University of Victoria

Selecting, Applying and Interpreting Climate Projections for Hydrologic Modelling: **The Forcing Ensemble**

CSHS Workshop

July 21st, 2022

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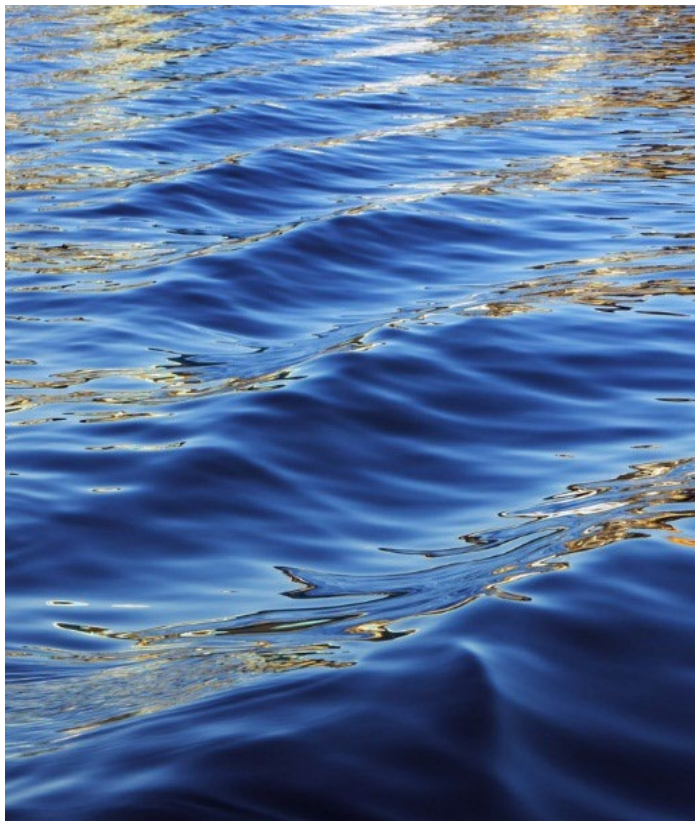
PACIFIC CLIMATE IMPACTS CONSORTIUM



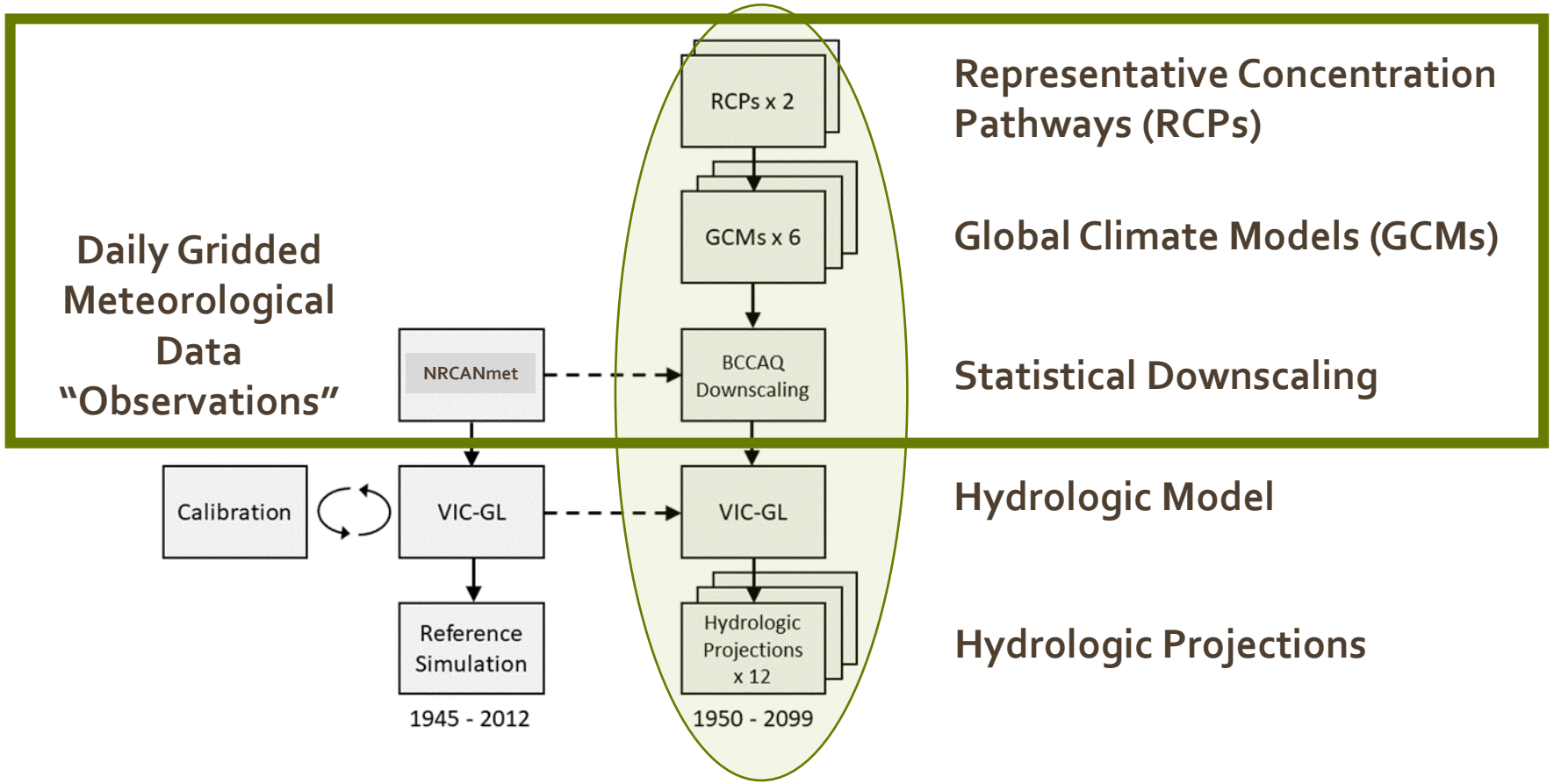
Objectives

- To describe goals for Hydrologic Projections study design
- To introduce PCIC's methods for GCM selection
- To understand the strengths and weaknesses of PCIC's climate projections
  - Downscaling Method
  - Gridded Observations
- To walk through
  - Analysis Tool

  https://pacificclimate.org/analysis-tools/pcic-climate-explorer
  - Data Portal

  https://pacificclimate.org/data/statistically-downscaled-climate-scenarios

Possible future hydrologic conditions are estimated by forcing a hydrologic model with multiple future climate conditions.



The Representative Concentration Pathways (RCPs) used in the fifth Coupled Model Intercomparison Projection (CMIP5) describe emissions pathways leading to different levels of warming by the end of this century.

RCP 8.5 refers to the concentration of carbon that delivers global warming at an average of 8.5 watts per square meter across the planet.

