Final Report for FSP project F090116

Increasing the spatial range of ClimateBC

Dave Spittlehouse, Research Branch, BC Min. Forests and Range, Victoria, BC
Tongli Wang, Centre for Forest Gene Conservation, UBC, Vancouver, BC
Andreas Hamann, Michael Mbogga, Dept. Renewable Resources, U. Alberta, Edmonton, AB
Trevor Murdock, David Bronaugh, Pacific Climate Impacts Consortium, U. Victoria, Victoria, BC

Executive Summary

Applying climate data in resource management requires matching spatial scales of climate and resource databases. ClimateWNA is a stand-alone MS Windows-based computer program that enables users to obtain selected monthly climate variables based on latitude, longitude, and elevation for any point in western North America. Historic data and future possible climates simulated by global climate models are available. The data represent weather station climate and variables include maximum, minimum and average monthly temperature, total precipitation and a suite of annual derived variables such as degree days, frost free period and fraction of precipitation as snow. Originally encompassing BC and the Yukon (ClimateBC), this year's project has expanded the range of the program to include the Prairie Provinces (ClimatePP), Northwest Territories and the western United States including Alaska. Estimates of annual evaporation and climatic moisture deficit were added to the output.

ClimateWNA's base data (PRISM) are monthly temperature and precipitation for the 1961-90 normals. Polynomial functions for environmental lapse rate were developed for each monthly temperature variable based on latitude, longitude and elevation. Functions were developed for three geographic regions within the domain of ClimateWNA and were cross checked at areas of overlap. The software bi-linearly interpolates the 4 km PRISM data to the latitude and longitude of interest. Elevation adjustment is then applied to the interpolated monthly values. Bi-linear interpolation provides adequate adjustment for monthly precipitation.

Five temperature-based approaches for calculating reference evaporation were compared to reference evaporation calculated with the Penman-Monteith equation. Testing was done at 58 weather stations distributed across western North America west of 100°W, chosen because they have monthly normals of sunshine hours as well as air temperature and precipitation data. The Hargreaves equation with a latitude correction to its evaporation estimate was chosen to calculate reference evaporation and the climatic moisture deficit in ClimateWNA.

A comparison was made between monthly normals for 2281 weather stations across western Canada and the US and values predicted by ClimateWNA. 94 to 99% of the variance was explained by ClimateWNA values. Standard errors for predicted monthly temperature were similar across all months except for slightly higher errors for minimum temperatures in winter months. Error varied from 0.6 to 1.1°C depending on the month and temperature variable. Monthly precipitation had a standard error of 3 to 10 mm.

A stand-alone software package, ClimateWNA, is available at no charge and can be downloaded from www.genetics.forestry.ubc.ca/cfcg/climate-models.html. A web-based version is also available at this site. The Pacific Climate Impacts Consortium Regional Analysis Tool is a web-based tool designed to analyze and display climate model data and provide access to gridded data (www.pacificlimate.org).

ClimateWNA provides ready access to historical and future climate data at any resolution. However, that there are important limitations. The data represent weather station climate. Thus, features such as rain shadows, temperature inversions, and slope and aspect effects are modeled at a scale of several kilometers, while lapse-rate driven temperature differences are represented at the scale hundreds of metres. Small-scale climate features such as frost pockets or local slope and aspect effects are not represented. The shorter the historical time interval of interest, the less reliable the climate surfaces.

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Introduction

High-resolution climate data have become essential in natural resource management and related climate change studies. Applying the climate data requires matching the spatial scales of the climate and resource databases. ClimateBC is a stand-alone MS Windows-based computer program that enables users to obtain selected monthly climate variables based on latitude, longitude, and elevation for any point in BC and the Yukon (Wang et al. 2006, Spittlehouse 2006). Historic data and future possible climates simulated by global climate models are available. The data represent weather station climate and variables include maximum, minimum and average monthly temperature, total precipitation and suite of annual derived variables such as degree days, frost free period and fraction of precipitation as snow. Multiple locations can be processed through input of a file comprising the coordinates and identifier of the locations. Output text files can be imported to geographic information systems (e.g., ArcGIS) or statistical software (e.g., SAS). ClimateBC has been widely used as an essential tool for natural resource management, forest genecology and climate change related studies (Spittlehouse 2006), such as developing population response and transfer functions (O'Neill et al. 2008, O'Neill et al. 2007, Wang et al. 2006b), predicting ecological changes under a range of climate scenarios (Hamann and Wang 2006, Hamilton and Haeussler 2008, Flower and Murdock 2008), and visualization of future impacts at high resolution for regional analyses (Pike et al. 2008, Dawson et Al. 2008a, Dawson et al. 2008b, Werner and Murdock 2008, Rodenhuis et al. 2007).

ClimateBC covers the region between 47 and 62°N in latitude and between 113 and 141°W in longitude. This includes British Columbia, the Yukon, and parts of Alberta, an area of about 130 million hectares. However, species of plants and animals found in BC also occur outside the boundary of ClimateBC. Consequently, it is not possible to define the climate envelopes for some species using the current format and we need to expand its range. Under a changing climate, BC may experience conditions analogous to those in the south of its boundaries. There is an immediate need to capture these climates within the program.

The objectives of this project where:

- expand the range of the program to include the Prairie Provinces, Northwest Territories and the western United States including Alaska - ClimateWNA;
- provide estimates of annual evaporation and climatic moisture deficit as output;
- evaluate the accuracy of predictions of temperature and precipitation over the whole domain;
- evaluate the accuracy of annual historic projection;
- provide data for the Pacific Climate Impacts Consortium's Regional Analysis Tool for data visualization and access.

Study Area and Data

Base data

ClimateWNA covers the region between 24.5 and 80°N in latitude and between 100 and 180°W in longitude (Figure 1 from Mexico in the south to Alaska in the north. A subsidiary part of the work has been developing a program to cover all of the Prairie Provinces (ClimatePP - Mbogga et al 2009). It includes all of Manitoba most of which is excluded from ClimateWNA. Climate data for the reference period (1961-1990) from PRISM were used for the continental

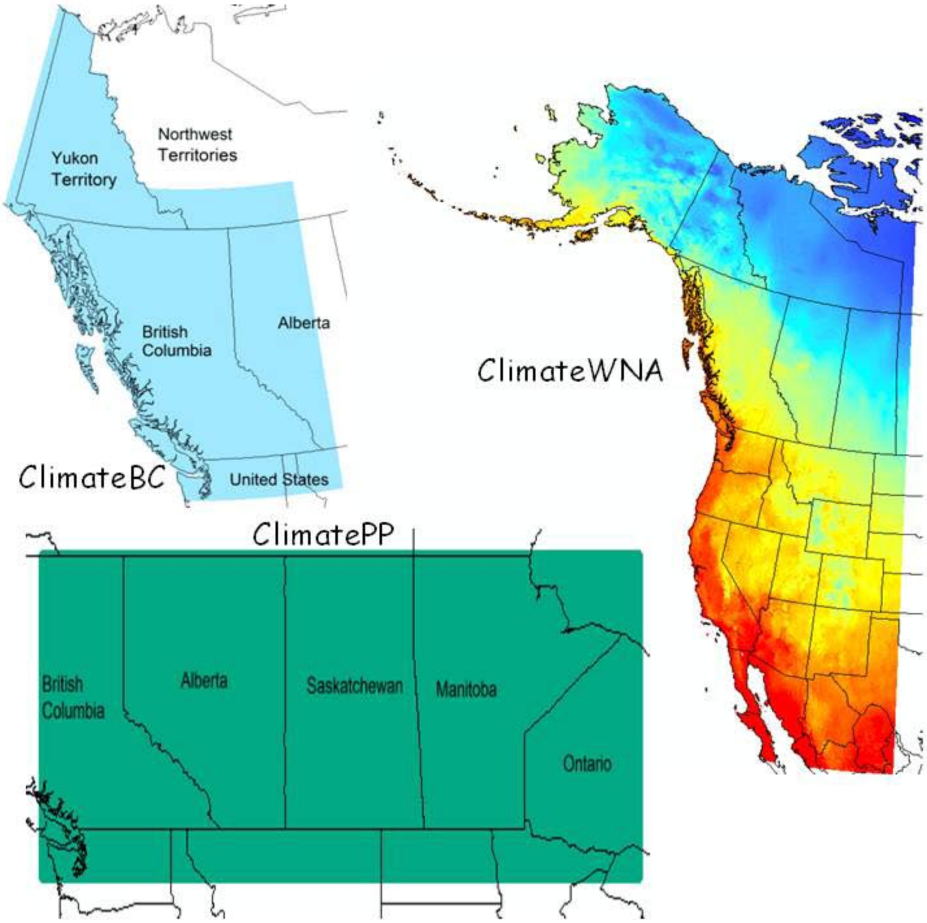


Figure 1: Spatial range of ClimateBC , ClimatePP and ClimateWNA.

