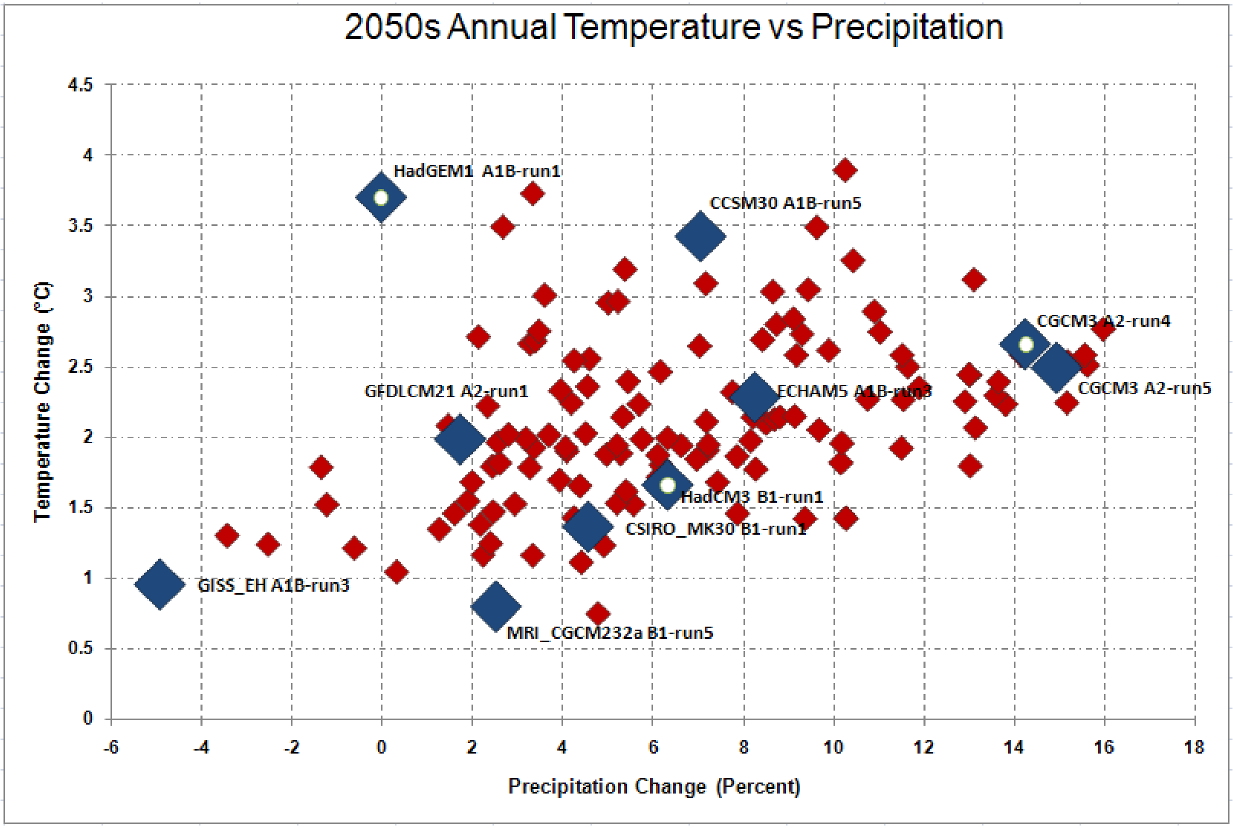

Figure 10: Range of change by the 2050s for all models and emissions scenarios (red diamonds) and including the set of 10 (blue diamonds with or without white dots) and the three recommended for illustrative purposes (blue diamonds with white dots). Source: PCIC.

4.4 Sensitivity Analysis

Suggestions in this section for sensitivity analysis apply to mean temperature and total precipitation. Investigation of any other variables, including daytime high or nighttime low temperature, rain, snow, etc. will require selection of values for sensitivity analysis using tools such as those described in Section 3.3.

It is recommended that the changes from a baseline of 1961-1990 listed below be used for sensitivity analyses. For temperature, the change would be applied to nighttime lows and daytime highs equally throughout the year. For precipitation, different changes would be applied for winter (December-January-February) and summer (June-July-August). A constant change to all days of these seasons is suggested, with a linear transition between the solstice seasons and the shoulder seasons.

- Temperature: +1°C, +2°C, +4°C
- Winter precipitation: -10%, +10%, +30%
- Summer precipitation: -30%, -10%, +10%

It is recommended that changes be made to single variables separately and then to a combination of the variables. Some examples of combinations are shown below. This set would be useful for general purposes for most areas of BC.

Table 7: Possible combinations of temperature and precipitation for sensitivity analysis.

