PACIFIC CLIMATE IMPACTS CONSORTIUM

Climate Analysis and Monitoring

Research Plan for 2015-2019

14 January 2015

University of Victoria

Faron Anslow

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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/.

Disclaimer

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Climate Analysis and Monitoring

Research Plan for 2015-2019

1. Introduction

1.1 Background: Means for Broad-Scale Understanding of BC's Climate

The province of British Columbia spans a diversity of climates ranging from moist, temperate forests along the southwest coast to arid regions in the interior, sub-arctic taiga in the northeast to high altitude ice fields in the Coast Range. Furthermore, the large-scale climate variations are perturbed locally by topography which induces such features as rainshadows, cold air pooling, and orographic influence on temperature and precipitation. These effects lead to diverse climate regimes in close proximity. This range is exemplified by the annual climatology of precipitation and temperature shown in Figures 1 and 2 respectively. The climate of BC is furthermore complicated by the province's proximity to the Pacific Ocean. Natural variability in the region owing to the El Niño Southern Oscillation has been widely documented and has impacts on temperature and precipitation especially during the winter months. related to this variability, recent research has been divided on whether climate change along the west coast of North America is detectible owing to the influence of sea surface temperatures on climate of the region and the large decadal and longer temporal scale natural variability associated with the northeast Pacific Ocean (Abatzoglou et al., 2014; Johnstone and Mantua, 2014). Inland of the coast, temperatures have warmed substantially and are less dependent on the modulating effects of the Pacific. Detection of BC regional change associated with the changing global climate will benefit from a description of British Columbia’s climate baseline in the form of station based measurements and spatially interpolated climatology. Analysis of climate data also allows for calculation of recent seasonal weather anomalies and extremes where they occur. These data, in conjunction with other atmospheric data sets, can also be used in a research context to examine physical mechanisms that lead to the occurrence of anomalies and extremes in British Columbia weather, and as targets for statistical downscaling.

Climate has most reliably been measured through instrumental observations of weather variables over long periods of time. In British Columbia, station measurements date back to the early 1870s and there are substantial numbers of measurements throughout the 20th century through to present. These data are useful for characterizing the mean climate state and the statistical variability about that mean, thus setting the background for climate change and extremes analysis. A nearly complete archive of station observations for British Columbia is now housed at PCIC and is supplemented in near real-time through automated connections with Environment Canada and two of the larger provincial observational networks: The Ministry of Transportation and Infrastructure and the Ministry of Forests, Lands and Natural Resource Operations. Automated procedures for delivery of monthly updates from BC Hydro are also in place.

In the last ~40 years, more observational tools have become available such as remote sensing. Examples of weather related remote sensing instruments include Doppler radar on the ground and satellites capable of measuring a wide variety of variables using multispectral sensing. These techniques are useful for assessing conditions over large areas nearly simultaneously, but their observational records are fairly short and the life-span of individual instruments is generally less than a decade making homogeneity a major issue. These factors continue to limit their use for understanding climate variability on multidecadal and longer timescales, yet remote sensing data are incorporated into atmospheric reanalysis which enable better climate analysis. Looking forward, observational records from remote sensing will become better homogenized and the records long enough for longer-term climatological work.

Station observations have their own pitfalls including changes in instrumentation, station location, and physical setting that occur over time. Observational records are also subject to interruptions in station records due to lack of funding, community needs, maintenance among other reasons. Station data represent a valuable resource to many types of users including applied researchers, the interested public, and industry despite these limitations (Miles and Associates, 2003). Furthermore, it is the responsibility of the custodians of climate data to ensure that the quality of the data and any efforts to improve the data are fully documented and that this documentation is passed on to subsequent users.

One application of station data is the production of spatially interpolated climatological fields. A four-kilometre resolution climatology was previously developed for BC over the 1961-1990 climate normal period by the PRISM Climate Group at Oregon State University (Daly *et al.*, 1994; Daly *et al.*, 2002; Daly *et al.*, 2008). This product has been used extensively by PCIC and many other users ranging from ecologists to glaciologists to foresters. Along with the value of the PRISM climatology, the ease of access to this data as made available through the ClimateWNA software (Wang *et al.*, 2006; Wang *et al.*, 2011) is a prime reason for its wide use. PCIC alone receives numerous requests for information from the CWNA product. Since the generation of PRISM for the 1961 -- 1990 climate normal period and the development of CWNA, PCIC has produced a new, high resolution climatology for the province as a result of a collaboration with the PRISM Climate Group. This product has been incorporated into Climate BC which is a sister product of CWNA. Despite this update, the end-year of the current mapped normal period is almost 15 years in the past. This places emphasis on the need for maps for the most recent climate normal period of 1981-2010. Once these maps are completed, regular updates will keep BC's climate normal picture up-to-date.

Table 1: Acronyms used throughout this document

Acronym	Meaning
BCMoE	BC Ministry of the Environment
BPA	Bonneville Power Administration
CAM	Climate Analysis and Monitoring
CLIMDEX	Climate Indices for Extremes
CRMP	Climate Related monitoring Program
ENSO	El Niño Southern Oscillation
HI	PCIC Hydrological Impacts Theme
NOAA	National Oceanic and Atmospheric Administration
OSU	Oregon State University
PCDS	Provincial Climate Data Set
PCIC	Pacific Climate Impacts Consortium
PDO	Pacific Decadal Oscillation
PICS	Pacific Institute for Climate Solutions
PRISM	Parameter Regression on Independent Slopes Model
RCI	PCIC Regional Climate Impacts
SCR	Seasonal Climate Review

1.2 The Climate Analysis and Monitoring Theme

The Climate Analysis and Monitoring (CAM) theme at the Pacific Climate Impacts Consortium aims to meet needs for reference climate data and also aims to interpret recent seasonal weather in light of climate data available for the province. Externally to PCIC, the CAM theme is actively supported by the BC Ministry of Environment (BCMoE) and the Pacific Institute for Climate Solutions (PICS) who recognize the fundamental importance of weather and climate observations in the Pacific region in the context of climate variability and change. This research plan identifies the complementary roles of each organization so that data is utilized for practical benefits to industry and government, in addition to its research value. The BCMoE leads the multi-agency effort of CRMP and is primarily responsible for the collection of meteorological data from multiple networks operated by provincial ministries and corporate organizations in the province.