US, AK, BC, and YT, while ANUSPLIN interpolated data for the same period were seamlessly added for the northern half AB, SK, MB, and NWT.

The PRISM data sets were developed using an analytical tool that incorporates point data, a digital elevation model, and expert knowledge of complex climatic conditions such as rain shadows, coastal effects, and temperature inversions (Daly et al. 2002, 2008). It has been recognized world-wide as one of the highest-quality spatial climate data sets currently available. This methodology is particularly well suited for modeling in mountainous terrain (Daly et al 2008). ClimateWNA uses monthly climate data for 1961-1990 normal period from PRISM full resolution data sets at 2.5 arcminute (about 4 km). Climate variables included in the program were monthly minimum and maximum temperatures, and monthly precipitation. ANUSPLIN (Hutchinson 1989) interpolated data were developed based on weather station records for the same period. In order to have seamless integration with PRISM data, the PRISM data at the border regions were also included as training data.

Historical data

The historical climate data used in ClimateWNA for the years 1901-2002 were from Mitchell and Jones (2005). The interpolated historical data are provided at 30 arcminute resolution with worldwide coverage (CRU TS 2.1). By subtracting the 1961-1990 average from their gridded surfaces of individual years and months, we recovered their original anomaly surfaces (deviations from the 1961-1990 normals). Mbogga et al. (2009) developed the anomaly surfaces covering North America for recent years (2003-2006) using the same methodology.

Predicted future climate data

Global Circulation Model (GCM) projections for future periods (2020s, 2050s and 2080s) were obtained from TYN SC 2.0 dataset (Mitchell et al. 2004) and from Pacific Climate Impacts Consortium (http://www.pacificclimate.org). We use anomaly data from the reference period 1961-1990. GCM predictions were obtained from the IPCC Third Assessment (AR3) (IPCC 2001) and the IPCC Fourth Assessment (IPCC 2007). Four emission scenarios (A1FI, A2, B1, B2) are available. Because different climate change models use different prediction locations and different spatial resolutions, we interpolated these coverages to a standardized 1° latitude by 1° longitude grid using ANUSPLIN (Hutchinson 1989).

Data Processing in ClimateWNA

Downscaling of baseline data

ClimateWNA uses a combination of bilinear interpolation and elevation adjustment to downscale the baseline climate data (4 x4 km) in run-time to scale free for locations of interest for the reference period (1961-1990) (Wang et al. 2006a). The program first extracts the monthly climate variables and elevations from the four neighboring tiles of the location based on its coordinates. It then calculates their bilinear-interpolated values for the location. As the interpolation is carried out in run-time, no additional storage space is required for the high-resolution data. Elevation adjustments are further applied to interpolated monthly temperature variables.

Following Wang et al. (2006), polynomial functions for environmental lapse rates were developed for each monthly temperature variable based on latitude, longitude and elevation. Functions were developed for 3 geographic regions - latitude > 60°, 47° < latitude < 60°, and latitude < 47°. In order to avoid steps in predicted climate data at the boundaries, data used for developing the elevation adjustment functions were extended to neighboring sections by 2° in latitude. Bi-linear interpolation provides adequate adjustment for monthly precipitation.

Calculated and derived climate variables

In total, ClimateWNA can produce 85 climate variables, including 48 monthly, 16 seasonal and 21 annual variables. The monthly and seasonal variables include minimum, maximum and average temperatures, and precipitation. Of the 21 annual climate variables, 8 are directly calculated variables from the monthly data including mean annual temperature (MAT), mean coldest month temperature (MCMT), mean warmest temperature (MWMT), continentality (TD, which is the difference between MWMT - MCMT), mean annual precipitaion (MAP), mean May to September precipitation (MSP), annual heat-moisture index (AHM), and summer heat-moisture index (SHM). Calculations of other annual variables, such as growing degree-days (DD>5°C), cooling degree-days (DD<0°C), frost-free period (FFP), usually require daily weather data. ClimateWNA derives these variables using either linearly interpolated daily data from monthly data or based on relationships between monthly climate variables and these variables (Wang et al. 2006a).

The climatic moisture deficit (CMD) is the sum of the monthly difference between a reference evaporation (E_{ref}) and precipitation. If E_{ref} is less than precipitation then the monthly CMD is zero (in this case the precipitation minus E_{ref} is a climatic moisture surplus). If the average monthly air temperature is less than zero then $E_{ref} =0$. Five temperature-based approaches for calculating reference evaporation were compared with reference evaporation calculated with the Penman-Monteith equation (Shuttleworth 1993, Allen et al. 1998). Testing was done for 58 weather stations distributed across western North America west of 100°W, chosen because they have monthly normals of sunshine hours as well as air temperature and precipitation data. The Hargreaves equation with a latitude correction to its estimate was chosen as the method for calculating E_{ref} in ClimateWNA (Spittlehouse 2009).

Downscaling and integration of historical and GCM data

When climate data were required for a particular year within the period covered by ClimateWNA (1901 - 2006), the historical anomaly data for that year are downscaled using bilinear interpolation in run-time and overlaid onto the downscaled baseline climate normal data as described above. Seasonal climate variables for winter are calculated based on the monthly variables for January and February in he year of interest and for December in the previous year, except for the year 1901, for which the climate data are not available for the previous year. The same method is also applied to the annual climate variables, extreme minimum temperature (EMT) and precipitation as snow (PAS).

For predicted future climate, ClimateWNA further downscales the standardized GCM anomalies using bilinear interpolation to the locations of interest, then overlay them onto the high-resolution baseline data. The program provides high-resolution climate data for future periods because spatial variation in anomaly data is much smaller and easier to be modeled than the absolute values (Mbogga et al. 2009; Mitchell and Jones 2005). Second, downscaling improves spatial resolution and may also improve precision. Finally, improved high-resolution baseline data for the downscaled anomalies further improve predictions. Mbogga et al. (2009) suggested that the historical climate data generated by this approach are much better than Mitchell and Jones’ (2005) low resolution climate normals. Using anomalies in the program can eliminate some prediction errors that result from the fact that GCM predictions in absolute values for the reference period can be substantially different from observations. Consequently, interpolation of variability data is expected to be more reliable than interpolating absolute values (Mbogga et al. 2009; Mitchell and Jones 2005).

Figure 2 illustrates downscaling of anomaly data from their original resolution to a high-resolution or to the locations of interest and overlaying them on high-resolution baseline. This is example is for a climate change but the same approach applies for the historic data.

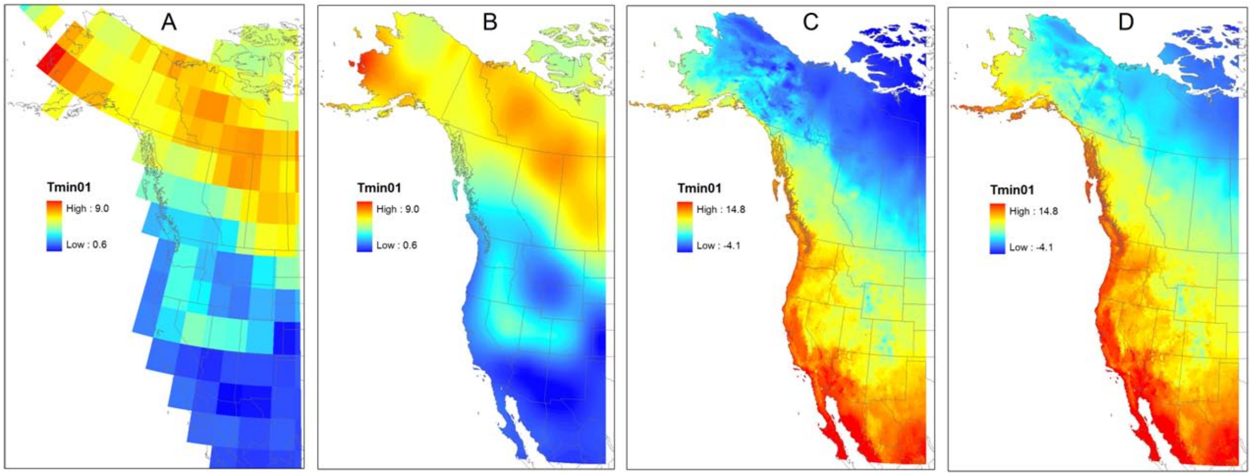


Figure 2: Application of downscaling for GCM data by ClimateWNA shown by the minimum temperature of January in 2050s predicted by the Canadian model GCM3 A2 run1. A) predicted anomalies at original resolution (3.75° x 3.7068°); B) downscaled anomalies (0.00833° x 0.00833°) by ClimateWNA; C) predicted for 1961-1990; and D) predicted for 2050s.