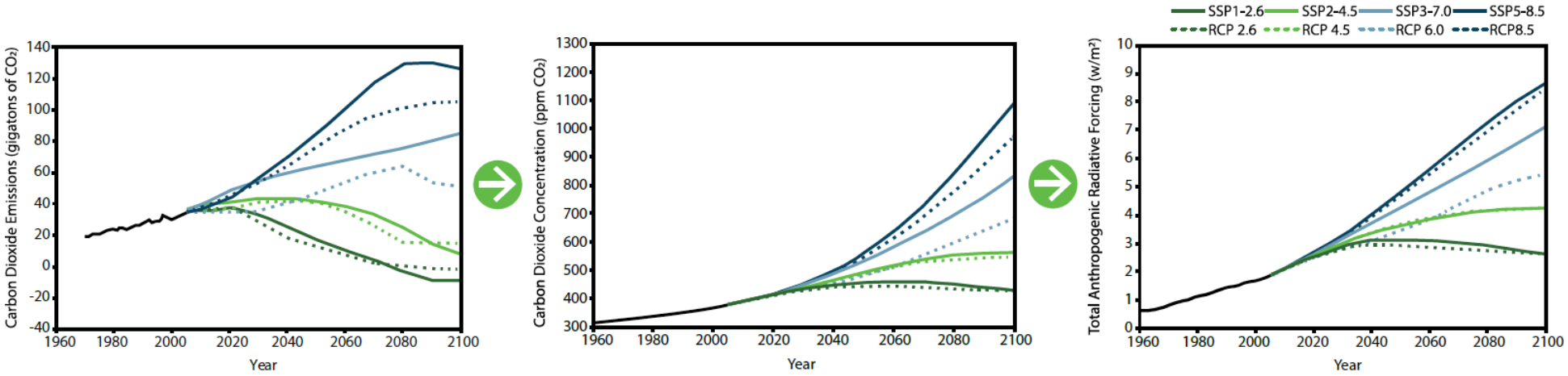
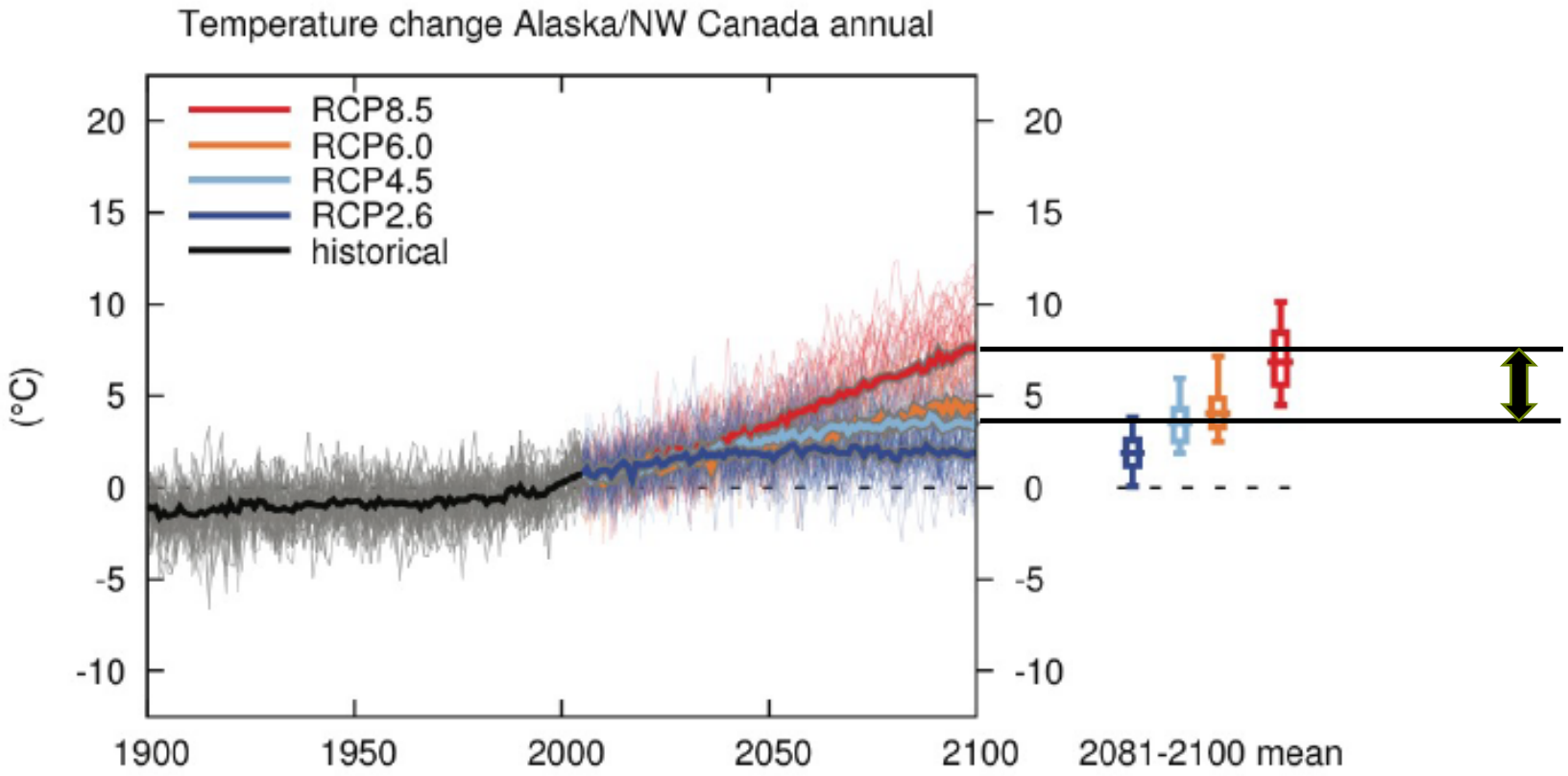


Figure 1: The emission of GHGs such as carbon dioxide (CO2) into the atmosphere (left) alters their global mean concentrations (centre), which results in a net radiative forcing (right; Aside). The magnitude of the radiative forcing, along with various feedback processes, determines how much the climate will change. This figure shows results for the Representative Concentration Pathways (RCPs, solid lines) of CMIP5 and Shared Socioeconomic Pathways (SSPs, dashed lines) of CMIP6. After O'Neill et al. (2016).

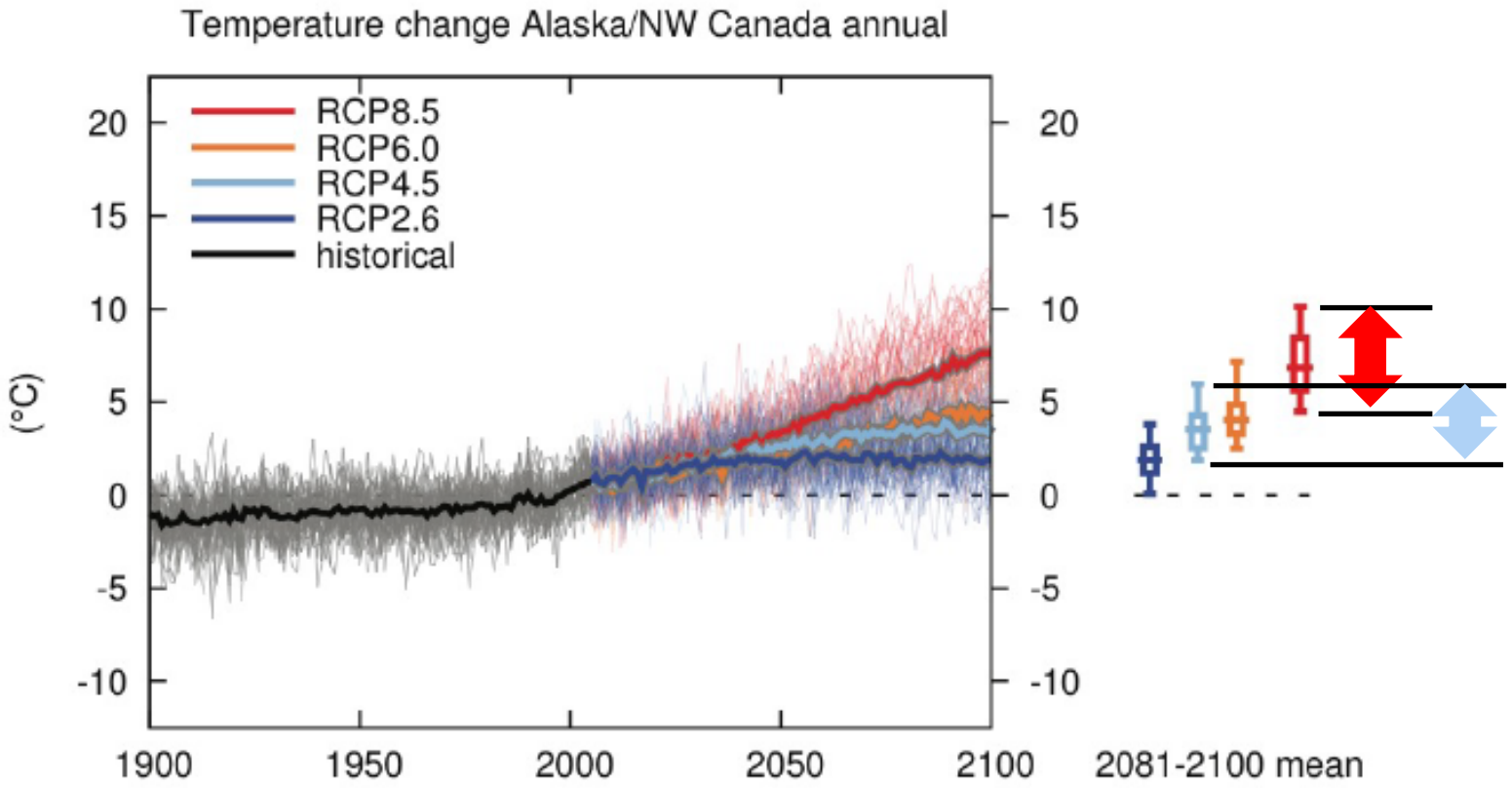
We are certain that the future is uncertain, that is why we have to look at range of possible futures.



Range in mean temperature change at the end of the century **between RCP 4.5 and RCP 8.5**

https://pacificclimate.org/sites/default/files/publications/Revised_Hydro_Scenarios_ENV_Water_Use_Allocation_Report_21Jun2021.pdf

We are certain that the future is uncertain, that is why we have to look at range of possible futures.