PCIC is committed to the CAM project as a major, strategic theme to provide reference climate data and near-real-time interpretation of recent seasonal weather. This includes, climate monitoring and interpretation of climate variability and trends, as well as the occurrence of extreme events. Presently, CAM remains a developing theme within PCIC. Nevertheless CAM is able to serve the needs for past climate data within PCIC and a broad range of users in BC. These data are used in the private sector, industry, and government for applied research, as well as for information to meet the public interest and as downscaling targets by PCIC's other themes.

The main purposes of the CAM theme are to:

- Incorporate ongoing observations and improve the quality of data in the Provincial Climate Data Set (PCDS): by assembling, hosting, maintaining and providing data access as described in the CRMP agreement (BC Ministry of Environment, 2010).
- Use these data to develop high spatial resolution maps of British Columbia climate for the variables Tmin, Tmax, Tmean, and Precipitation for all months of the year and for the annual mean/total as described in the CRMP agreement and PRISM agreements (2010a,b). Subsequently, use PRISM to develop timeseries maps of monthly mean temperature and precipitation.
- Apply the PCDS to monitor seasonal weather anomalies and relate these anomalies to known modes of seasonal variability in western North America such as the El Niño Southern Oscillation.
- Deliver this information (PCDS, climate maps, and the results of climate monitoring) to the private sector, commercial enterprises, and governments for research, planning and policy guidance. Seasonal information on climate anomalies, trends and extreme events will also meet the interests of the public in British Columbia.

The research activities of the CAM theme can be broken down into three temporal scales which are consistent with those under consideration by the other PCIC themes. For CAM, these timescales are oriented toward the past because this theme is not aimed at forecasting or making climate projections. Specifically, the timescales of interest for the past are:

- *Short-term* – Monthly to annual
- *Near-term* – Annual to decadal
- *Long-term* – Multidecadal to centennial.

Because the majority of CAM research activities are limited by the temporal extent of available station data, activities will be limited to the period from 1870 through the present with an emphasis on the period from the 1950s onward for which observational data are more widely available.

1.3 Progress referenced to the 2012-2016 five-year plan

A useful metric for the planning process and for the progress of the theme itself is to review the previous research plan and assess its prescience. The subsections below reflect the division of the applied research activities from the previous research plan and within each one, the broad accomplishments and remaining unaccomplished activities will be described. Together, these will help lead into the upcoming research plan.

1.3.1 Develop the PCDS

To-date, the PCDS is incorporated into a database and is accessible via a web based portal through a simple interface that makes accessing the data simple for basic and advanced use. An initial version of climate normals has been placed on the data portal for the stations that have sufficient record for this. The database is being updated in near-real time through automated feeds from Environment Canada, the Ministry of Transportation and Infrastructure, and the Ministry of Forests, Lands, and Natural Resource Operations Wildfire Management Branch. Automated monthly updates are also provided by BC Hydro and ingested manually. Together, this comprises the backbone of meteorological data collection in the province but does require PCIC-initiated requests for data from the remaining network operators to keep the dataset as up-to-date as possible. The data in the PCDS has now undergone a basic set of range checks and other simple quality control procedures. There remain a large number of relatively simple quality control methods that should be applied to the data and this remains a priority of the theme as outlined in the research proposed here. However, this remains a yet-to-be realized piece of low hanging fruit to enhance the usability of the dataset for PCIC's users. For a project investigating the occurrence of extreme rainfall due to so-called atmospheric rivers, precipitation records were analyzed for extreme single and multi-day rainfall events. Finally, in support of the recent release of the IPCC WG1 report, temperature records were analyzed for trends in the occurrence of frost-days across BC.

1.3.2 PRISM Mapping

The biggest advancement of the theme in the past two years has been the development and release of new PRISM climate normal maps for British Columbia for the 1971 -- 2000 climate normal period. This process involved significant collaborative work with the PRISM Climate Group at Oregon State University, assistance from a research intern for the spring 2012, and development of a means of integrating snow and glacier observations into the precipitation observation network for the province. These maps have been made available via a web portal through the efforts of PCIC's computational support theme. Most recently, the mapping effort has preliminarily been extended toward developing timeseries maps of monthly average maximum temperature, minimum temperature, and precipitation from 1950 onward. PCIC has also been contracted by the BPA and NOAA to develop climate maps for the 1981 -- 2010 climate normal period and this work is underway. Developing methods to assess uncertainty and sensitivity of PRISM has not been tackled save for initial methodological discussions with Chris Daly and the inclusion of Alex Cannon in the effort. Finally, a comparison between PRISM and the output from other gridded climate products is yet to be completed but would be valuable both internally and externally to PCIC.

1.3.3 Seasonal Climate Reviews

The CAM theme has been regularly issuing maps showing the monthly temperature and precipitation anomalies at observational sites in BC. The maps are now made available on the PCIC website on the second of every month for the preceding month and refreshed with updated data on the 15th of each month. In the past year, some time has been invested in developing a similar, automated system for mapping anomalies from an atmospheric perspective using the North American Regional Reanalysis. This supports rapid analysis of atmospheric conditions that may have led to anomalies observed at stations as presented in the earlier product. In both of these efforts, progress has been made to cast the anomalies in the perspective of the statistical distribution of the historical record such that each month's anomaly at each station (or location in the reanalysis) is presented in the context of expectation for that location. Although not yet a component of the seasonal climate reviews, CAM has invested effort in developing methods to spatially interpolate anomalies and then use the interpolated products to investigate trends in temperature, precipitation and their derivatives (such as Frost Days) province-wide as well as over smaller regional subsections such as the Ecoprovinces.