Calculations of climate data for additional normals and decades

In addition to provide historical climate data for individual years, ClimateWNA also calculates seven 30-year normals and 10 decade averages within the period 1901 - 2006.

Evaluation of ClimateWNA Output

Improvements in spatial resolution

Improvements in spatial resolution of PRISM data by ClimateWNA are considerably better than commonly used spatial interpolation approaches. Elevation adjustment alone reflects the topographical pattern to a great extent; however, steps at the boundaries between adjacent PRISM tiles are visible. Differences in climate data among the neighboring tiles are not entirely driven by the differences in elevation among these tiles (Daly et al. 2002), elevation adjustment alone cannot generate seamless surfaces across tiles. Bilinear interpolation and elevation adjustment applied to the variables means that the variable surface seamlessly following the topography (Figures 2 and 3).

Improvements in statistics

Observed climate normals for the same reference period (1961-1990) from weather stations were used to evaluate the quality of ClimateWNA output and improvements over the baseline PRISM data. Climate normal for 1049 stations in US were obtained from National Oceanic and Atmospheric Administration and for 1122 stations in western Canada from Environment Canada archives.

Improvement in precision of ClimateWNA was evaluated by comparison in variances explained and standard errors of climate variables between baseline climate data and ClimateWNA outputs. Baseline data explained the majority (93 - 99%) of the total variation in all monthly climate variables (Figure 4). These values are greater than what we found in previous

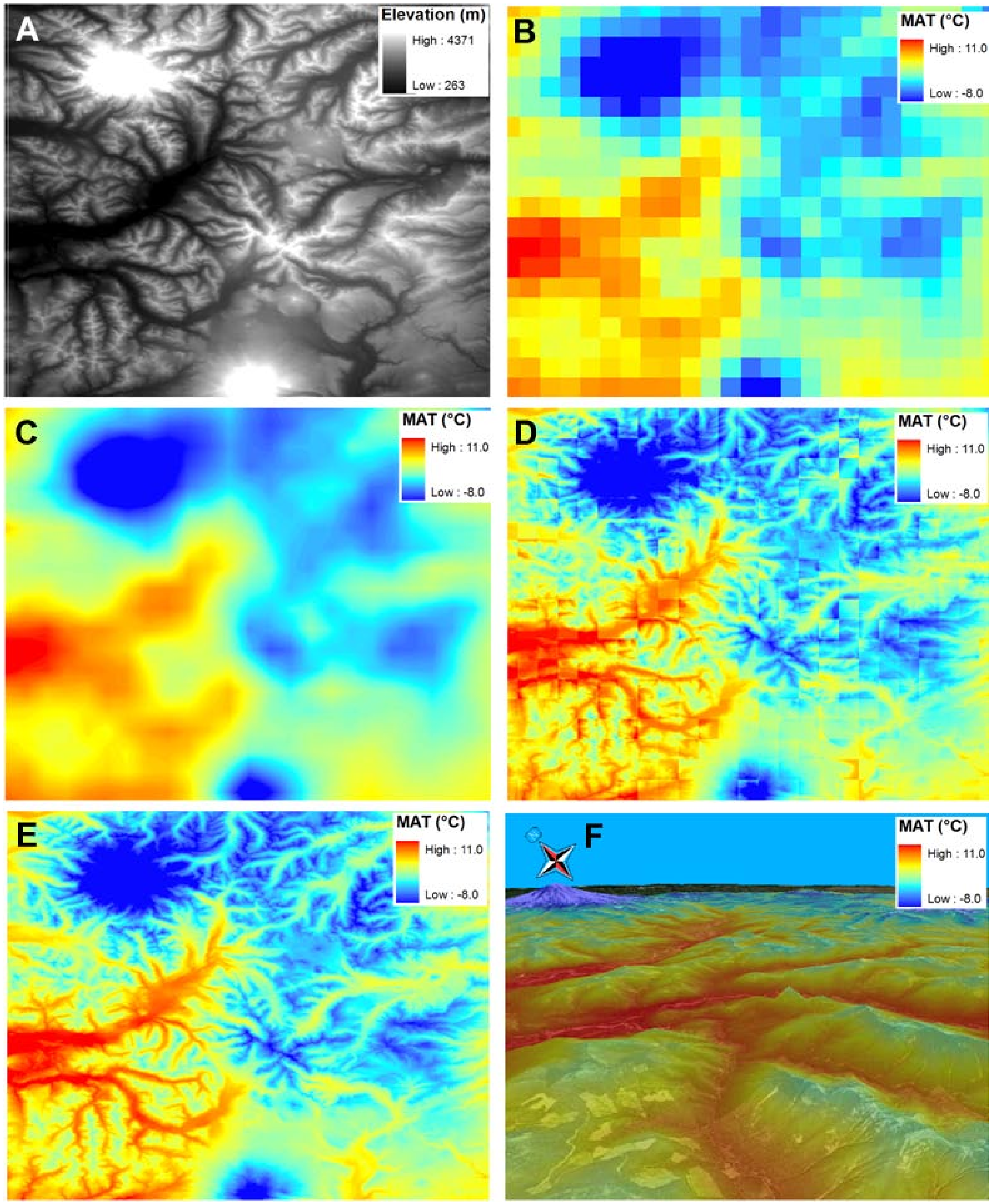


Figure 3: Application of the downscaling processes in ClimateWNA shown in a mountain area of south Washington (centered at Lat. 45°35' N and Long. 121°31' W) at a resolution of 90m. A) DEM at 90m; B) Mean annual temperature (MAT) generated by PRISM at 4km; C) Interpolated MAT using bilinear interpolation; D) elevation adjusted MAT using nearest data values from PRISM data and elevation adjustment function developed in this study; E) ClimateWNA downscaled MAT using a combination of bilinear interpolation and elevation adjustment; F) ClimateWNA downscaled MAT overlaid to a satellite image to show the trend of MAT along topography in the upper-left part of this area.

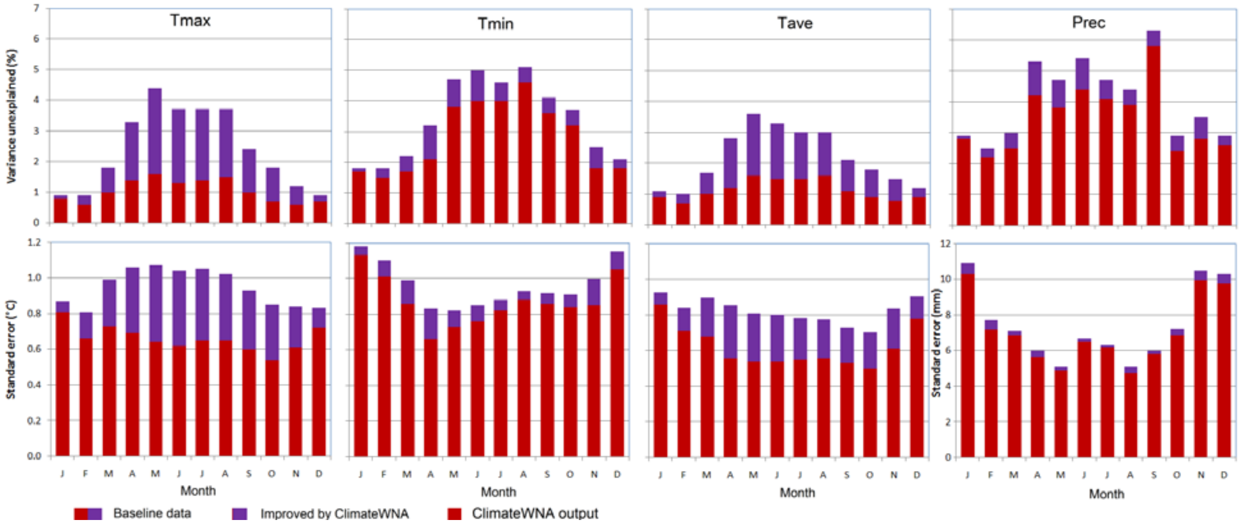


Figure 4: Reductions in variance unexplained and prediction standard errors for monthly maximum (Tmax), minimum (Tmin) and average (Tave)ait temperatures, and monthly total precipitation (Prec).

studies for ClimateBC (Wang et al. 2006a) and ClimatePP (Mbogga et al. 2009) due to greater variation in climate variables across a much larger area in this study. Therefore, the higher values in variance explained in this study does not necessarily mean better predictions for particular locations, for which the amount of (relative) variance unexplained and prediction standard errors (for absolute values) are more relevant. Based on variance unexplained, baseline data provided better predictions of temperature for winter months than for other months (Figure 4). In contrast, the downscaling methodology implemented in ClimateWNA is more effective for the other months. ClimateWNA eliminated the majority of the variance unexplained in maximum temperatures for April through October through downscaling. Similarly, around half amount of the variance unexplained in average temperatures were also removed by ClimateWNA for the same months.