Range in mean temperature change at the end of the century **between GCMs and natural variability** for RCP 4.5 and RCP 8.5

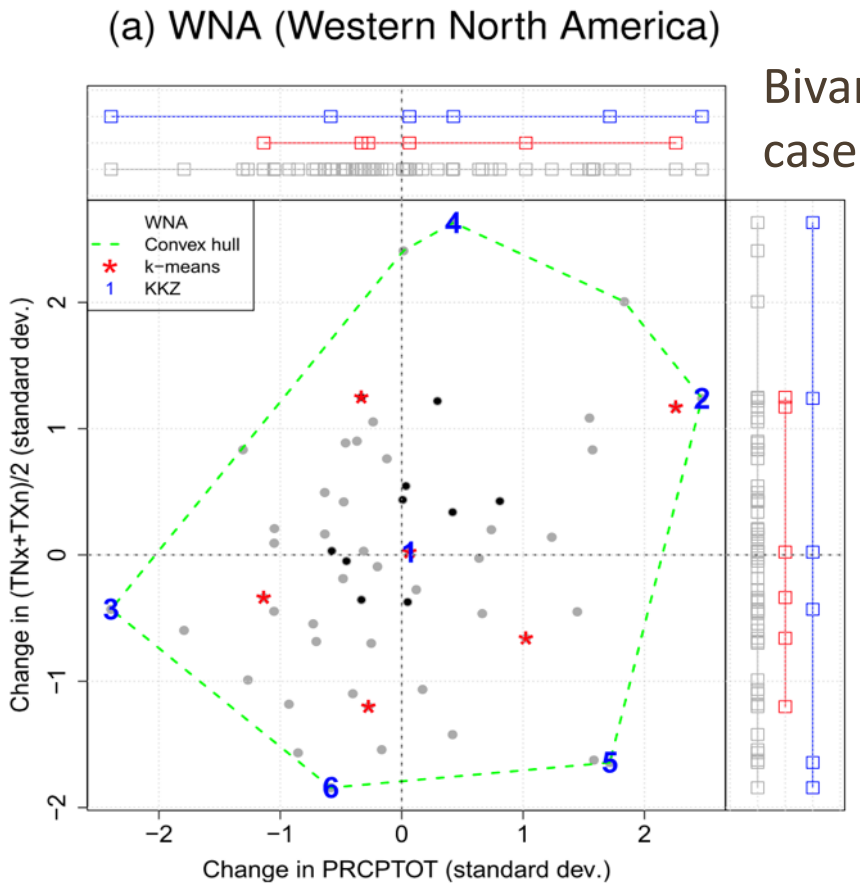
https://pacificclimate.org/sites/default/files/publications/Revised_Hydro_Scenarios_ENV_Water_Use_Allocation_Report_21Jun2021.pdf

PCIC has a method for sub-setting the CMIP5 GCMs that captures the range in future climate by region.

For CMIP5, PCIC employed the algorithm of Katsavounidis-Kuo-Zhang (KKZ), as implemented by Cannon (2015), computing Euclidean distance in multi-dimensional space between standardized variables and those from the entire ensemble, according to:

1. Select GCM closest to ensemble mean first;
2. Select GCM furthest from this model next;
3. Select subsequent GCMs to be furthest from the model closest to the centroid of the already-selected models
4. Repeat from step 3. until specified stopping criterion (e.g., max. range of changes vs. ensemble) is achieved

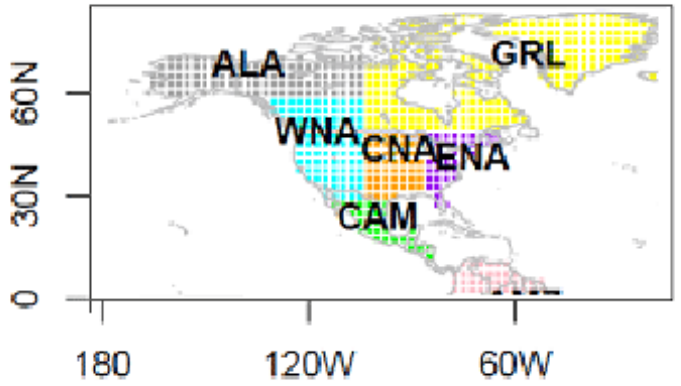
Cannon, A.J., 2015: Selecting GCM Scenarios that Span the Range of Changes in a Multimodel Ensemble…, *J. Climate.*, **28**, 1260.



Bivariate case

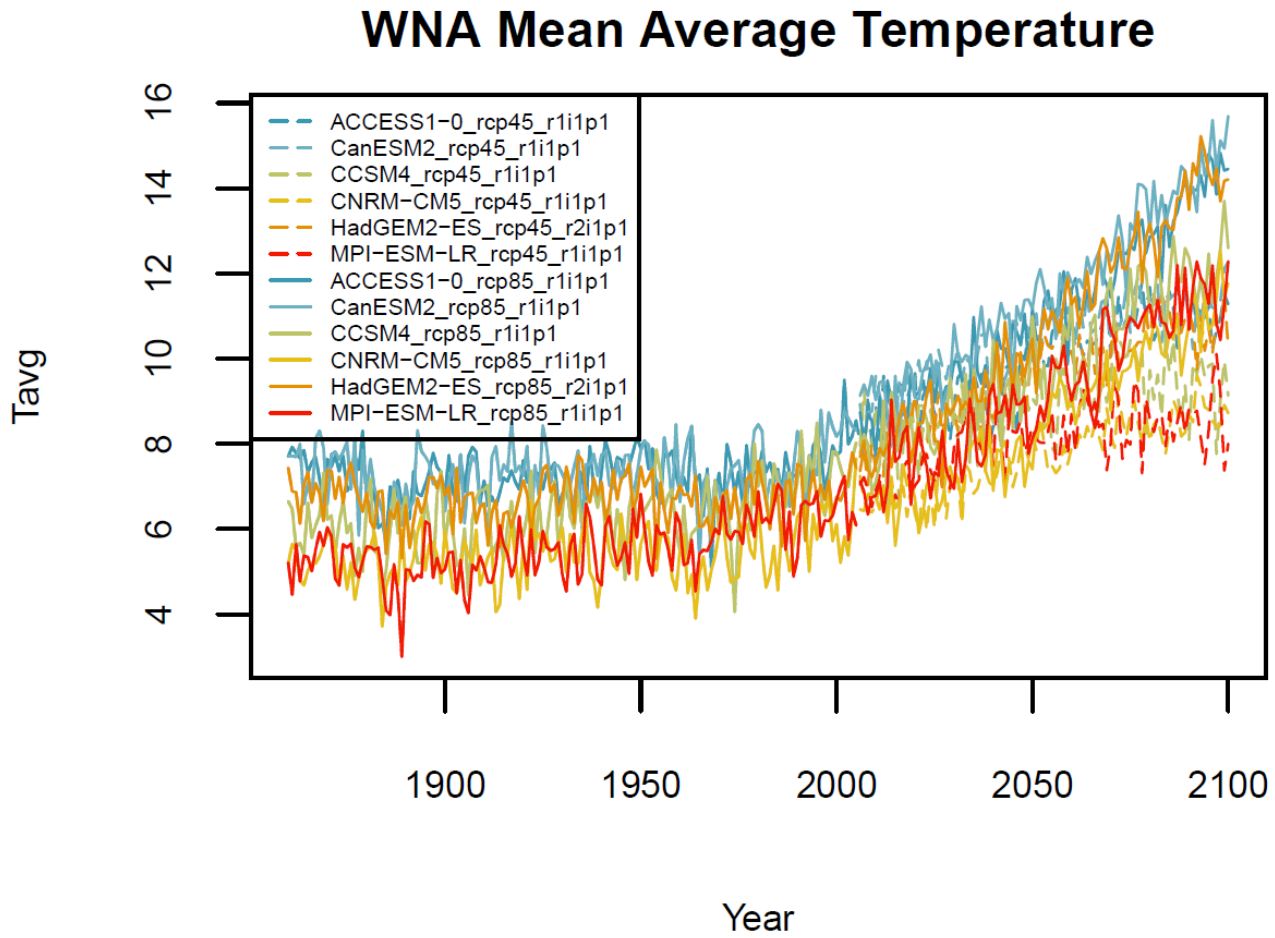
PCIC lists the 12 CMIP5 models that represent 90% of the range in projected change in T and P by Giorgi region.

Model Ensembles and Giorgi Regions					
Order	WNA	ALA	CNA	ENA	GRL
1	CNRM-CM5-r1	CSIRO-Mk3-6-0-r1	CanESM2-r1	MPI-ESM-LR-r3	MPI-ESM-LR-r3
2	CanESM2-r1	HadGEM2-ES-r1	ACCESS1-0-r1	inmcm4-r1	inmcm4-r1
3	ACCESS1-0-r1	inmcm4-r1	inmcm4-r1	CNRM-CM5-r1	CanESM2-r1
4	inmcm4-r1	CanESM2-r1	CSIRO-Mk3-6-0-r1	CSIRO-Mk3-6-0-r1	CNRM-CM5-r1
5	CSIRO-Mk3-6-0-r1	ACCESS1-0-r1	MIROC5-r3	HadGEM2-ES-r1	ACCESS1-0-r1
6	CCSM4-r2	MIROC5-r3	HadGEM2-ES-r1	CanESM2-r1	CSIRO-Mk3-6-0-r1
7	MIROC5-r3	HadGEM2-CC-r1	MPI-ESM-LR-r3	MRI-CGCM3-r1	HadGEM2-ES-r1
8	MPI-ESM-LR-r3	MRI-CGCM3-r1	CNRM-CM5-r1	CCSM4-r2	MIROC5-r3
9	HadGEM2-CC-r1	CCSM4-r2	CCSM4-r2	MIROC5-r3	HadGEM2-CC-r1
10	MRI-CGCM3-r1	CNRM-CM5-r1	GFDL-ESM2G-r1	ACCESS1-0-r1	CCSM4-r2
11	GFDL-ESM2G-r1	MPI-ESM-LR-r3	HadGEM2-CC-r1	HadGEM2-CC-r1	MRI-CGCM3-r1
12	HadGEM2-ES-r1	GFDL-ESM2G-r1	MRI-CGCM3-r1	GFDL-ESM2G-r1	GFDL-ESM2G-r1