2. Research Plan

2.1 Purpose

This section is intended to outline the research activities of the CAM theme from 2014 through 2018. Individual activities are organized into two-year and five-year outlooks and are separated among the broad research areas of the CAM theme. The proposed methodology for achieving the objectives outlined below is given in section 3.

2.2 Two-year Research Objectives

2.2.1 Development of the Provincial Climate Dataset

In its present state, the PCDS is assembled and available through PCIC's data portal. Activities related to the dataset will therefore focus on maintaining the near real-time ingestion of observational data and improving the data already present in the database such that its value is enhanced for users. This effort will be furthered by working jointly with the CRMP to begin cataloguing metadata for stations in the PCDS. This is a major task, so it will extend over the two- and five-year timespans of this research plan. Initial efforts are underway to establish basic, standardized information at stations that are part of the CRMP’s climate network. These include sensor siting, orientation, exposure, and basic sensor information. Surprisingly, while some of these data are gathered by most networks, there is not yet a unifying standard for all networks in BC’s government. Further efforts to gather this basic data will greatly enhance the value of the PCDS data. Additionally, projects focussed on analyzing the station data and adding value will be conducted. The current activity of computing trends on province-wide and regional scales is one example. Within the two-year timeframe, calculation of the CLIMDEX indexes on the station data will be a priority. This activity necessarily follows on the heels of further quality control efforts, including the homogenization of key long-duration records that have not yet been homogenized by Environment Canada.

2.2.2 PRISM Mapping

Creating the 1981-2010 climate normal maps is one of the most important applied research activities for the CAM theme in the near term. This work has been contracted by NOAA and the BPA in the United States. At the time of this writing, the process is under way with a deliverable date of March, 2015. Beyond this timeframe, focus will turn toward generating a set of monthly time-series maps of temperature and precipitation with aim toward completion by 2016. This will enable the merging of PRISM mapping products with seasonal climate review activities which rely on a separate stream of spatially interpolated data. The third major research goal is to develop an uncertainty product to accompany PRISM climate and timeseries maps.

2.2.3 Delivery of Climate Information and Service Objectives

Activities in this section are tied to work in the previous two in terms of data delivery and public-facing products. Regional anomaly and trend maps will be used to update the 2002 climate indicators report (BC Ministry of Environment, 2002) and these methods may be used to update trends and assess monthly and seasonal anomalies in terms of the historical record. This will be part of the seasonal climate review process in the next two years and will contribute to updating the regional climate summaries that the RCI theme is undertaking this year. In the near-term, automated generation of circulation anomalies from the North American Regional Reanalysis (Messinger et al., 2006) will be released with the monthly and seasonal anomaly maps to aid in interpreting observational anomalies. Finally, the station-based anomaly product will be modified to reflect anomalies in terms of the historical record of the station to indicate the anomaly normalized to each station's variability. This will allow users to quickly grasp how unusual a given month or season's anomaly is within the scope of the station's record. Finally, we aim to make an initial release of the monthly PRISM timeseries maps on the web portal by the end of the 2015-1016 fiscal year. The generation of the maps is an ambitious undertaking, and the full release is not likely to occur prior to the end of fiscal year 2016-2017. However, once the maps are generated, delivery of the maps will be straightforward owing to the extensible nature of the data portal developed by PCIC's Computational Support group.

2.3 Five-year Research Objectives

2.3.1 Development of the Provincial Climate Dataset

Developing the PCDS will be an ongoing effort throughout the span of this and subsequent research plans. It is expected that work collecting, storing, and delivering metadata will be take a substantial amount of time and will not be completed even in the 5-year scope of this document. However, this effort will add substantial value to the PCDS and is supported by BC government. More importantly from a research perspective, CAM will initiate efforts to homogenize longer records in the PCDS. The aim is to supplement the work of Vincent *et al.* (2002) and Mekis *et al*. (1999) in making a more comprehensive set of benchmark climate records for British Columbia. These efforts will focus on temperature and precipitation variables to begin with. Completion of homogenization efforts is dependent on acquiring metadata on the station data (such as station re-siting, instrument changes and changes to the measurement environment) as well as completion of rigorous quality control of the station data. Because of these somewhat onerous requirements, approaching the homogenization as a staged effort is most appropriate. Initial efforts may focus on automated change detection within records and identification of suitable long-term stations and nearby partner stations. As this is conducted, quality control and metadata process could be performed in parallel. Thus far, much of the work with the PCDS has been oriented toward the primary climate variables of temperature and precipitation. In the long-term, extending anomaly and trend analysis to other variables in the dataset such as wind, snow, and humidity will be explored.

2.3.2 PRISM Mapping

The long term efforts associated with PRISM will be oriented toward near real-time production of maps and extension of the mapping efforts to other variables or derived variables. Early in the extended period, work with PRISM will be oriented toward releasing monthly maps in near real-time as data becomes available from feeds into the PCDS. Efforts to assess the viability of developing a daily PRISM timeseries will also be made. The PRISM Climate Group in the US has an operational component aimed at producing daily maps that is comprised of several full-time employees dedicated to the task in addition to an overall greater availability of observational data. The task is somewhat onerous given the resources available to CAM and PCIC as a whole so daily maps will remain investigational within the scope of this plan. An example of one of the hurdles is the comparative lack of archived and spatially comprehensive radar coverage over Canada. The PRISM group's efforts to create daily maps of precipitation rely strongly on nearly complete radar coverage of the US to establish the precipitation occurrence mask for a given day. Furthermore, as temporal scales shorten, so do the correlation lengths of observed anomalies thus making higher spatial density of observations critical for producing accurate fields. Some portions of British Columbia may not have sufficient spatial coverage to justify high resolution daily PRISM products. However, if users see a need for daily PRISM maps and the task proves feasible, then this may be pursued in future if resources are made available. The most novel application of PRISM will be investigating the potential for using PRISM to map extremes. Preliminary work with station data indicates that extremes follow spatial gradients in a manner similar to longer term averages. Mapping extremes would provide a good framework for ongoing collaboration with the PRISM Climate Group at Oregon State University once uncertainty work is completed. This brings up a broader issue of maintaining the PRISM code in the future. A fruitful approach might involve ongoing collaboration with the PRISM Climate Group through the exchange of in-kind support with each institute contributing resources in their areas of expertise. In the instance of developing an extremes product, PCIC's expertise lies in statistical understanding of extremes as well as nuances of climate and meteorological phenomenon in British Columbia. PRISM Climate Group has experience applying PRISM to alternative climate variables such as humidity, and standard deviation in daily temperature. Combining efforts could lead to a mutually beneficial approach to fulfill a growing demand for understanding extreme events.