The amount of prediction standard errors for monthly temperatures was rather similar across all months except for slightly higher standard errors for minimum temperatures in winter months (Figure 4). ClimateWNA reduced the prediction standard errors by up to 40% for monthly maximum temperatures and 30% for monthly average temperatures. For example, the standard error for May maximum temperature was reduced from 1.07°C to 0.64°C (Figure 4), a decrease of 40%.

The amount of improvement for monthly minimum temperatures and monthly precipitation by ClimateWNA was relatively small in terms of both variance unexplained and prediction standard error (Figure 4). This agrees with what we found in a previous study (Wang et al. 2006a). As elevation adjustment was not applied to monthly precipitation, the improvements in this variable resulted from simple bilinear interpolation. Based on our previous study (Hamann and Wang 2005; Wang et al. 2006a) and Figure 4, the improvements in temperature variables through downscaling by ClimateWNA are mainly attributable to elevation adjustments. Clearly, monthly maximum temperatures have stronger elevational patterns than minimum temperatures.

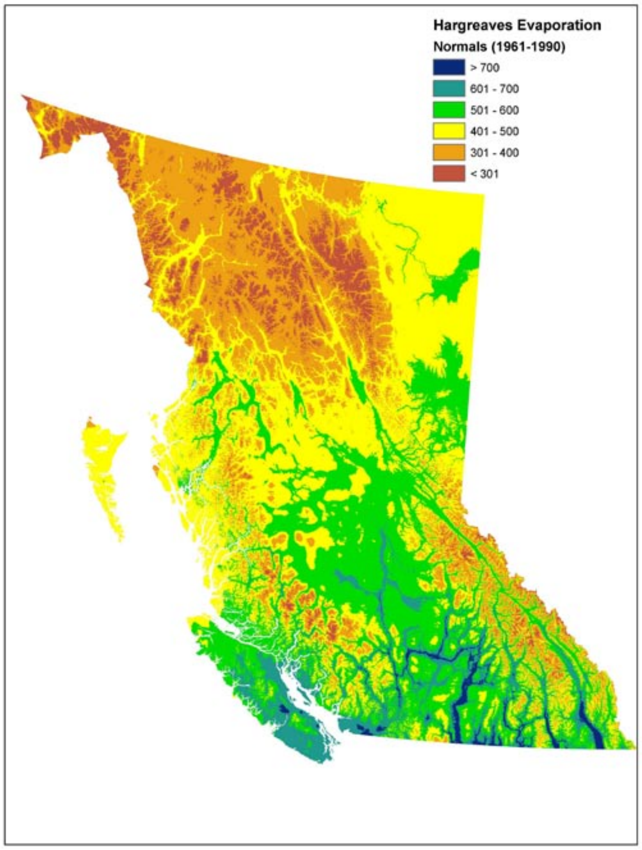


Figure 5: Annual reference evaporation (mm) for British Columbia for the 1961-90 normals. (Map produced by A. Walton, BC MoFR).

Evaporation and climatic moisture deficit

The Hargreaves equation had the best agreement with the reference method under current and a large climate change scenario (Spittlehouse 2009). There was a trend for increasing discrepancy with latitude under current climate and climate change scenarios. It also tended to underestimate evaporation at high elevations by up to 15%. Consequently, reference evaporation (E_{ref}) in ClimateWNA is calculated with the Hargreaves equation (E_{Har}) with a latitude correction applied, i.e., $E_{ref} = E_{Har}(1.18 – 0.0067\text{latitude})$, $n=56$, $R^2=0.734$, $se_{xy}=0.039E_{Har}$ and the latitude is in degrees. Reference evaporation for BC for the 1961-90 normals is shown in Figure 5. Climatic moisture deficits calculated with normals tend to underestimate the average of individual years.

Effects of downscaling on historical and GCM data

Stochasticity in weather patterns means that the shorter the period the lower the accuracy of estimating climate variables using interpolation. Assessment of annual variables for individual years at 180 stations across western Canada (Mbogga et al. 2009) showed that precision remained high, except for the first third of the century (Figure 6). May to September precipitation shows considerably more variation in statistical precision among individual years. Monthly temperature variables have quite high R^2 values compared to their corresponding 30-year normal. However, they show sharp declines in precision for approximately one out of 10

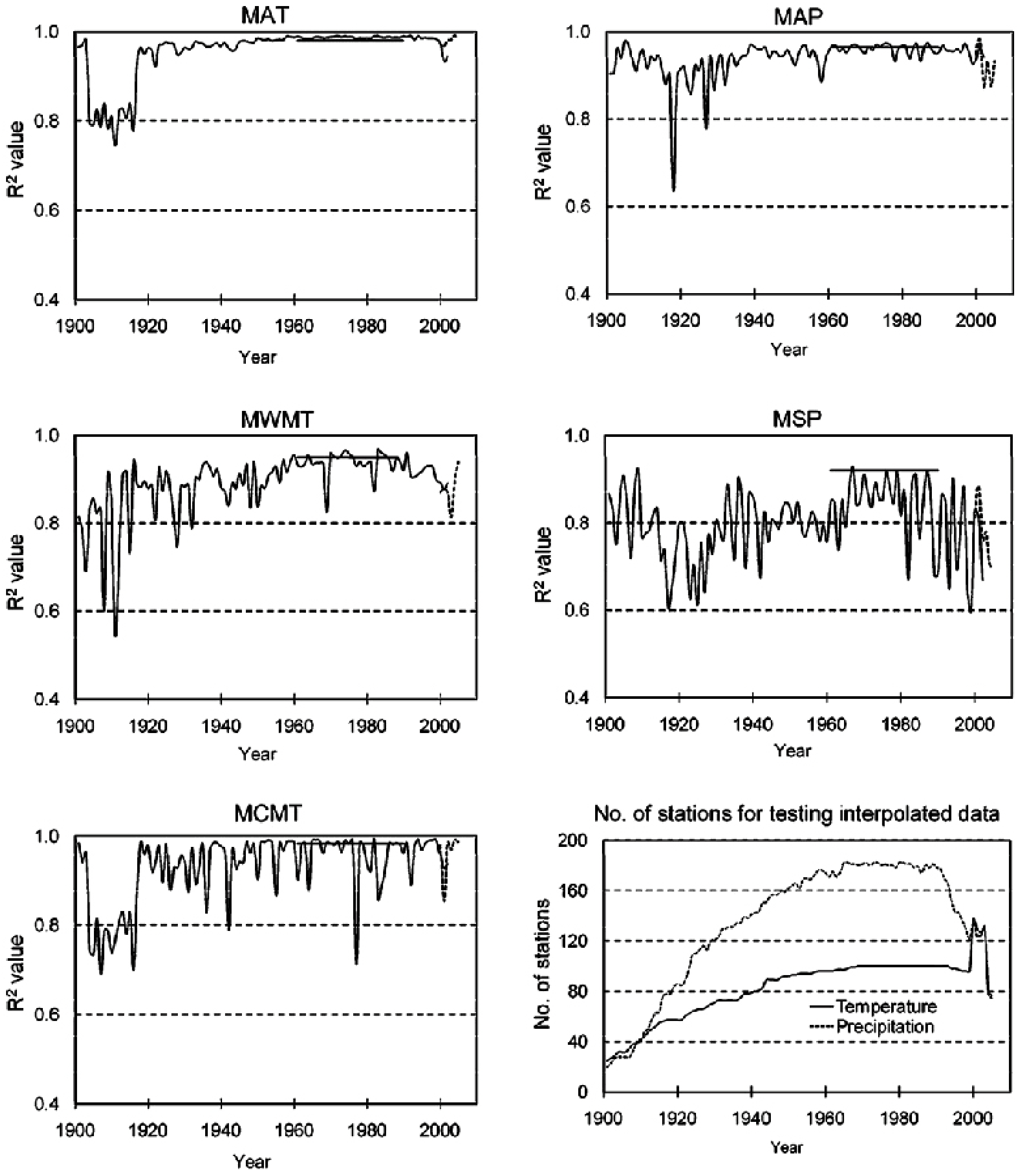
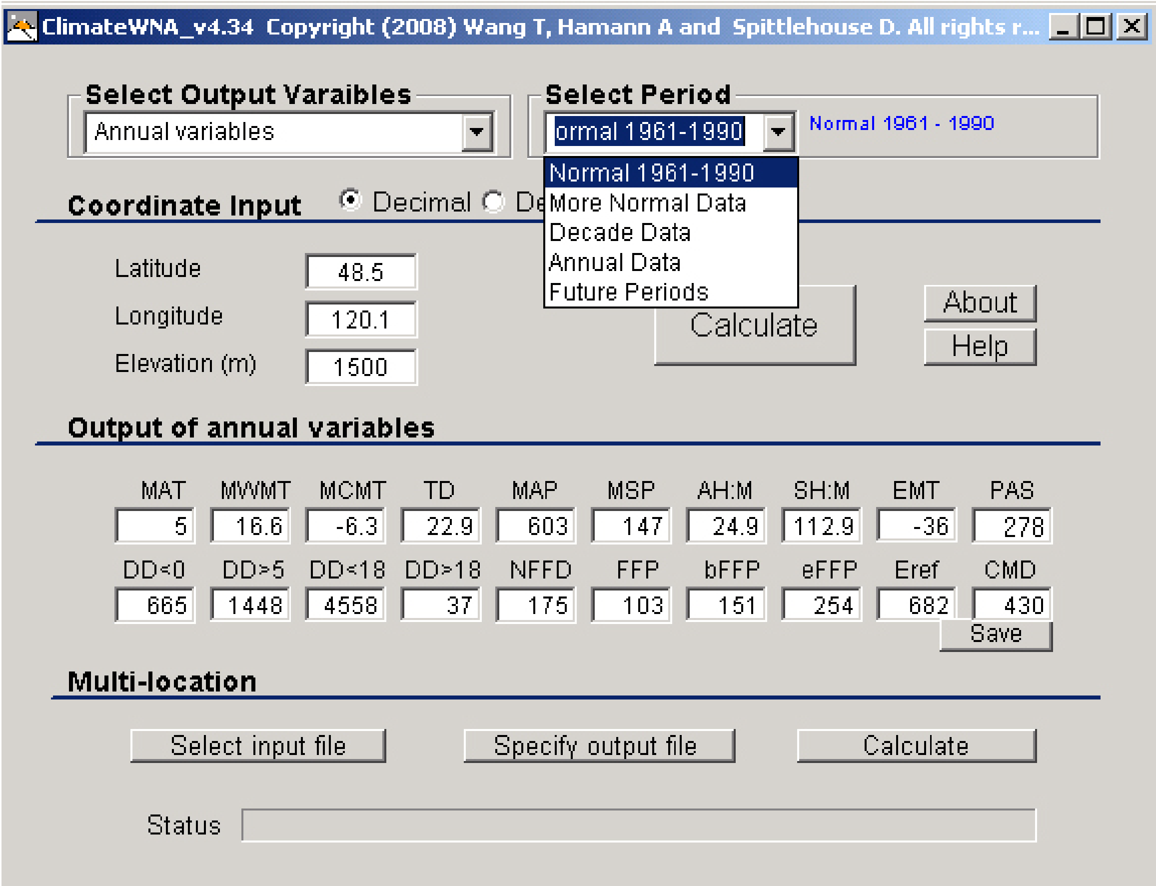