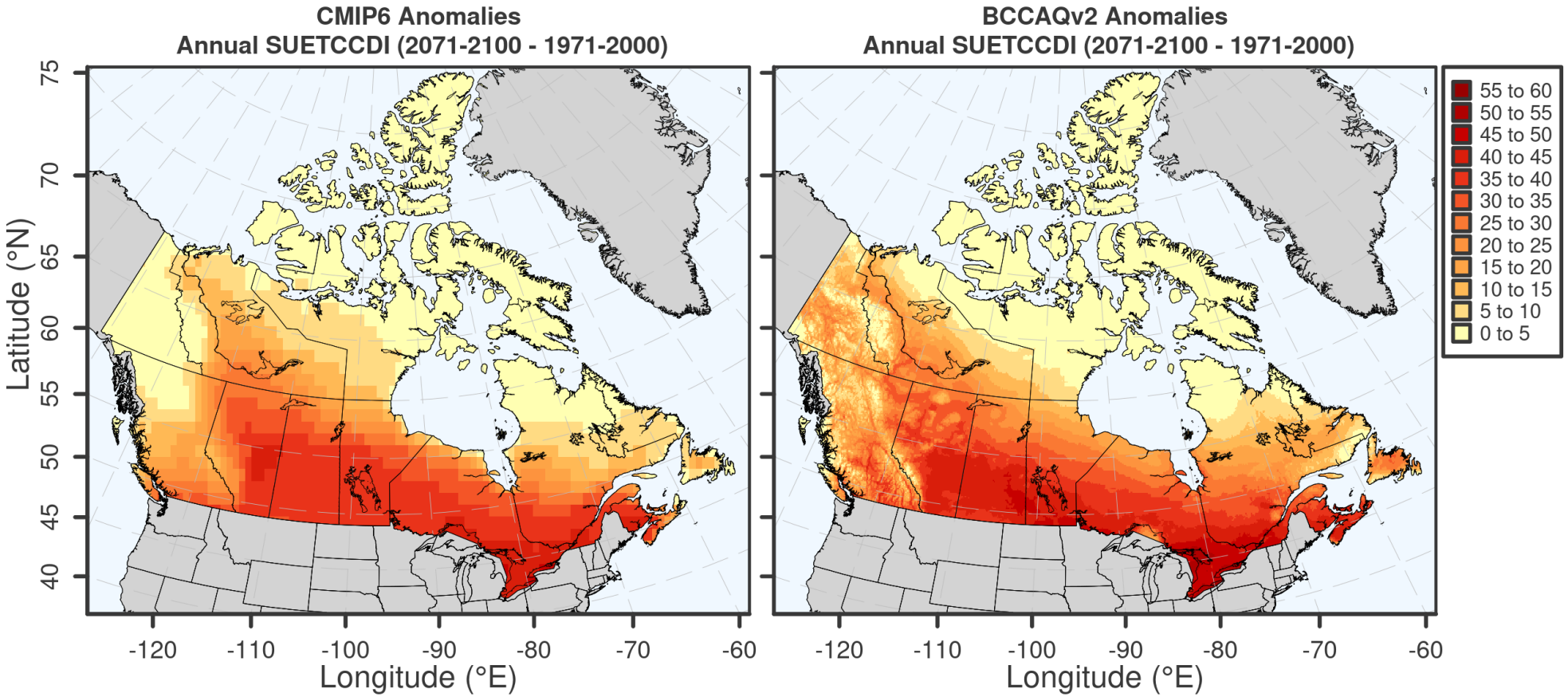
Giorgi regions that intersect with Canada: Alaska (ALA), Western North America (WNA), Central North America (CNA), Greenland (GRL), Eastern North America (ENA) and Central America (CAM).

Tavg over WNA for six GCMs and two RCPs selected for our Hydrologic Projections.



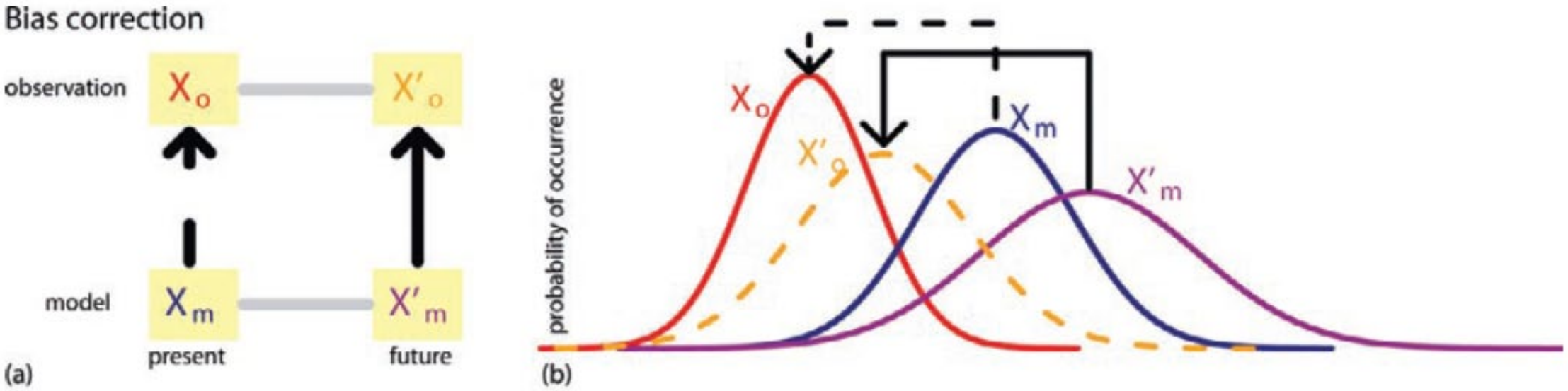
Range in Tavg in WNA by 2100 due to two RCPs and six GCMs

GCMs are available at ~100 km grid boxes while we need data to run our hydrologic model at ~10 km.



Statistical Downscaling - Bias Correction/Constructed Analogues with Quantile Mapping Reordering (BCCAQv2)

Bias Correction Statistical Downscaling



Daily Gridded Meteorological Datasets are created from interpolating observed station data to a grid.