Description	Temperature	DJF Precipitation	JJA Precipitation
Medium	2°C	+10%	-10%
Cool-Wet	1°C	+30%	+10%
Hot-Dry	4°C	-10%	-30%
Seasonal	2°C	+30%	-30%

4.5 Time Series and Extremes

The use of projections of monthly or daily time series poses some challenges. The added temporal resolution comes with complications in terms of uncertainty inherent in shorter temporal scales, additional steps required to create time series, the need to downscale the data, as well as the sheer amount of data to manage. Section 3.5 describes relatively simple methods of creating synthetic daily and monthly time series of future projected climate.

All models participating in CMIP3 simulate daily and sub-daily variability, but not all groups were able to save their output to the archive at high temporal resolution. The CMIP3 database of GCM projections used for the AR4 thus contained daily data from only a limited number of GCMs. It has subsequently been updated with daily data from a greater number of models. However, as the original limited set has been available for several years and has been used for many analyses, we will concentrate on that subset here.

Daily values of daily mean temperature and total daily precipitation were available for eight GCMs participating in CMIP3 that demonstrated skill across several different measures (Gleckler et al. 2008; Werner 2011). These models are: CCCMA-CGCM3, UKMO-HadCM3, UKMO-HadGEM1, GFDL-CM21, MPI-ECHAM5, MIROC32 (medres), NCAR-CCSM30, and CSIRO-MK30. It is recommended that projections from run 1 of all eight of these models be considered for any analysis that depends on daily mean temperature and total daily precipitation. Almost all have run 1 available for B1 and A1B (the exception is HadGEM1 B1). However, for most purposes it is adequate to consider the A2 emissions scenario only. Doing so will allow for comparison with 2050s RCM results. If the latter half of the 21st century is important or there is an explicit need to consider the influence of emissions scenarios, B1 should also be included. The resulting range does not cover the full range of projections that are obtained without being limited by daily data availability. It is therefore recommended that the resulting range of change in this set be compared to wider sets (Section 4.3) using the tools described in Section 3.3.

If daily minimum and/or maximum temperature is required, then the set of projections is somewhat diminished: the A2 emissions scenario for CCSM, GFDL21, and MIROC32 (medres) had no runs, CSIRO was not available for A2 run 1, and ECHAM5 was not available for A1B run 1. In the last case, ECHAM5 A1B run 4 had the needed data and can be substituted for run 1. Although it will no longer be directly comparable to the ECHAM5 projections for the A2 and B1, it maintains the ensemble size. Similarly, possible substitutions of projections from similar models that are not in the above set of eight because they score slightly worse in performance measures (Gleckler et al. 2008; Werner 2011) included GFDL21 in place of GFDL20 and MIROC32 (hires) in place of MIROC32 (medres).

In the case of more complex downscaling techniques such as Expanded Downscaling (EDS), the limited availability of additional data normally used by such methods (e.g., 3-D fields of atmospheric variables such as geopotential height), significantly reduces the number of scenarios that are easily available. For EDS, the only models with all the required data (to run the method in its typical configuration) were CCCMA-CGCM3, MPI-ECHAM5, and UKMO-HadGEM2.

RCM simulations, although fewer in number than GCM simulations, generally do have daily data available via the NARCCAP project. These include runs from multiple RCMs: RegCM3, ECPC, PRECIS, CRCM, WRF, and MM5 regional models, each forced by NCEP reanalysis as well as the 20th century (20C3M) and the A2 runs of each of the following GCMs: GFDL, HadCM3, CGCM3, and CCSM. See http://www.narccap.edu for more information on the RCMs and their driving GCM projections. NARCCAP projections have been used in recent projects that include the consideration of extremes (BCMOTI 2010; Nash and Dobson 2010; Murdock and Sobie, 2011).

The Canadian GCM and RCM also have several projections run by Ouranos that allow for the exploration of variability. CGCM3 has daily data for a total of 15 runs, five runs for each of the three emissions scenarios. CRCM 4.2.3 has been forced by each of the five A2 projections. Also, CGCM3 A2 run 3 has been used to drive three different versions of the Canadian RCM (CRCM 3.6.3, 3.7.1, and 4.2.3) that differ mainly in their land surface scheme and other parameterizations. This ensemble of CGCM3 + CRCM projections has recently been used to address hydrologic impacts in BC (see Rodenhuis et al. 2010)

Finally, indices of extremes that themselves depend on daily data are available for several CMIP3 GCMs. No recommendations are made regarding use of these projections as they are not directly available from PCIC online tools. They must be used with care due to the coarse scale of the models and the short temporal scale of some of the extremes. It is anticipated that AR5 will produce a much more complete set of projected extremes. In the meantime, projections of indices of extremes is possible (and ongoing at PCIC) using the RCMs described in this section, and from statistical downscaling techniques.