Figure 6: R^2 between observed and interpolated mean annual temperature (MAT), mean warmest month temperature (MWMT), mean coldest month temperature (MCMT) data, mean annual precipitation (MAP) and mean summer precipitation (MSP) for the 1901–2002 period and corresponding values for the 1961–1990 normals comparison with observed data. Number of stations for data comparison for each year is also shown. (From Mbogga et al 2009.)

years (Figure 6). These results show clearly that particular weather patterns that are unique to an individual month or season cannot always be accounted for by the climate grids.



Select Output Varaibles: Annual variables

Select Period: ormal 1961-1990 — Normal 1961 - 1990

Coordinate Input ● Decimal ○ De

Latitude: 48.5
Longitude: 120.1
Elevation (m): 1500

Output of annual variables

MAT	MWMT	MCMT	TD	MAP	MSP	AH:M	SH:M	EMT	PAS
5	16.6	-6.3	22.9	603	147	24.9	112.9	-36	278

DD<0	DD>5	DD<18	DD>18	NFFD	FFP	bFFP	eFFP	Eref	CMD
665	1448	4558	37	175	103	151	254	682	430

Multi-location

Status

Figure 7: A screenshot of ClimateWNA desktop version interface.

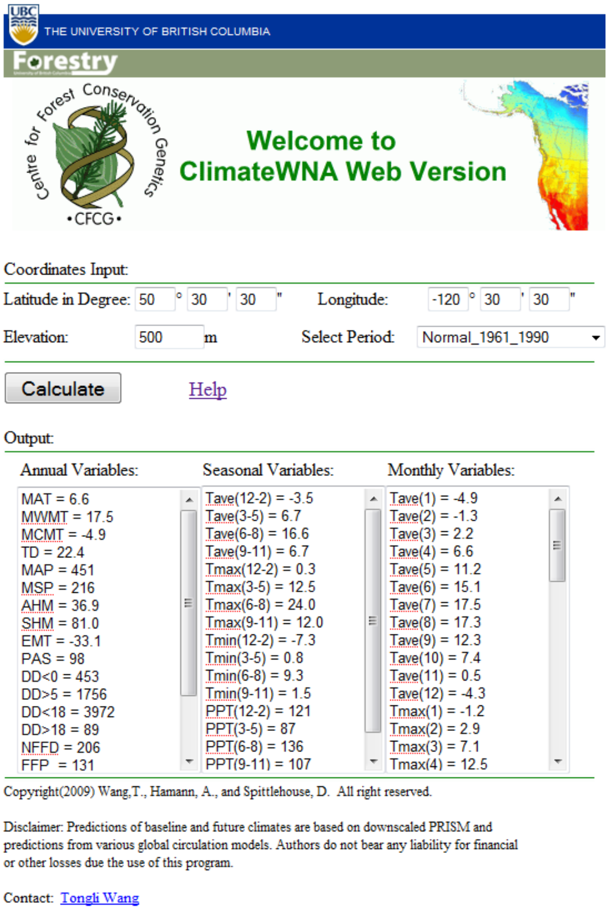
Access to ClimateWNA Data

A stand-alone software package was developed following the approach used in ClimateBC. The ClimateWNA package is available at no charge and can be downloaded from http://www.genetics.forestry.ubc.ca/cfcg/climate-models.html . No installation is required. So far, it works on all versions of MS Windows. Simply uncompress the files to a folder on a local hard drive, e.g., "C:\ClimateWNA\". The interface is shown in Figure 7.

ClimateWNA can be used interactively for single location at a time by inputting the coordinates and elevation of the location. It can also be used to process multiple locations through an input file that comprising coordinates and elevations for multiple locations. There is no limitation on the number of locations included. Detail instructions for preparing the input file is available in the help file of the program.

A web-based application is under development (Figure 8).

The Pacific Climate Impacts Consortium's Regional Analysis Tool (RAT) is a web-based tool designed to analyse and display climate model results (GCM, RCM) and historical climate data (Figure 9). It is designed for knowledgeable stakeholders and researchers. The tool allows for visualization of data on maps and facilitates easy comparison between monthly, seasonal,



Coordinates Input:

Latitude in Degree: 50 ° 30 ' 30 " Longitude: -120 ° 30 ' 30 "

Elevation: 500 m Select Period: Normal_1961_1990

Output:

Annual Variables:	Seasonal Variables:	Monthly Variables:
MAT = 6.6	Tave(12-2) = -3.5	Tave(1) = -4.9
MWMT = 17.5	Tave(3-5) = 6.7	Tave(2) = -1.3
MCMT = -4.9	Tave(6-8) = 16.6	Tave(3) = 2.2
TD = 22.4	Tave(9-11) = 6.7	Tave(4) = 6.6
MAP = 451	Tmax(12-2) = 0.3	Tave(5) = 11.2
MSP = 216	Tmax(3-5) = 12.5	Tave(6) = 15.1
AHM = 36.9	Tmax(6-8) = 24.0	Tave(7) = 17.5
SHM = 81.0	Tmax(9-11) = 12.0	Tave(8) = 17.3
EMT = -33.1	Tmin(12-2) = -7.3	Tave(9) = 12.3
PAS = 98	Tmin(3-5) = 0.8	Tave(10) = 7.4
DD<0 = 453	Tmin(6-8) = 9.3	Tave(11) = 0.5
DD>5 = 1756	Tmin(9-11) = 1.5	Tave(12) = -4.3
DD<18 = 3972	PPT(12-2) = 121	Tmax(1) = -1.2
DD>18 = 89	PPT(3-5) = 87	Tmax(2) = 2.9
NFFD = 206	PPT(6-8) = 136	Tmax(3) = 7.1
FFP = 131	PPT(9-11) = 107	Tmax(4) = 12.5

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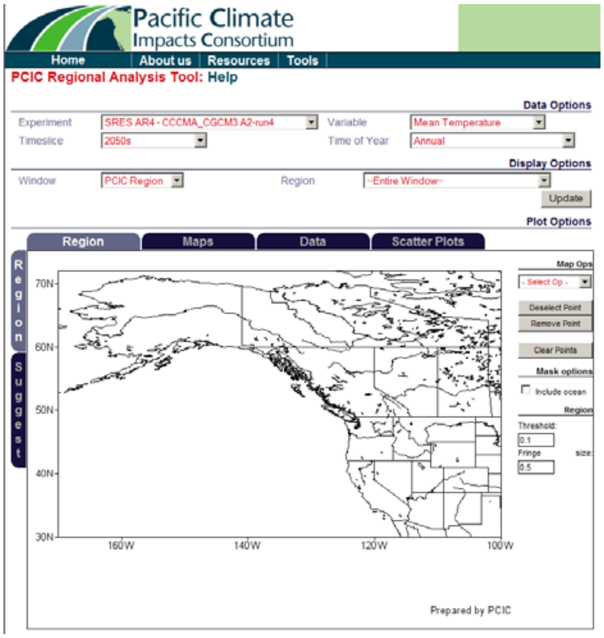
Disclaimer: Predictions of baseline and future climates are based on downscaled PRISM and predictions from various global circulation models. Authors do not bear any liability for financial or other losses due the use of this program.