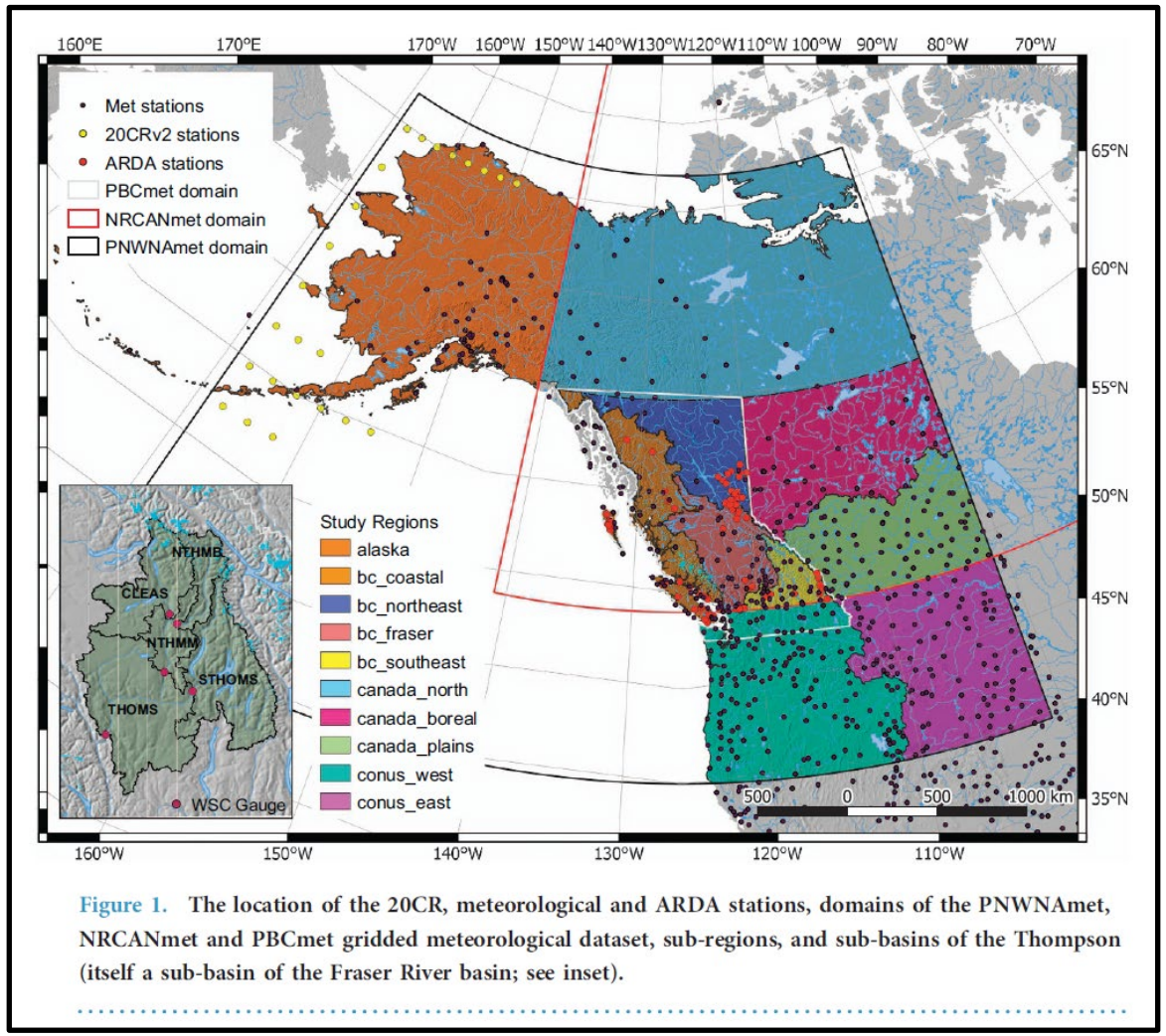
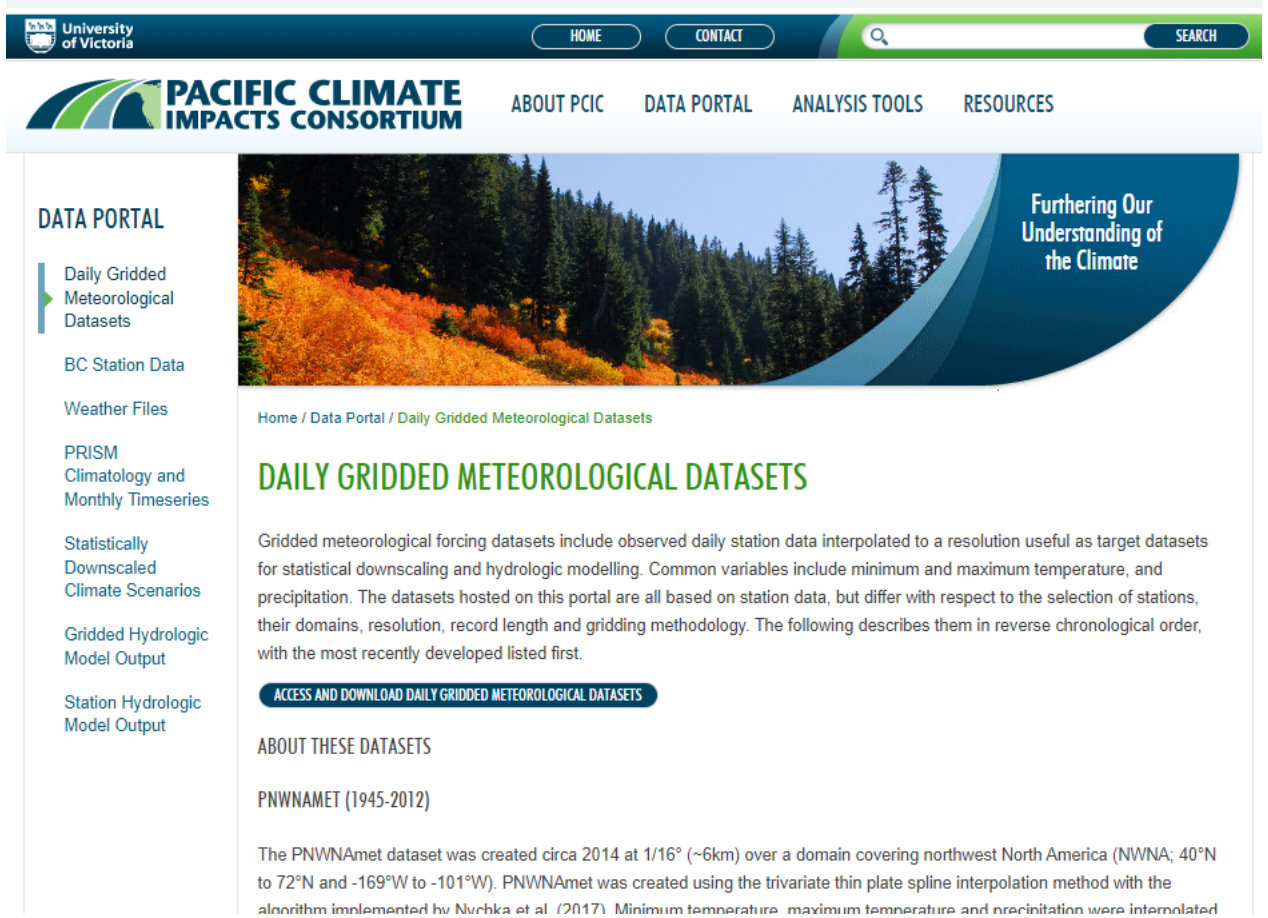


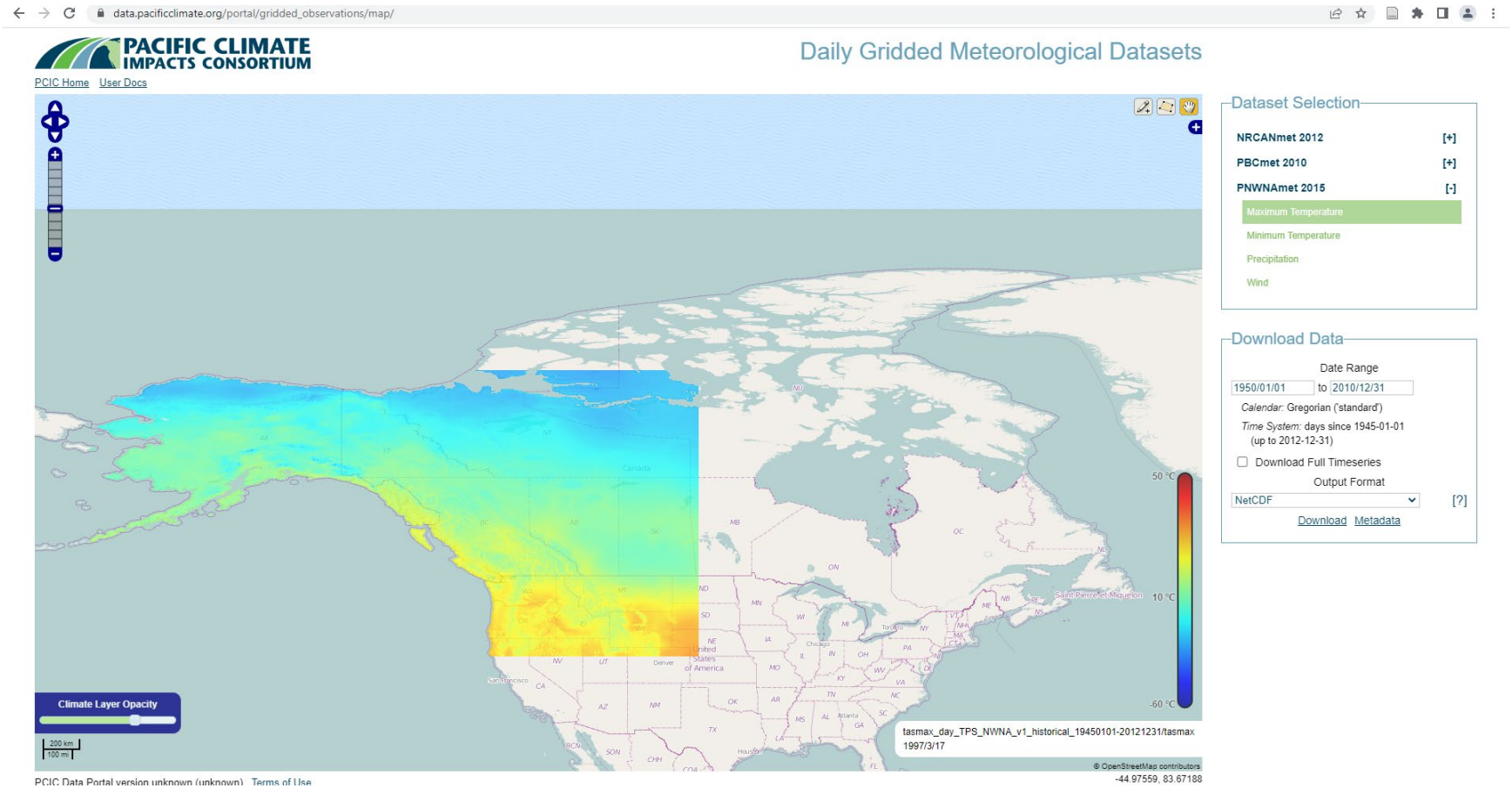
Figure 1. The location of the 20CR, meteorological and ARDA stations, domains of the PNWNAmet, NRCANmet and PBCmet gridded meteorological dataset, sub-regions, and sub-basins of the Thompson (itself a sub-basin of the Fraser River basin; see inset).