Table 2: Research objectives of the Climate Analysis and Monitoring theme.

Objective	Description	Temporal range of study	Priority
1	**PRISM Climatology Mapping:** Development of the 1981-2010 period monthly and annual climate normal maps for British Columbia.	Long-term	1
2	**Development of the PCDS:** Update and maintain the database of historical station data. Implement near-real-time quality control. Begin process of identification of long station records suitable for homogenization and application of change-point techniques. With sufficient meta-data complete homogenization.	Short-term and Long-term	1
3	**PRISM Uncertainty and Sensitivity Analysis:** Perform analysis of PRISM to assess the uncertainty and parameter sensitivity of the maps and use this assessment as an indicator of the utility of the maps as well as to inform users of PRISM climate maps.	Long-term	1
4	**PRISM Time-series Mapping:** Generation of a time series of 30 arc-second maps of temperature and precipitation in British Columbia on a monthly basis. Initially, these maps will be produced for years 1950 to present. Future work will explore production of monthly in near real-time and investigation of production of daily PRISM maps.	Long-term	2
5	**Develop Seasonal Climate Reviews:** Expand the existing station anomaly maps to include regional gridded anomalies and atmospheric circulation anomalies. Aspire to develop a web-tool to allow a user to create custom maps of station and gridded anomalies and data to meet their own needs. Utilize PRISM monthly maps in the anomaly mapping process.	Short-term	2

2.3.3 Delivery of Climate Information and Service Objectives

Activities aimed at delivering climate information will be oriented around the data portal and eventually toward allowing users to begin to customize products to meet their own needs. As they are generated, the PRISM monthly maps will be placed on the data portal. Anomaly maps may be calculated from these but doing so will require careful analysis of the effects of an evolving network on the PRISM maps. Although the present effort of generating monthly analysis of temperature and precipitation anomalies for the province is not labour intensive, the process is not highly flexible. An approach tailored to users' needs by allowing them to select timeframes and variables of interest to generate their own maps and data sets would be ideal. Thus, a useful avenue for seasonal reviews is to develop such automated tools for use by the lay person and the technical user as well. An example use case would answer needs that could arise after the occurrence of a high magnitude precipitation event. The proposed tool could be used to analyse the extent of anomalies, the magnitude (on the timescale of days or hours where data is available) and some of the contributing atmospheric conditions that lead to the event. Because PCIC's services are not intended to be serving the immediate and real-time operational time scale, this tool would be most useful to policy makers, planners, and scientists looking at recent or distant historical events rather than addressing conditions of an evolving system. One existing example of a similar tool was created jointly by Ouranos and Environment Canada and is managed through Climate-Québec (see http://www.climat-quebec.qc.ca). Customized mapping could have a very large scope as described above. For this research plan, we will aim to focus on surface temperature and precipitation observations and a small set of atmospheric circulation variables such as geopotential height, wind components, water vapor, and temperature at several pressure levels and enable analysis on monthly and seasonal time scales first. Once a proof of concept is established and the demands of developing such a tool are understood, then we can reassess any possibility of expanding the tool. Finally, a long-term goal of the theme has been to issue seasonal documents outlining the anomalies for the previous periods and highlighting some of the atmospheric drivers behind those anomalies. By the end of the 5-year research cycle, this should be a firm component of the CAM theme.

2.4 Spatial Domain

The activities outlined in this research plan are intended to provide greater climate understanding over the entirety of the province of British Columbia. The Seasonal Climate Reviews will be described for the province as a whole and also by sub-region. Additionally, some coverage of all of western Canada will be provided through the use of reanalysis data and station data made available by Environment Canada. However, broad and thorough extension of these efforts is somewhat precluded by the lack of a data sharing agreement between these provinces/territories analogous to the CRMP Agreement, although data are becoming better organized in recent years. Subregional break-down of weather reviews will be made following the eco-provinces as shown in Figure 3 as well as the BC Resource Regions which are actively used by organizations within FLNRO as well as other ministries. Descriptions of regional details will enable users of Seasonal Climate Reviews to quickly focus on the locations that they are most interested in. It is important to note, especially for seasonal climate products, that the inferences that can be made for the north and northeast part of BC will be accompanied by greater uncertainty than those for the south of the province owing to the much lower station density in those regions. While much of CAM's focus is province wide, some aspects of the seasonal climate products will apply at the point, or individual station, scale.

3. Approach

3.1 Roles and Resources

The research proposed in this plan will principally be conducted by PCIC with aid from PICS, the BCMoE, and the PRISM climate group. There will be a distribution of work among the research themes of PCIC with CAM taking the leading role, and the CAM lead taking responsibility for assignment and completion of tasks. External collaborative work is planned with the PRISM Climate Group at Oregon State University although PCIC's formal agreement with the PRISM Climate Group has ended. Furthermore, collaborations are expected between the various British Columbia Ministries for the purpose of data sharing and the transfer of metadata.

Data delivery and ongoing work with quality control and metadata will be done in association with the BCMoE CRMP Program, who will also participate by reviewing and interpreting results for planning and policy applications. Furthermore, the BCMoE will insure that the collaborating British Columbia ministries and cooperating organizations who have contributed observational data and site metadata will also receive the benefits from climate analysis and monitoring by PCIC; e.g., access to datasets (PCDS), climate maps and time series.

PCIC's computational support group's resources and expertise will be needed for the development of web-facing tools to access PCDS data, various climate products produced by the CAM theme, and interactive analysis tools. Their support has enabled very efficient development of existing web products and other software at a much higher level of quality than so-called research grade software.