Contact: Tongli Wang

Figure 8: A screenshot of the interface of the web-based version of ClimateWNA.



PCIC Regional Analysis Tool: Help

Data Options

Experiment: SRES AR4 - CCCMA_CGCM3 A2-run4

Variable: Mean Temperature

Timeslice: 2050s

Time of Year: Annual

Display Options

Window: PCIC Region

Region: --Entire Window--

Threshold: 0.1

Fringe: 0.5

Figure 9: Screen shot of PIC's Regional Analysis Tool.

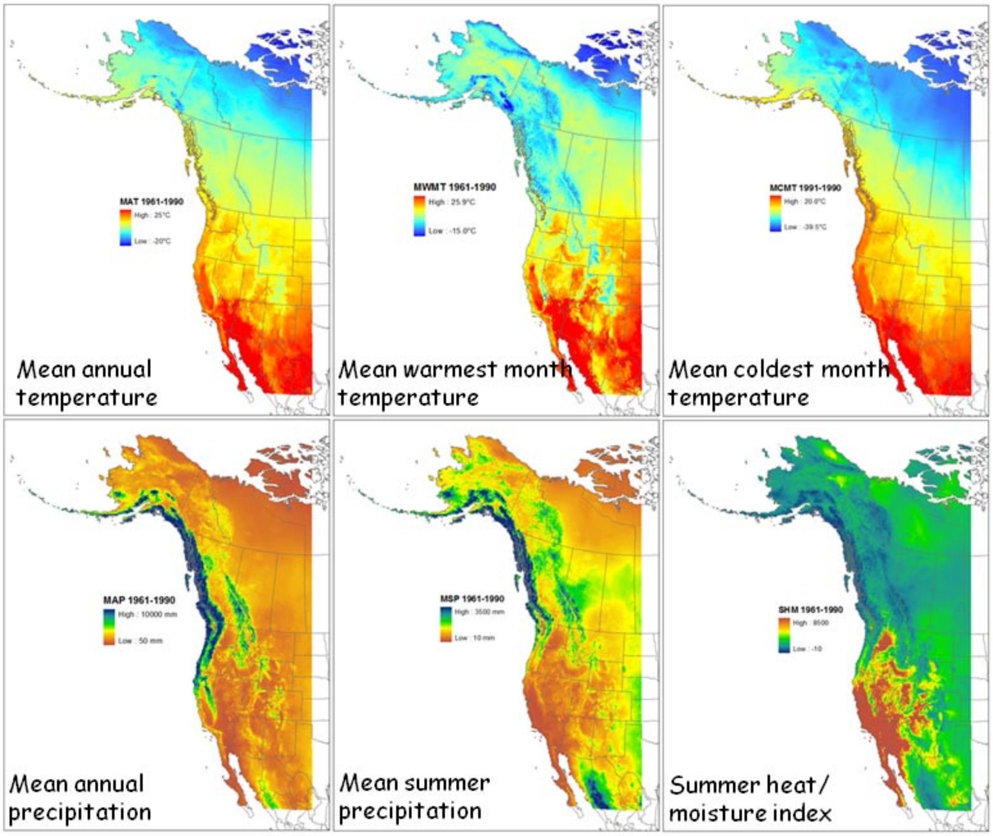


Figure 10: Maps of six major biologically relevant climate variables in Western North America generated from ClimateWNA data.

and annual results. Features include averaging over pre-defined or custom regions, creating maps, meta-data summaries, plots, and downloading data. Web access is at http://www.pacificclimate.org/tools/regionalanalysis/

The RAT was originally a source of future GCM climate projections until spring 2008 when historical climate at high resolution from ClimateBC (Wang et al. 2006) was made available. The high resolution data were later extended using output from ClimatePP (Mbogga et al. 2009) as well as historical data from a global 0.5° dataset (CRU-TS) (Mitchell and Jones 2005). The future time period 2040-2069 (2050s) has been added over the entire BC and Western Canada domain for five different Global Climate Models (GCMs) and emissions scenarios.

Examples of Using Spatial Climate Data from ClimateWNA

Spatial distribution in reference evaporation in BC is shown in Figure 5. The high evaporative demand of the Okanagan valley stands out against the lower demands on the surrounding Okanagan Plateau. Maps of six climate variables frequently used in modeling plant-climate relationships are shown in Figure 10. These maps provide an excellent view of the spatial distribution in climate. Annual precipitation falling as snow and how it might change under a

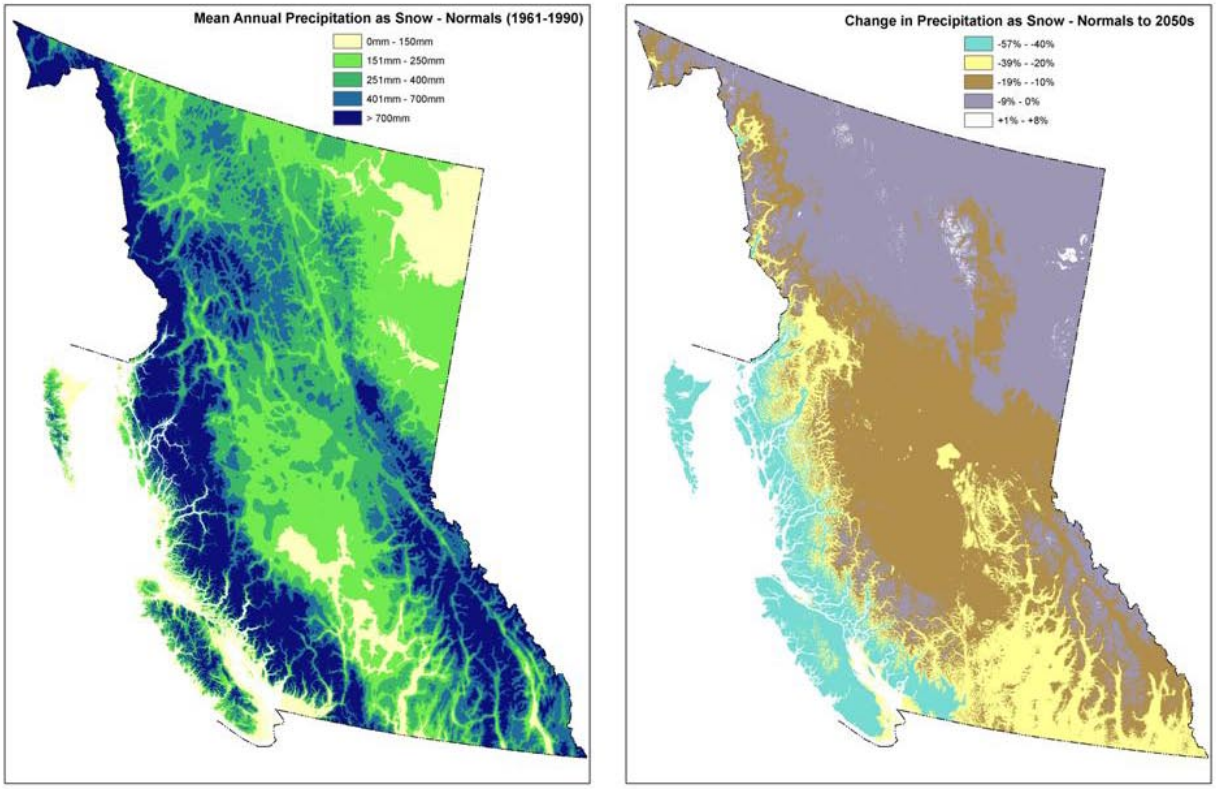


Figure 11: Precipitation as snow (mm) for 1961-90 normals (left panel) and percent change by 2050s under the A2global warming emissions scenario and the Canadian GCM2 (right panel). (Maps produced by A. Walton, BC MoFR.)