Target Daily Gridded Meteorological Datasets Used in Statistical Downscaling at PCIC – **Data Portal**

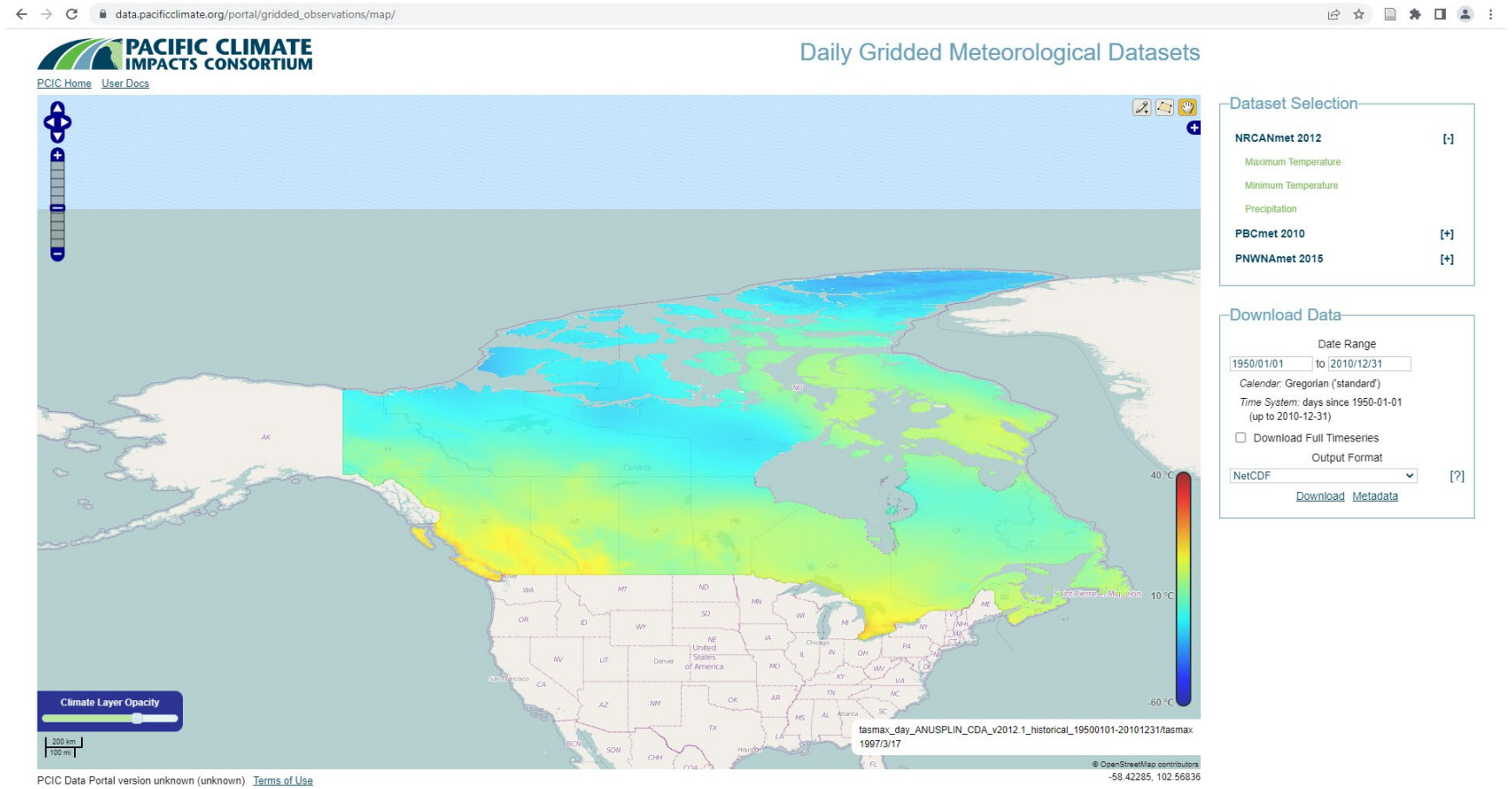
https://pacificclimate.org/data/daily-gridded-meteorological-datasets



Target Daily Gridded Meteorological Datasets Used in Statistical Downscaling at PCIC - **PNWNAmet**



Target Daily Gridded Meteorological Datasets Used in Statistical Downscaling at PCIC - **NRCANmet**



BCCAQv2 has been found to be stronger than several other statistical downscaling approaches for temporal and spatial representation of daily temp. and prec.

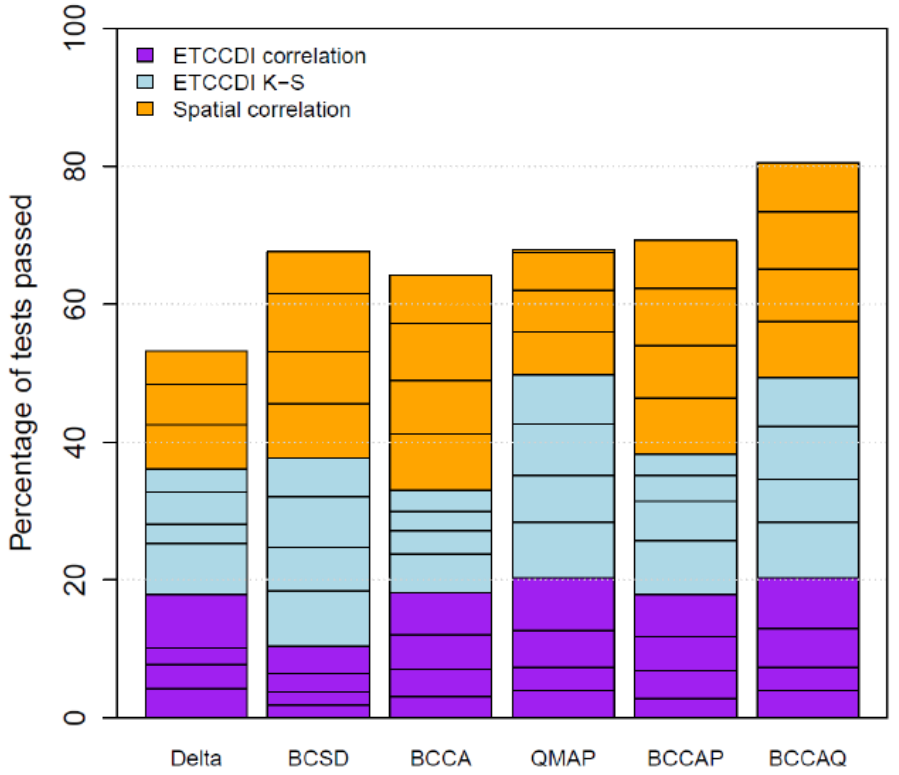


Figure 2: test results across different downscaling methods, that assess the ability of each method to represent temporal sequencing (correlation, purple), distribution of values (blue), and spatial patterns, across different test cases (horizontal bars). For more details refer to Murdock, Hiebert and Sobie (2016).

Bias Correction/Constructed Analogues with Quantile Mapping Reordering (BCCAQv2)

The NRCANmet Daily Gridded Meteorological Dataset has a dry bias in the mountainous regions of BC and the Yukon versus PNWNAmet.

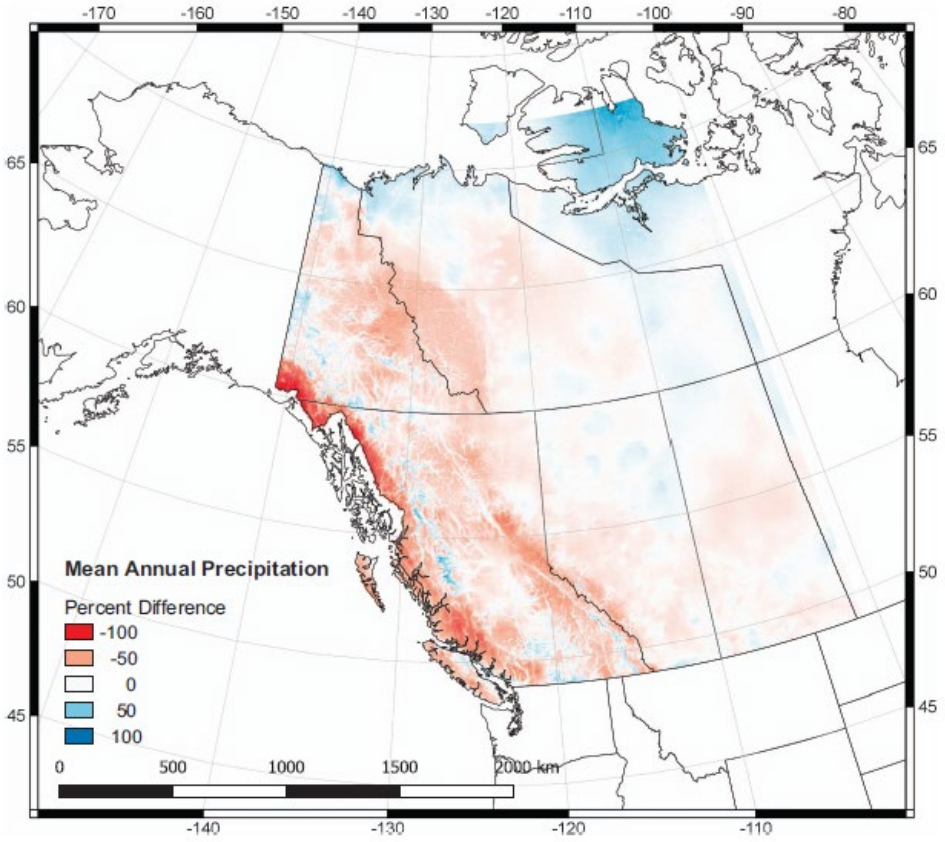


Figure 5. Percent difference in mean annual precipitation for NRCANmet minus PNWNAmet.