3.2 PCDS

3.2.1 Quality Control

Much of the research work associated with the formation of the PCDS revolves around the intertwined efforts of performing quality control on the data and calculating station normals. Beyond the already-applied range checks, further quality control will incorporate nearby station data to identify outliers and, at the most sophisticated, will incorporate machine learning-based methods for the detection of errors in measurements. Some examples can be found in the work of Dereszynski et al. (2007) and Hill et al. (2009). These approaches will not be implemented until the later part of this research plan.

Comparison of measurements at one station with those from a nearby station is a part of so-called buddy checking. The PRISM climate mapping process provides an avenue for doing this at the monthly timescale, so by proceeding with climate mapping, better quality controlled station data will arise iteratively. In addition to the PRISM approach, we propose to apply a unified set of quality control procedures to the temperature and precipitation records in the data set at the daily time scale using techniques already published in operational manuals (such as those from the WMO) and the scientific literature. Specifically, these will focus on approaches that use the statistics of the data within a given station to identify outliers as well as approaches using nearby stations to identify faulty measurements or periods of offset (a selection of methods are outlined in Belousov et al., 1972; Miller and Benjamin, 1992; Shafer et al., 2000; Durre et al., 2010; Dunn et al., 2012). This analysis will be aided for temperature by using the daily Adjusted Homogenized Canadian Climate Dataset whose stations can serve as anchor stations in regions with sufficient station density for providing "buddy" checks. We will investigate applications of single station quality control in a study region with low station density and combined single-station and station methods in a study region with higher station density. Quality control using nearby stations will be tested in the sparse area as well. It is expected that the precipitation data are of lower quality and will present a greater challenge, especially the observations from the winter season and for remote/high elevation sites. Toward the latter parts of the 5-year period these quality control techniques will be applied to other variables in the PCDS.

3.2.2 Calculating CLIMDEX Indicies

A useful expansion of the description of climate for a given station is to detail the magnitude of extremes observed in the station's record. The CLIMDEX indices provide a standardized suite of quantified descriptors of temperature and precipitation extremes. PCIC has contributed greatly to the understanding of extremes both through contributing to work analyzing extremes in climate projections (Sillmann et al., 2013a,b) and through the development of the "climdex.pcic" R programming package to analyze gridded and station data for the CLIMDEX indices (available at http://cran.r-project.org/web/packages/climdex.pcic/index.html). This R package makes calculation of the CLIMDEX indices straightforward once appropriate quality control measures have been applied to the data. Some of this has been completed as part of a project investigating so-called atmospheric rivers in the province wherein 95th and 99th percentile precipitation events were analyzed. When completed, the CLIMDEX indices will provide an important additional climate descriptor for stations in BC. In a major extension of the PRISM mapping effort, these indicators may be used to create high resolution maps of extremes as outlined below. This will give a novel picture of climate in British Columbia.

3.2.3 Homogenisation of station data

For the purposes of climate analysis, long, continuous records of climate variables are very useful for determining trends. Environment Canada has a set of homogenized temperature, precipitation, sea level pressure, and wind speed data for selected locations Canada-wide. In British Columbia, this comprises ~50 stations for temperature (Vincent *et al.*, 2012; Vincent *et al.*, 2002) and ~100 stations for precipitation (Mekis and Vincent, 2011; Mekis *et al.*, 1999). These records have been created using Environment Canada stations which are often situated at relatively low elevations in BC near human habitation. A similar dataset using stations from the PCDS could extend the spatial coverage to less populous regions and also to high elevation sites. However, the records available in the PCDS are typically shorter than those available from many Environment Canada stations. This does not prevent the creation of homogenized records, but would necessitate the combination of multiple records to make single, long records. Methodology for this has been pioneered by Environment Canada scientists. Adjusting records from a differing locale to create a combined record introduces some uncertainty which would need to be addressed in the final product. Although software and methods are available for homogenizing data records, the process is time consuming and hinges on assembling good metadata for stations. This is important for confirming identified inhomogeneities in a given record arising from station relocation, sensor changes, or issues of station siting. The optimal approach would be to conduct the homogenization effort in stages. The first stage would comprise applying automated algorithms to identify change-points within individual records. Concurrently, or following this, nearest suitable neighbor stations that may be used to create a composite, extended record would be identified. When metadata become available, the automatically identified change-points will be compared with the records for the station possibly confirming or denying a justification for a given shift in the record. Because of the magnitude of the effort and the needed preconditions or station quality control and good metadata, homogenization efforts will be entered into toward the end of the research horizon outlined in this document.

3.3 PRISM

3.3.1 Timeseries Mapping

One of the primary goals with the agreement between the PRISM Climate Group and PCIC was to generate a time series of high-resolution maps of monthly average temperature and precipitation for the province. Production of these maps will provide useful feedback on the quality of the station data they are derived from and a good foundational data set for generating driving data for impacts models (such as hydrologic models, wildfire models, crop models, etc.). The methodology for producing maps has so-far been adopted from the PRISM Climate Groups approach. Maps are generated using climate normals for a given month as one of the predictors in what the PRISM group terms "climatologically aided interpolation". Because monthly mean temperature and precipitation totals demonstrate very similar elevation relationships as climatological values, using PRISM in this mode generates very strong linear relationships between the climatology predictor and the monthly predictand. This is most strongly demonstrated for temperature owing to more complicated interactions between precipitation and topography on month-long timescales. Where stations contain inaccurate or erroneous data, the misfit is often readily obvious which enables the generation of monthly timeseries maps to feedback to the quality assessment of station data. This approach may be somewhat comparable to using thin plate splines with the climatology as one of the covariates and that method may be investigated for comparative purposes.