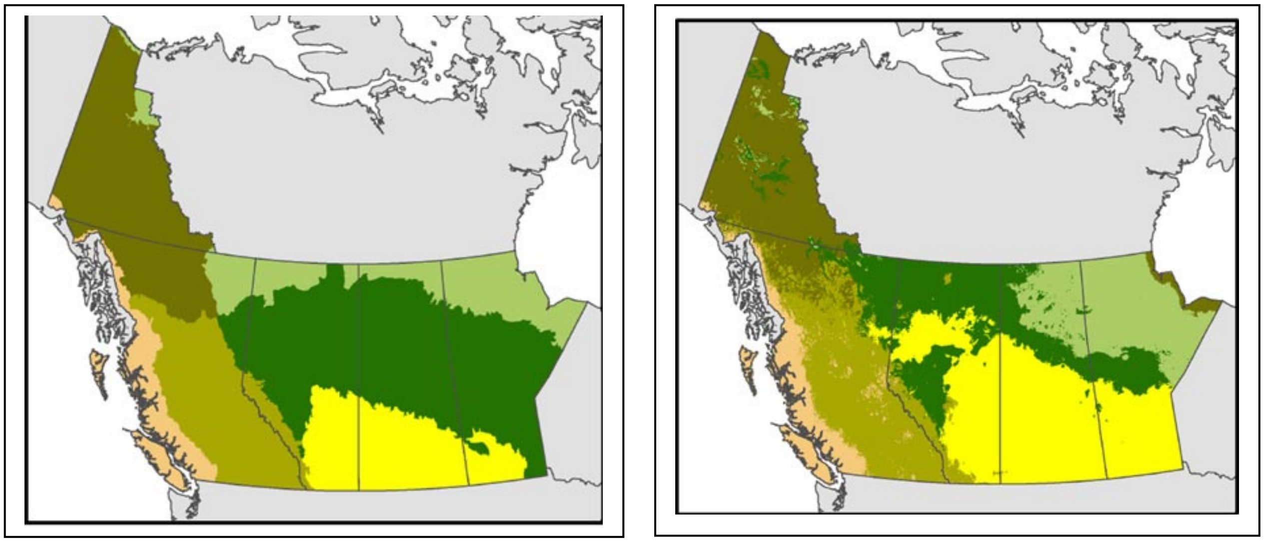


Figure 12: Modelled ecoregion climate envelops under 1961-90 climate and projected for 2020s based on Canadian GCM2-B2 scenario in Western Canada. Spatial climate data were generated from ClimatePP. (Modified from Mbogga etal. 2009).

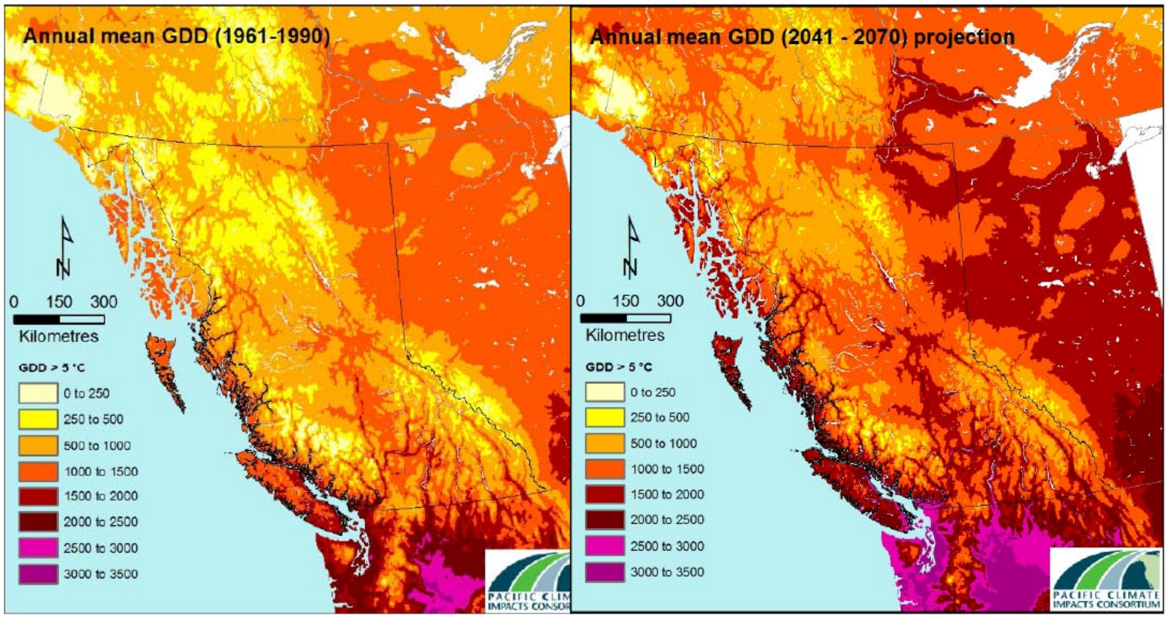


Figure 13: Growing degree days (>5 degrees C) as derived by ClimateBC for the 1961-1990 normals (left panel) and the CGCM3 SRES A2 run 4 2041-2070 projection (right panel).

global warming scenario are shown in Figure 11. Figure 12 illustrates how spatial climate data can be used to generate climate envelopes for ecosystems and review where the ecosystem climate might occur under a global warming scenario.

The Pacific Climate Impacts Consortium is using spatial data such as derived variables such as growing degree days (Figure 13) and frost free period (Figures 14) to illustrate impacts of climate change for community climate impacts analyses and several different community projects to be published 2009/2010. The gridded data from ClimateBC have been used to prepare maps of historical analog years to future periods. The intention is to give stakeholders examples that will help them to understand what future climate might be like and response of the resources they manage and societal response. For example, Figures 15a and 15b indicate that the winter of 1997/1998 was similar to that projected for the mean climate in 2050’s (for one climate change scenario and GCM). Consequently, management actions in response to weather in 1997/98 may become the norm by the middle of the century. A recently submitted manuscript entitled “Geographic variation in growth response of Douglas-fir (Pseudotsuga menziesii) to climate variability and projected climate changes” made use of data from ClimateWNA.

Extension

A scientific article was published on ClimatePP, the Prairie Provinces program, (Mbogga et al. 2009) and one is being prepared on ClimateWNA. Desktop and web-based versions of the program were produced (Figure 7 and 8) to aid users. The Pacific Climate Impacts Consortium is developing a system to visualize gridded data and provide access to such data (Figure 12) under FSP Project F090115. About 20 presentations have been made to scientists, foresters,

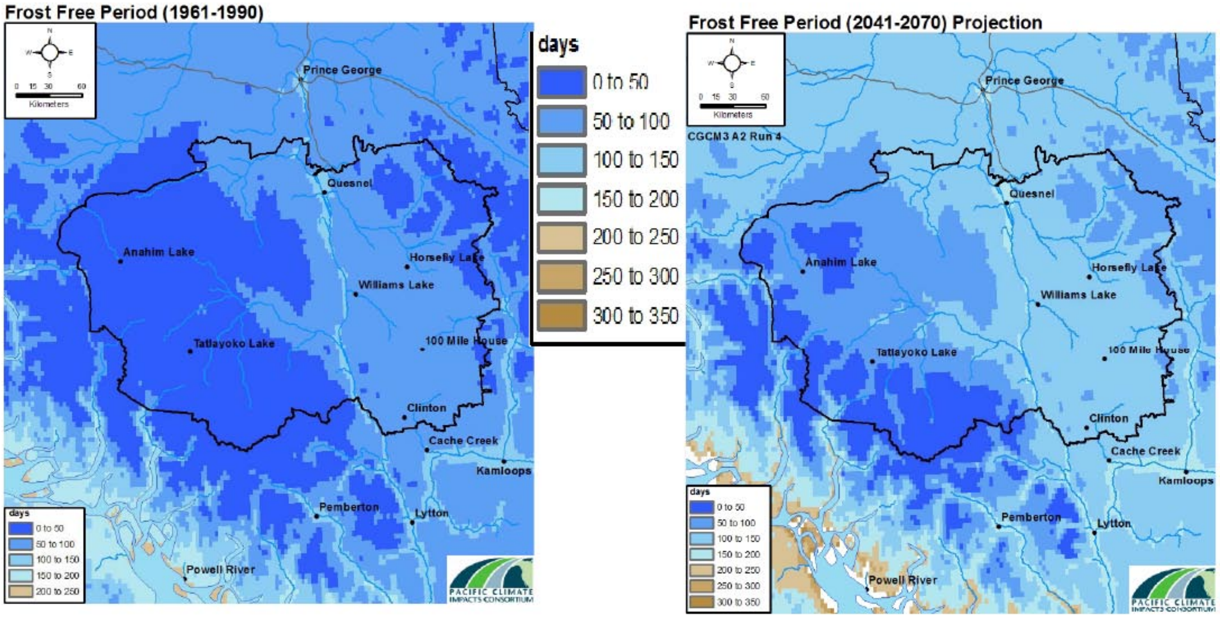


Figure 14: Frost Free Period as derived by ClimateBC over the Cariboo Chilcotin for the 1961-1990 normals (left panel) and the CGCM3 SRES A2 run 4 2041-2070 projection (right panel).