Other websites and tools where PCIC's BCCAQv2 NRCANmet CMIP5 data is used:

- PCIC Climate Data Explorer

https://pacificclimate.org/analysis-tools/pcic-climate-explorer

- Prairie Climate Centre Climate Atlas

https://climateatlas.ca/

- Climatedata.ca

https://climatedata.ca/

- CCCS Climate Data Extraction Tool

https://climate-change.canada.ca/climate-data/#/downscaled-data

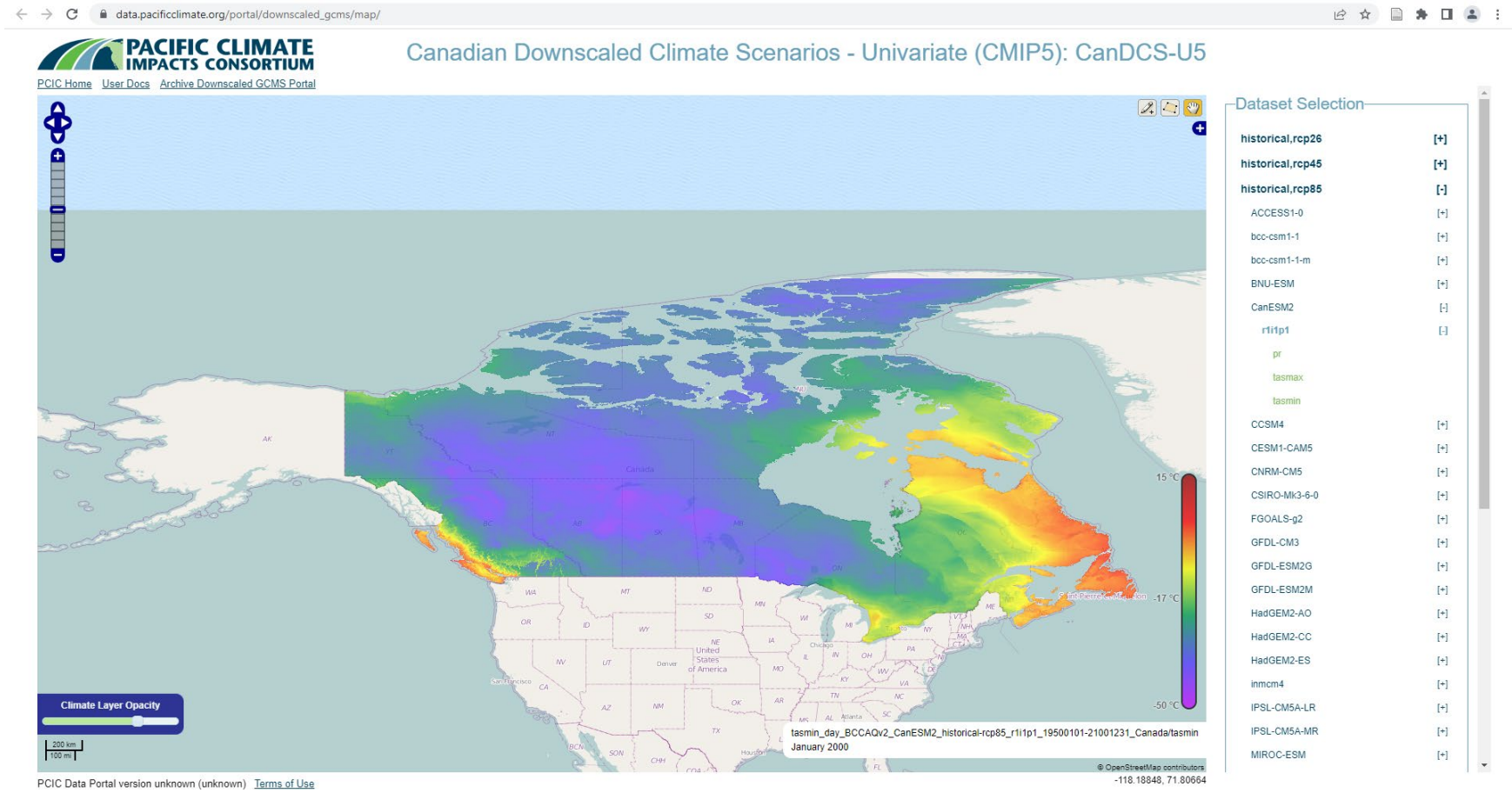
- IDF-CC Tool

https://www.idf-cc-uwo.ca/

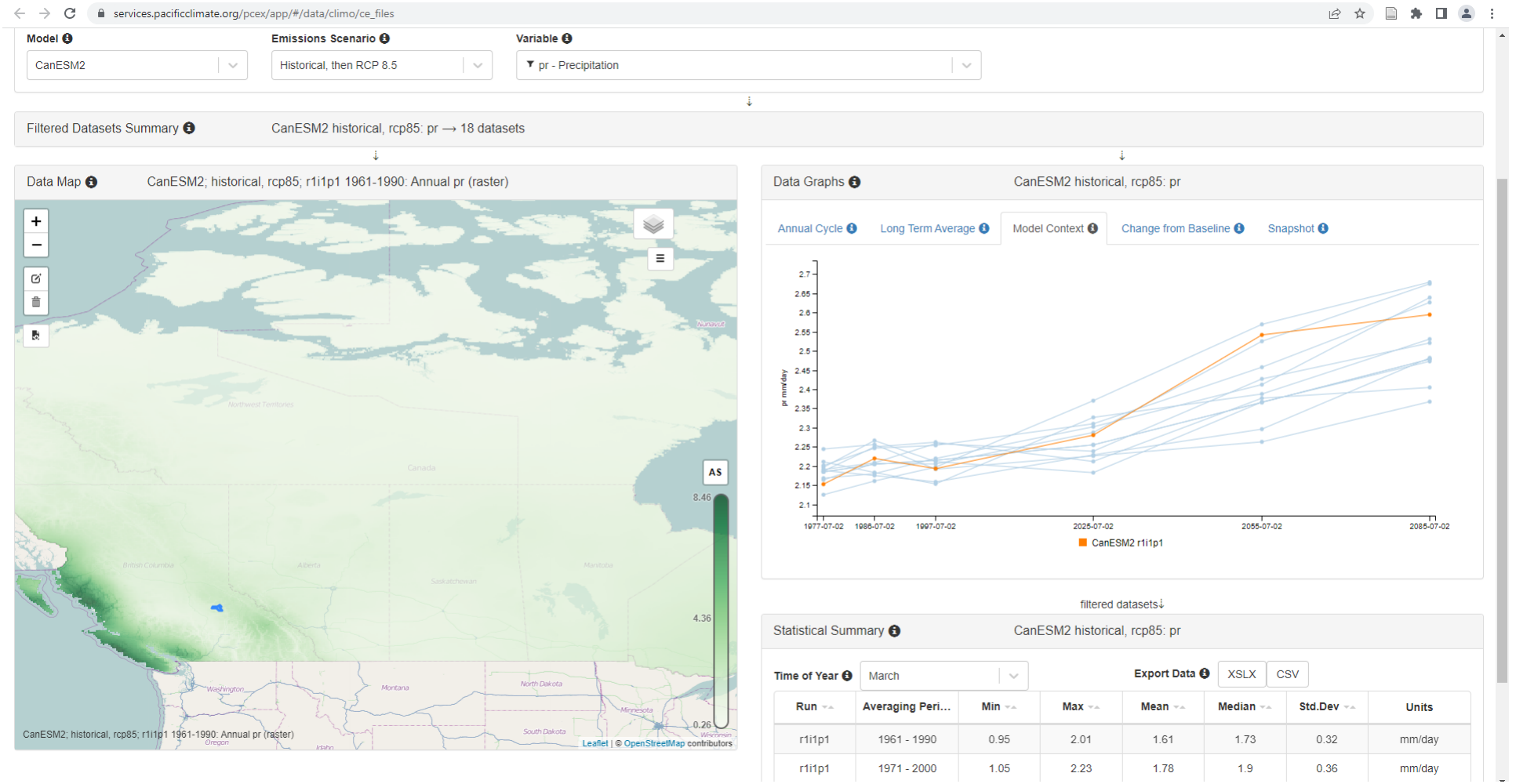
- Power Analytics and Visualization for Climate Science (PAVICS)

https://www.crim.ca/en/computer-research-institute-of-montreal/achievements/pavics-power-analytics-and-visualization-for-climate-science

BCCAQv2 Statistically Downscaled Climate Scenarios NRCANmet (ANUSPLIN) are available across Canada.