Once the process for generating monthly maps is established, the ongoing production of maps is relatively straight forward. Despite that, one of the potential issues that arises from this kind of mapping is the effect of changes to the observational network from month-to-month. Especially in locations with sparse observational coverage or seasonal variation in coverage, PRISM can be sensitive to the loss of observational points and this often results in relatively sharp discontinuities when viewing a given monthly map as an anomaly map relative to the normal. Development of uncertainty estimates and attaining an understanding of PRISM sensitivity will aid in mitigating these issues or at least help quantify the effects. Because of these issues, the utility of the monthly timeseries maps for trend analysis is not readily clear. If trends appear insensitive to such changes in the network, then the timeseries will allow the calculation of very high resolution trend maps for BC. The most likely scenario is that trend analysis will be feasible in locations with high station densities such as the lower mainland and southern Vancouver Island and possibly more densely instrumented valleys such as the Okanagan. Elsewhere, discontinuities in station coverage may make trends inaccurate. In locales where trends may be calculated. The results could be highly useful to research activities aimed at understanding changes in small scale processes such as local eco systems.

3.3.2 Uncertainty

In order for maps of the climatology to be credible and most useful to their users, they must be accompanied by estimates of the uncertainty associated with the data. There are three major uncertainty sources in this map making process. The total uncertainty arises from:

1. uncertainties in the accuracy of the underlying station data due to siting and instrument error;
2. uncertainties associated with interpolating a measured climate value to locations where no observations are present;
3. uncertainties associated with parameter selection for the PRISM model;
4. uncertainties associated with choice of regression model used to develop spatial relationships among stations;

To assess the uncertainty associated with station measurements, a boot-strap approach can be used wherein synthetic datasets are created by sampling from the uncertainty range of each station in the data set and generating maps from the sampled values. Here measurement uncertainty is that associated with station siting and instrument accuracy. This effort should converge on a distribution of maps that has a characteristic mean and variance. Addressing the uncertainty associated with station sparseness is probably best addressed through a "jack-knife" technique in which stations are randomly removed and the influence of the removal on mapped climate is assessed. It can be foreseen that removal of stations in data limited areas will result in dramatic changes in the mapped climate because of a lack of information. This kind of evaluation could also be used to establish uncertainty estimates on mapped weather anomalies, so this activity will benefit other CAM research aims. Uncertainty due to model parameters is more difficult to quantify objectively. PRISM is a knowledge-based system; so much of the parameter tuning is done with an eye to reducing model error at station locations, but also toward generating known features in climate such as matching growth envelopes for vegetation known to exist in a given location. One approach to assessing this uncertainty entails selecting multiple sets of input parameters by selecting parameter values at random within an accepted range. Another approach would involve tuning groups of PRISM parameters to selected regions in the province and comparing the mapped climate using all possible groups to that tuned for the specific region. The resulting variation in the mapped climate fields will indicate sensitivity to parameters as well as uncertainty due to parameter selection. Finally, the uncertainty associated with the linear regression used in the model will provide an estimate of uncertainty in modelled values. The uncertainty estimates derived from these methods can be combined to give a total uncertainty to the mapped climate variables.

3.3.3 Extension to Extremes.

Over the course of calculating CLIMDEX indices on some of the station data from the PCDS, it was apparent that extremes tend to follow similar spatial patterns as do long-term means. This suggests that using PRISM to map extremes may be a feasible line of investigation. This could be done either as a climatologically aided interpolation as is done for the timeseries maps or as a standard PRISM mapping process using a digital elevation model as a predictor. Approaching this activity will require either justification for application of current weighting approaches in the PRISM algorithms, or developing new weighting algorithms suitable for processes unique to extremes. For example, cold extremes in winter are likely to be associated with unusually deep temperature inversions which may not be captured in the present PRISM parameterizations. Additionally, extreme precipitation events in summer months are likely associated with convective systems for which orographic precipitation processes and thus elevational dependence of precipitation may not apply. Finally, this activity will hinge on the production of CLIMDEX indices for the PCDS stations so will need to take place after those are produced during the 2015-2016 fiscal year.

4. Applied Research Activities and Deliverable Products

The research approaches outlined above can be broken down into individual applied research projects which together will accomplish the broader research goals outlines in this plane. This section breaks apart the research path into the individual components with targeted completion dates or, where applicable, commencement dates.

4.1 Developing the PCDS

4.1.1 Maintain data ingestion and improve data quality in the provincial climate data set. Ongoing from present. Secondary quality control by fiscal year end 2015-2016.

4.1.2 Work with CRMP partners to improve the meta-data content and delivery with PCDS data (student opportunity). Begin 2014-2015 and ongoing throughout this research plan

4.1.3 Calculate CLIMDEX indices on the data in the provincial climate data set. Complete by 2015-2016.

4.1.4 Homogenize long records of climate station data in concert with Environment Canada scientists. Changepoint detection complete by 2016-2017.

4.2 PRISM climate mapping

4.2.1 Update PRISM climate normals to most recent normal period and produce monthly timeseries maps. Complete by fiscal year end 2014-2015.

4.2.2 Release of monthly PRISM maps. 2015-2016. have routine map release up and running by 2016-2017.

4.2.3 Begin to quantify the reliability of PRISM products. Release climate map uncertainty products by 2015-2016.

4.2.4 Expanded application of PRISM to daily timeseries and mapping of extremes. Under investigation and PRISM/PCIC roles established by 2017-2018.

4.3 Seasonal Climate Reviews

4.3.1 Deliver monthly and seasonal anomaly maps in both point and gridded format. Complete 2014-2015.

4.3.2 Expand seasonal analysis to include atmospheric circulation anomalies. Complete automated mapping products by 2015-2016.