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5. Conclusions

Scenarios of future climate change are being used in BC for community and land use planning, policy development exercises, vulnerability or risk assessments, and the development of adaptation plans. The level of detail needed and capacity for further analysis by users can vary widely. This report should assist analysts in the selection of future scenarios and help them decide on the spatial and temporal scales of the data and methods to use. The report focuses on scenarios used for the IPCC Fourth Assessment Report and describes tools for data access that are readily available in BC.

There are a large number of projections of future climates available as a result of different greenhouse gas emissions scenarios and differences between climate models. We recommend the HadGEM A1B run 1 (hot/dry), CGCM3 A2 run 4 (warm/very wet), and HadCM3 B1 run 1 (cool/wet) projections as a minimal set of three to use. Additional model or emissions scenario combinations are recommended depending on the purpose of the study. Examples are presented for the use of global climate model output to do sensitivity and time series analyses, while assessing the impact of a range of projected climate change.

Sources for obtaining scenario data as well as visual images of the degree of projected climate change for western North America and regions of British Columbia are described. Climate model output is often too spatially coarse to provide sufficient local detail. A range of tools for increasing spatial and temporal resolution through statistical or empirical downscaling are available and are described in this report. These tools are designed to address the needs of users with varying technical skills and backgrounds.

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Appendix A: Definitions

See the IPCC AR4 Glossary of Terms for authoritative technical definitions of terms (http://www.ipcc.ch/publications_and_data/publications_and_data_glossary.shtml). Below we provide plain language definitions of some terms as they are used in this report.

Climate Model: Representation of the climate system within a computer based on physical principles (e.g., GCM, RCM, EMIC).

Climate Projection: One "run" from one climate model using one emissions scenario (e.g., CGCM3 A2 run 4).

Climate Scenario: A representation of a plausible future climate, usually obtained by adjusting a climate projection, for example by downscaling.

Downscaling: The process of projecting climate change at a finer scale based on observed and/or simulated climate at a coarser scale.

Emissions Scenario: Representation of possible future emissions of greenhouse gases such as CO_2, CH_4, N_2O and CFCs as well as particulates like soot, based on assumptions about future population growth, technological development, sources of energy, and global cooperation (e.g., A2, A1B, B1).

Ensemble Mean: Average of a number of climate projections from multiple runs, models, and/or emissions scenarios.

IPCC AR4: Intergovernmental Panel on Climate Change Fourth Assessment Report.

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Appendix B: Additional Sources of Future Regional Climate Projections

Table 8: Additional sources of future regional climate projections.

Source	**Description and link**
PCIC statistical downscaling	PCIC is undertaking a statistical downscaling inter-comparison using each of the following techniques and tools, similar to the European STARDEX project http://www.cru.eua.ac.uk/projects/stardex/ • EDS (Expanded Downscaling) (Bürger 1996) • TreeGen (Stahl et al. 2008) • ASD / SDSM (Automated Statistical Downscaling / Statistical Downscaling Model) (Hessami et al. 2008; Wilby et al. 2002) • BCSD (Bias Corrected Spatial Disaggregation) (Wood et al. 2002) • Biosim (Régnière et al. 1995) • LARS-WG5 (Semenov 2007; Semenov 2008)
North American Regional Climate Change Assessment Program (NARCCAP)	regional climate model projections for North America http://www.narccap.ucar.edu
Ouranos	regional climate modelling consortium http://www.ouranos.ca
Data Access Integration	Canadian Regional Climate Model data http://loki.qc.ec.gc.ca/DAI/rcm-e.html
Canadian Forestry Service	selected high resolution interpolated GCM scenarios http://cfs.nrcan.gc.ca/subsite/glfc-climate/climatechange
Earth System Grid	Download data from CMIP3, CMIP5, NARCCAP, and other climate modelling programs. http://esg-pcmdi.llnl.gov/
Climate Information toolkit (CLIK)	Online interface to global climate models, downscaling, and seasonal forecasts, run by Asia-Pacific Economic Cooperation Climate Center. http://clik.apcc21.net/
Pacific Northwest Climate Mapping Tool	Climate Impacts Group (University of Washington, Seattle) tool for visualizing scenarios and data for the (US and Canadian) Columbia River Basin. http://cses.washington.edu/cig/maps/index.shtml
Climate Wizard	A web-based tool (Girvetz et al. 2009) that provides simple analyses and graphical depictions of how climate has and is projected to change within specific geographic areas throughout the world. http://ClimateWizard.org
Canadian Climate Change Scenarios Network	Environment Canada network of scenarios access portals http://www.cccsn.ca
Canadian Centre for Climate Modelling and Analysis (CCCma)	Download data directly from the Canadian Global Climate Model. http://www.cccma.ec.gc.ca
HectaresBC	Overlay high-resolution historical climate and selected climate scenarios with other geographical layers, particularly those relevant to biodiversity. http://www.hectaresbc.org/app/habc/HaBC.html
GeoBC	Overlay historical climate information with other BC government data geographical layers. http://geobc.gov.bc.ca/