One can explore where the GCMs they've selected fit within the PCIC12 on PCIC's Climate Explorer.



Summary

- Because the future is uncertain we chose to look at a range of possible futures.
- PCIC has summarized the top 12 CMIP5 GCMs the cover 90% of the range in T and P by Giorgi climate region on its data portal.
- In our hydrologic projections study, we selected two RCPs and six GCMs to explore uncertainty contributed by emission trajectories, natural climate variability and GCM sensitivity to green house gas forcing.
- We calibrate our hydrologic model to the same Daily Gridded Meteorological Dataset the statistical downscaling (BCCAQv2) is calibrated to.
- For CMIP5 and CMIP6 BCCAQv2 statistically downscaled GCMs, NRCANmet is the Daily Gridded Meteorological Dataset GCMs were bias corrected against.

Tutorial #1 – Selecting and Extracting BCCAQv2 Data

Tutorial #1 - Selecting and Extracting BCCAQv2 Data

Three of the Pacific Climate Impact Consortium's (PCIC's) websites are helpful to hydrologic modellers:

1) The Statistical Downscaled Climate Scenarios data portal:
   https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios
2) The Daily Gridded Meteorological Datasets data portal:
   https://pacificclimate.org/data/daily-gridded-meteorological-datasets
3) The PCIC Climate Explorer:
   https://www.pacificclimate.org/analysis-tools/pcic-climate-explorer

In this exercise, we are going to learn how to use a combination of these tools to select and extract gridded precipitation, minimum and maximum temperature projections for an area of interest. We focus on results from the fifth Coupled Model Intercomparison Project (CMIP5) that were downscaled with BCCAQv2 (Bias Correction/Constructed Analogues with Quantile delta mapping reordering), which is a hybrid method developed at PCIC that combines results from Bias Corrected Constructed Analogs (BCCA; Maurer et al. 2010) and Quantile Delta Mapping (QDM; Cannon et al. 2015). BCCA uses spatial aggregation from a linear combination of historical analogues for daily large-scale fields. QDM applies a form of quantile mapping where relative changes in GCM quantiles are preserved to avoid inflationary effects that can occur with standard quantile mapping. This technique has been shown to be successful in downscaling such that changes in hydrologic extremes can be well simulated (Werner and Cannon 2016). BCCAQv2 is an updated version of BCCAQ (version 1), which employed standard quantile mapping. CMIP5 GCMs were downscaled using NRCANmet as a target. NRCANmet + CMIP5 + BCCAQv2 = CanDCS-U5. CanDCS-U5 is available over all of Canada at ~10 km a side, on a daily time step, for 23 Global Climate Models (GCMs) and 3 Representative Concentration Pathways (RCPs) (Figure 1).

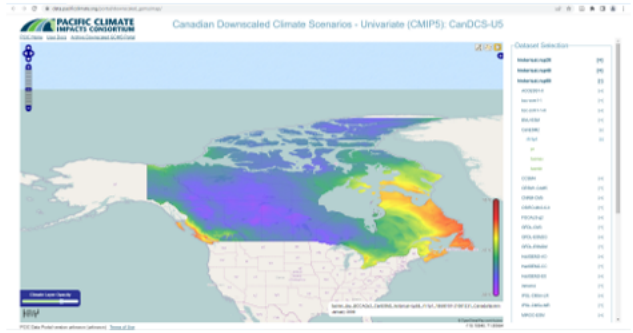


Figure 1 - Screen shot COUPLED MODEL INTERCOMPARISON PROJECT PHASE 5 (CMIP5) data portal

PCIC - CSHS Webinar July 21st, 2022 10:00 AM to 12:00 PM PST
Title: "Selecting, Applying and Interpreting Climate Projections for Hydrologic Modelling"

Running and analyzing multiple hydrologic simulations can be quite onerous and computationally challenging. PCIC proposes a set of 12 GCMs that represent 90% of the range in several climate extremes by Giorgi region (Figure 2). In the case of our recent work with VICGL in BC, we chose a subset of six models and compared the response of each of these models under RCP 4.5 and RCP 8.5. In addition, to including the top three models for Western North America (WNA): CNRM-CM5-r1, CanESM2-r1 and ACCESS1-0-r1 based on the ranking by Cannon 2015, we also included CCSM4, HadGEM2-ES and MPI-ESM-LR because they were in the PCIC12 and matched those used by other institutes in Canada we collaborate with, such as Ouranos.

Exercise:

1) **Find the top six GCMs in your Giorgi region.**
2) **Compare temperature and precipitation changes in the 2050s from these six models for a region or watershed of interest using the PCIC Climate Explorer.**
3) **Download one of the GCMs as netCDF that is in the top six in your region of interest using the Statistical Downscaling Climate Scenario data portal.**
4) **When does the netCDF start and when does it end?**
5) **What are the variable names of the files you have downloaded?**

Working ahead:

Downloading multiple models from the server using 'wget' statements. This is possible with a point (specified in array indices) or a bbox (a range of indices):

https://data.pacificclimate.org/portal/docs/raster.html#power-user-howto

PCIC - CSHS Webinar July 21st, 2022 10:00 AM to 12:00 PM PST
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Tools and packages for working with NetCDFs:

- R ncdf4:
  https://cran.r-project.org/web/packages/ncdf4/index.html
- R gdal:
  https://cran.r-project.org/web/packages/rgdal/index.html
- R raster:
  https://cran.r-project.org/web/packages/raster/index.html
- NetCDF Operators (NCO):
  http://nco.sourceforge.net/
  http://research.jisao.washington.edu/data_sets/nco/
- Climate Data Operators (CDO):
  http://www.idris.fr/media/ada/cdo.pdf
  https://code.mpimet.mpg.de/projects/cdo/wiki/Tutorial
- ncview:
  http://meteora.ucsd.edu/~pierce/ncview_home_page.html

References

Cannon, A.J., 2015: Selecting GCM scenarios that span the range of changes in a multimodel ensemble: application to CMIP5 climate extremes indices(link is external). Journal of Climate, 28(3): 1260-1267. doi:10.1175/JCLI-D-14-00636.1

Cannon, A.J., S.R. Sobie, and T.Q. Murdock, 2015: Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes?(link is external) Journal of Climate, 28(17), 6938-6959, doi:10.1175/JCLI-D-14-00754.1.

Giorgi, F. and Francisco, R., 2000: Evaluating uncertainties in the prediction of regional climate change. Geophysical Research Letters, 27(9), 1295-1298, doi:10.1029/1999GL011016.

Hiebert, J., A. Cannon, A. Schoeneberg, S. Sobie, and T. Murdock, 2018: ClimDown: Climate Downscaling in R. The Journal of Open Source Software, 3(22), 360, doi:10.21105/joss.00360.

Hopkinson, R.F., D.W. McKenney, E.J. Milewska, M.F. Hutchinson, P. Papadopol, and L.A. Vincent, 2011: Impact of Aligning Climatological Day on Gridding Daily Maximum–Minimum Temperature and Precipitation over Canada. Journal of Applied Meteorology and Climatology, 50, 1654–1665. doi:10.1175/2011JAMC2684.1.

Hunter, R. D., and R. K. Meentemeyer, 2005: Climatologically Aided Mapping of Daily Precipitation and Temperature. Journal of Applied Meteorology, 44, 1501–1510, doi:10.1175/JAM2295.1.

Eum, H.-I., Y. Dibike, T. Prowse and B. Bonsal, 2014: Inter-comparison of high-resolution gridded climate data sets and their implication on hydrological model simulation over the Athabasca Watershed, Canada. Hydrol. Process., 28, 4250–4271. doi: 10.1002/hyp.10236.

Tutorial #1 - Selecting and Extracting BCCAQv2 Data

1) The Statistical Downscaled Climate Scenarios data portal:

https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios

2) The Daily Grided Meteorological Dataset data portal:

https://www.pacificclimate.org/data/daily-gridded-meteorological-datasets

3) The PCIC Climate Explorer:

https://www.pacificclimate.org/analysis-tools/pcic-climate-explorer

4) User Docs are your friend:

https://data.pacificclimate.org/portal/docs/raster.html#power-user-howto

Coupled Model Intercomparison Projects (CMIPs).

- CMIPs are a collection of Global Climate Models that work along side the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports with agreed on approaches.
- PCIC recently used BCCAQv2 to downscale CMIP6. Now available.
- A new GCM selection approach is being developed by Dhouha Ouali, Stephen Sobie, and Charles Curry for CMIP6. This is a PCIC initiative.
- PCIC's Hydrologic Projections are based on CMIP5.