4.3.3 Produce descriptive seasonal climate analyses at regular intervals. 2016-2017.

4.3.4 Development of a web tool for generation of custom maps for climate analysis in BC. 2016-2017.

4.3.5 Develop high-resolution climate anomaly maps based on the ongoing monthly PRISM maps. 2017-2018.

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6. Figures

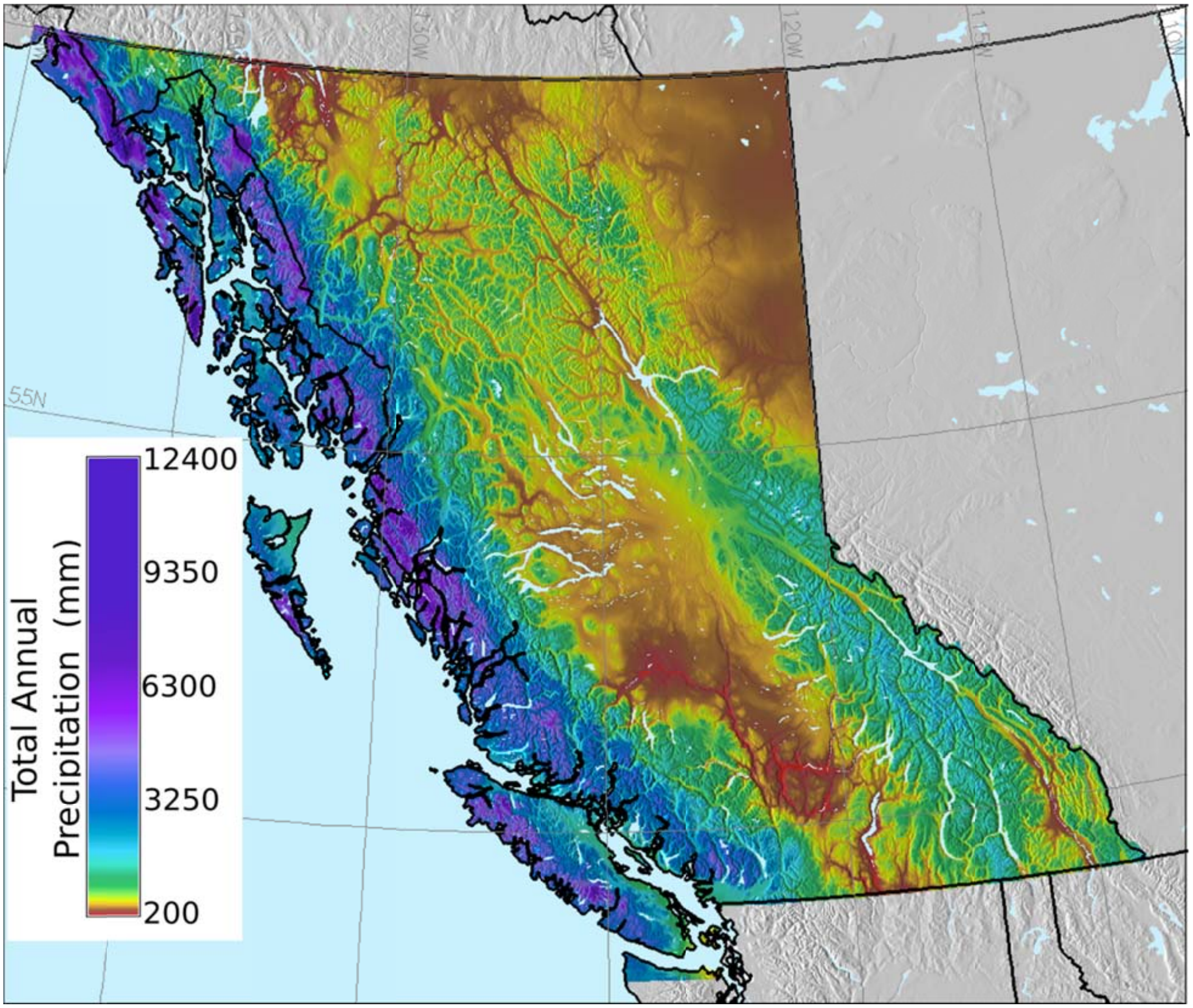

Figure 1: Map of PRISM climate normals for annual total precipitation for the 1971 -- 2000 climate normal period.