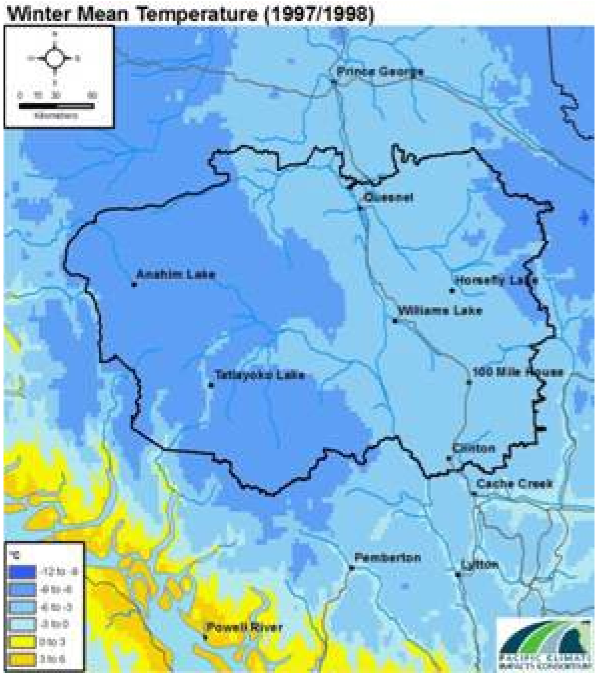


Figure 15a: Winter mean temperature for 1997/1998.

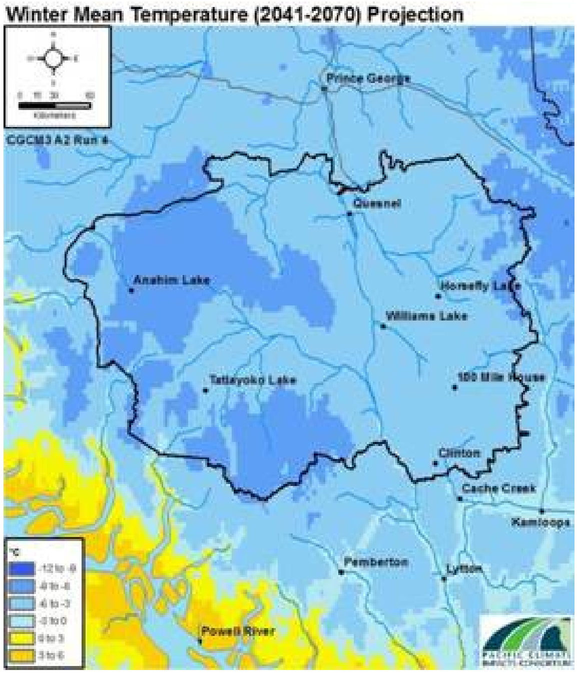


Figure 15b: CGCM3 SRES A2 run 4 winter mean temperature projection for 2050s.

hydrologists and the general public that used data from the software, or described the project. A presentation on ClimateWNA was made at Paclim09 by Dave Spittlehouse in April 2009 to publicize the program amongst researchers in western North America.

Summary

ClimateWNA provides ready access to historical and future climate data at any resolution. It is easy to use and provides reliable estimates of a wide range of climate variables. Along with ClimateBC and ClimatePP, ClimateWNA has become a valuable tool in climate change studies in resource management. However, there are limitations to what ClimateWNA can do. The data represent weather station climate. Consequently, features such as rain shadows, temperature inversions, and slope and aspect effects are modeled at a scale of several kilometers while lapse-rate driven temperature differences are represented at the scale hundreds of metres. Small-scale climate features such as frost pockets or local slope and aspect effects are not represented. Finally, the shorter the historical time interval of interest, the less reliable the climate surfaces.

Literature Cited

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper FAO56, U.N. Food and Agriculture Organization, Rome. www.fao.org/docrep/x0490E.

Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. *Climate Research* 22:99-113.

Daly,C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *Int. J. Climatol*. (2008) DOI: 10.1002/joc.1688.

Dawson, R., A. Werner, and T.Q. Murdock, 2008. Cariboo-Chilcotin: Climate change analysis suggests future work needed to assess vulnerabilities, *LINK* Fall 2008 10(3), FORREX.

Dawson, R. A. Werner, and T.Q. Murdock, 2008. Preliminary analysis of climate change in the Cariboo-Chilcotin Area of British Columbia. Pacific Climate Impacts Consortium, Victoria, BC, 49 pp. http://www.pacificclimate.org/docs/publications/CaribooChilcotinClimate.08Sept08.pdf

Flower, A., and T.Q. Murdock, 2008: Symposium addresses science of researching forest pests, climate change, *LINK* Fall 2008 10(3):20-21.

Hamann, A., and T. L. Wang. 2005. Models of climatic normals for genecology and climate change studies in British Columbia. *Agric. For. Meteorol.* 128:211-221.

Hamann, A., and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. *Ecology* 87:2773-2786.

Hamilton, E. H., and S. Haeussler. 2008. Modeling stability and resilience after slashburning across a sub-boreal to subalpine forest gradient in British Columbia. *Can. J. For. Res.* 38:304-316.

Hutchinson, M. F. 1989. A new objective method for spatial interpolation of meteorological variables from irregular networks applied to the estimation of monthly mean solar radiation, temperature, precipitation and windrun. Division of Water Resources Technical Memorandum, CSIRO, Australia 89.

IPCC. 2001. Third Assessment Report of the Intergovernmental Panel on Climate Change IPCC (WG I & II). Cambridge, Cambridge University Press.

IPCC. 2007. Climate Change 2007: The Physical Science Basis. Working Group I, Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Mbogga, M., A. Hamann, and T. Wang. 2009. Historical and projected climate data for natural resource management in western Canada. *Agric. For. Meteorol.* 149:881-890.

Mitchell, T. D., T. R. Carter, P. D. Jones, M. Hulme, and M. New. 2004. A comprehensive set of climate scenarios for Europe and the globe. Tyndall Centre for Climate Change Research.

Mitchell, T. D., and P. D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.* 25:693-712.

O'Neill, G., A. Hamann, and T. Wang. 2008. Accounting for population variation improves estimates of climate change impacts on species' growth and distribution. Journal of Applied *Ecology* 45:1040-1049.

O'Neill, G. A., N. Gordon, T. Wang, and P. K. Ottb. 2007. Growth response functions improved by accounting for non-climatic site effects. *Can. J. For. Res.* 37:2724-2730.

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock and A.T. Werner, 2008. Climate change and watershed hydrology, Part II – Hydrologic implications for British Columbia. *Streamline Watershed Manage. Bull.* 11:8-13.

Rodenhuis, D.R., K.E. Bennett, A.T. Werner, T.Q. Murdock, and D. Bronaugh, 2007: Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium, Victoria, BC, 131 pp.

Shuttleworth, W. J. 1993. Evaporation. *In* Handbook of Hydrology, D.R. Maidment (ed), McGraw-Hill Inc., New York, pp. 4.1-4.53.

Spittlehouse, D. L. 2006. ClimateBC: Your access to interpolated climate data for BC. *Streamline Watershed Manage. Bull.* 9:16-21.

Spittlehouse, D.L. 2009. Evaluation of temperature-based equations for calculating reference evaporation and a climatic moisture deficit at sites in western North America. Unpublished manuscript.

Wang, T., A. Hamann, D. L. Spittlehouse, and S. N. Aitken. 2006a. Development of scale-free climate data for western Canada for use in resource management. *Intl. J. Climatol.* 26:383-397.

Wang, T., A. Hamann, A. Yanchuk, G. A. O'Neill, and S. N. Aitken. 2006b. Use of response functions in selecting lodgepole pine populations for future climate. *Global Change Biol.* 12:2404–2416.

Werner, A.T. and T.Q. Murdock, 2008. Summary Report: Changes in Past Hydro-climatology and Projected Future Change for the City of Whitehorse. Pacific Climate Impacts Consortium, Victoria, BC, 23 pp.