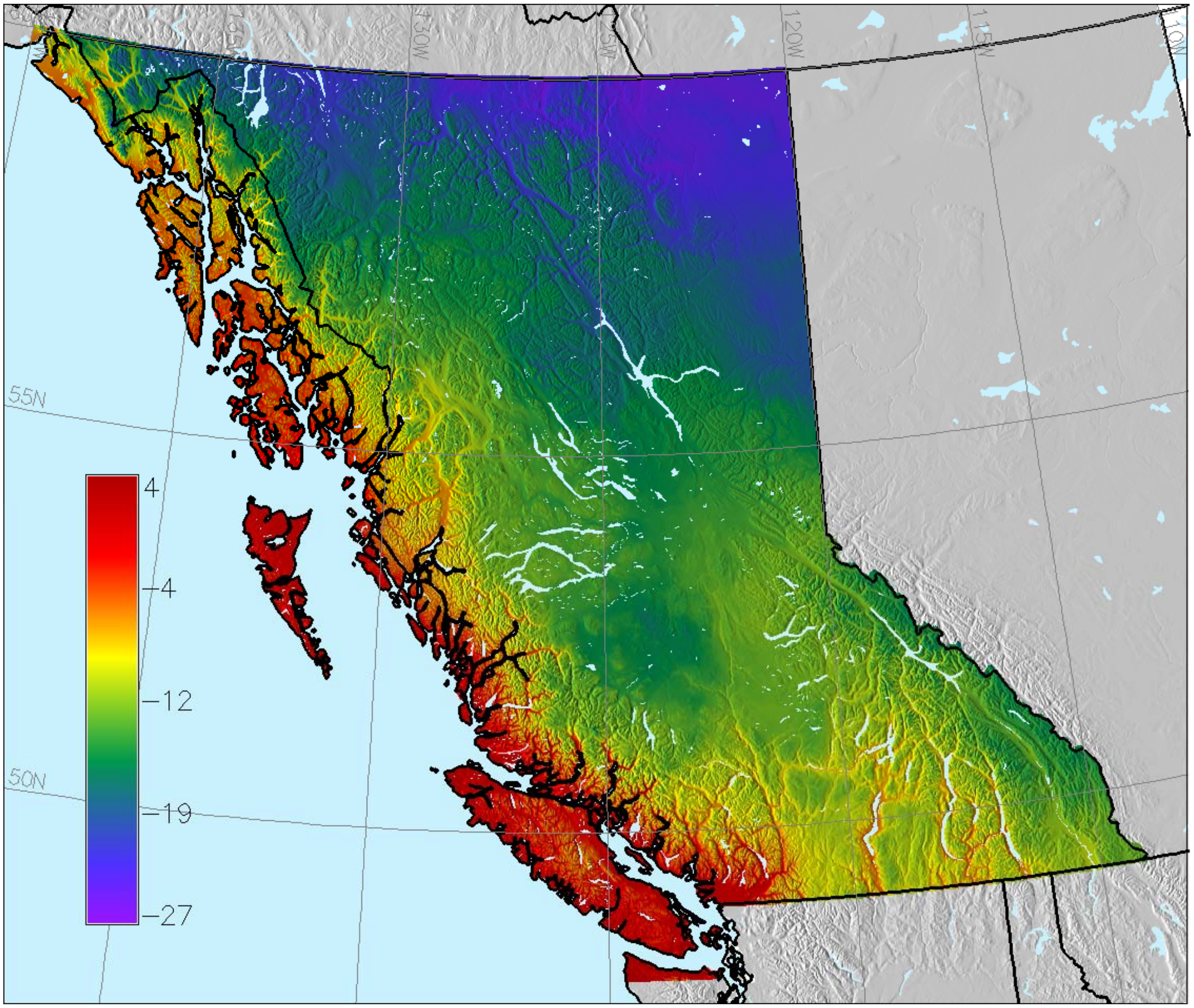

Figure 2: Map of PRISM climate normals for January mean minimum temperature for the 1971 -- 2000 climate normal period. Temperature scale is in °C.

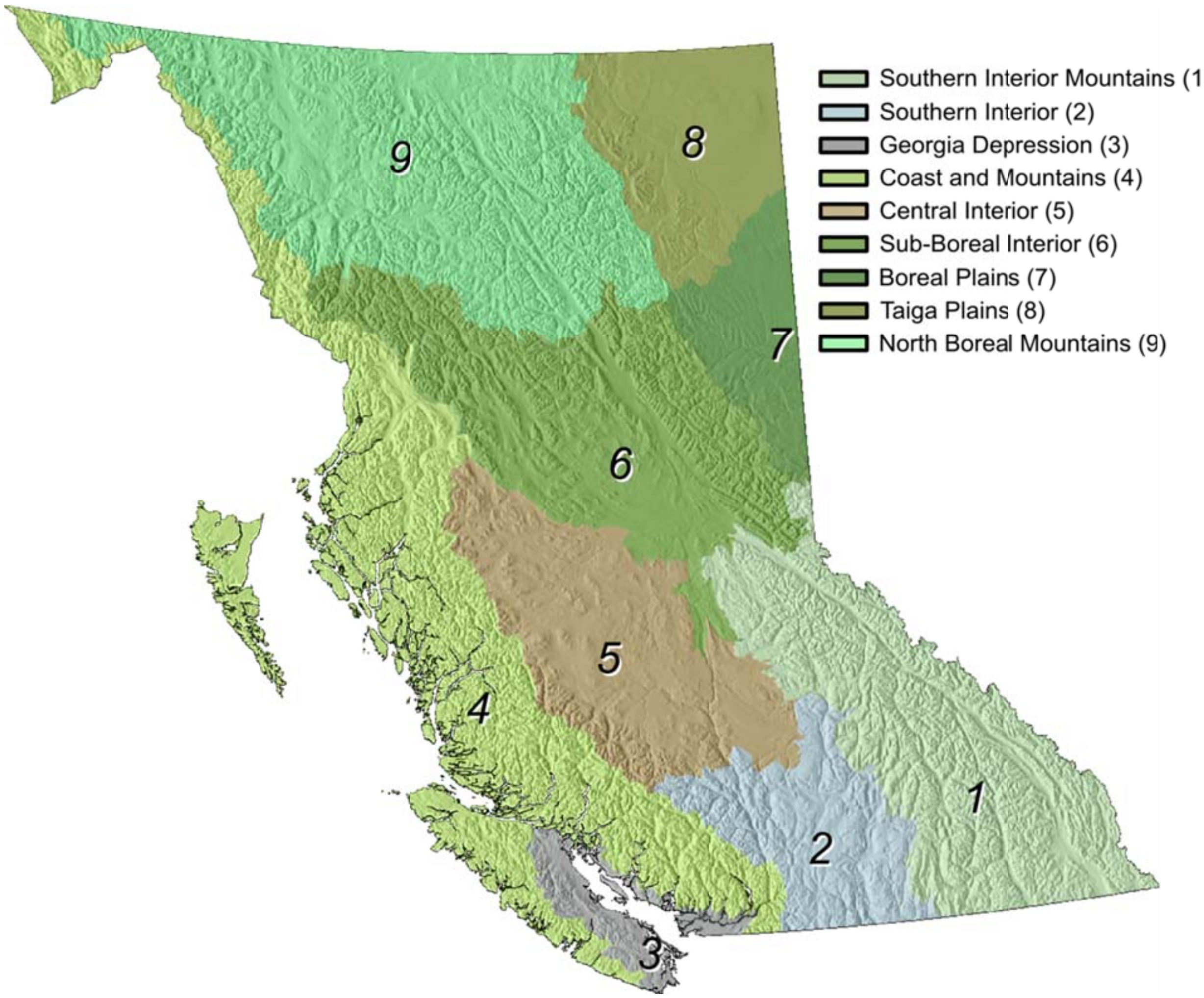

Figure 3: Map of British Columbia showing the eco provinces which will be the focus for the regional descriptions of seasonal climate in SCRs. Underlying the eco provinces is the shaded relief of the topography demonstrating the diversity of landscapes with relatively flat plains in the northeast and very rough topography along the coast and in the southeast of the province. Furthermore, the coast contains many islands and fjords which allows the ocean great influence over much of the Coast and Mountains ecoprovince.