Climate Analysis and Monitoring

Research Plan for 2012-2016

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PACIFIC CLIMATE IMPACTS CONSORTIUM

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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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1. Introduction

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. This range is exemplified by the 9 eco-provinces distributed through BC (Figure 1). 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. 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 distributed climatology. Analysis of the station based measurements and the BC climatology allows for detection of recent seasonal weather anomalies and extremes where they occur. These data, in conjunction with other data sets (such as global and atmospheric reanalysis, upper air observations, ocean temperature observations, etc.) 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. Instrumental data are useful for characterizing the mean climate state and the statistical variability about that mean thus setting the background for extremes analysis.

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 often less than a decade making homogeneity a major issue. These factors limit their use for understanding climate variability on multidecadal and longer timescales.

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, etc. Station data represent a valuable resource both to 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 distributed 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) and 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. in press) is a prime reason for its wide use. PCIC alone receives numerous requests for information from the CWNA product. Although ClimateWNA continues to be a useful tool, an update on the PRISM mapping is needed as the 1971-2000 climate normal period wanes toward the 1981-2010 period thus leaving the existing normal maps two decades behind current climatologies. Furthermore, the PRISM climatology on which the tool is based was created from relatively few observational stations. Thus, an updated PRISM product is greatly needed. This research aims to update the climatologic maps of British Columbia first to the 1971-2000 normal period for which the most data is currently available. Later maps will be made for the 1981-

2010 period. This work is enabled by the establishment of the Climate Related Monitoring Program (CRMP) through a joint data sharing agreement (BC Ministry of Environment, 2010) between the province of British Columbia, Environment Canada, RioTinto AlCAN, BCHydro, and PCIC. The CRMP has initiated the transfer of station observations made at more than 6000 sites across the province of BC (figure 2).

The Climate Analysis and Monitoring (CAM) theme at the Pacific Climate Impacts Consortium aims to meet the need for providing reference climate data and also aims to interpret recent seasonal weather in light of the climate data available for the province. The CAM theme is actively supported by the BC Ministry of Environment (BCMoE) and the Pacific Institute for Climate Solutions (PICS). All organizations 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 collection of meteorological data from multiple networks of 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 is a developing theme within PCIC and will soon be able to serve the needs for past climate data within PCIC. Such data will also be 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.

Table 1: Acronyms used throughout this text

Acronym	Meaning
AHCCD	Adjusted Historical Canadian Climate Dataset
BCMoE	BC Ministry of the Environment
CAM	Climate Analysis and Monitoring
CCCMA	Canadian Centre for Climate Modelling and Analysis
CDCD	Canadian Daily Climate Data
CIG	Climate Impacts Group
CRMP	Climate Related monitoring Program
ECMWF	European Centre for Medium Range Weather Forecasting
ENSO	El Niño Southern Oscillation
HI	Hydrological Impacts
NCEP	National Center for Environmental Prediction
OCS	Oregon Climate Service
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	Regional Climate Impacts
SCR	Seasonal Climate Review
WRF	Weather Research and Forecasting Model

The main purposes of the CAM theme are to:

- Serve as the custodian for 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 the PCDS station observations 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 MOU and Collaborative Agreement (PRISM agreements, 2010a,b).
- 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 timescales 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.

2. Research Plan

2.1 Purpose

The present document is intended to outline the research activities of the CAM theme from 2012 through 2016. Much of the first two years of activity is governed by agreements with the BC Ministry of Environment (2010), and with the PRISM Climate Group at Oregon State University (PRISM/PCIC agreement, 2010a,b). The first two activities will establish the PCDS and generate high-resolution climate maps from those data. Analysis of seasonal weather and issuance of Seasonal Climate Reviews (SCRs) will accompany this work from the onset. Further development of the program includes expansion of the SCRs, generation of time-series maps of monthly and then daily weather variables, addressing primary scientific questions that arise from CAM activities, and introducing new ways to serve the interest of stake-holders to access the work of CAM. Because this theme is intended to expand in the next several years, the goals become more ambitious as time goes on.

2.2 Research Objectives

There are five major objectives of the CAM research themes over the next five years. These are intended to meet the needs of stakeholders such as the private sector, commercial organizations, governments and public interests. These objectives will deliver: (1) local, station-based descriptions of climate; (2) the spatial distribution of temperature and precipitation within British Columbia; (3) a high resolution collection of monthly, historical maps of monthly averaged temperature and precipitation; (4) the occurrence and an explanation of anomalous seasonal weather and extreme events; (5) Scientific research into climate phenomena or changes in local climate. These are summarized in slightly different form in Table 2.

2.2.1 **Development of the PCDS**

The foundation of the research activities of CAM is the agreement between the BC province and PCIC allowing PCIC to assemble and take custody of the provincial climate data set (See CRMP/PCIC agreement, 2010). This agreement is at the heart of the CRMP program for which details may be accessed at http://www.env.gov.bc.ca/epd/wamr/crmp.htm. The CRMP data are the basis for the four other objectives of this research plan. The goal in developing the PCDS is to host the data in a publically available database accessible via a web browser with a map-based interface. The data will undergo multiple levels of quality control which will be viewed as an ongoing process. Where sufficient temporal coverage exists, the data will be used to calculate station climate normals for as many locations in British Columbia as possible. Once the historical data are brought in, the PCDS will be updated hourly with data from EC and BC networks that are made available on that basis.

2.2.2 **PRISM Climatology Mapping**

The generation of PRISM climate maps is a crucial component of the CAM theme and is a major part of an agreement between the PRISM Climate Group and PCIC (see PRISM/PCIC agreement, 2010). These mapping activities will culminate in transfer of use of the PRISM software to PCIC. This work will result in the generation of 30 arc-second resolution maps of the climate of BC for the variables maximum temperature, minimum temperature, mean temperature, and total precipitation. The maps will be computed for each month and an annual mean/total will also be calculated. There is a strong, two-way interaction between the PRISM climate mapping efforts and formation of the PCDS. This interaction is described in figure 3. A description of the approach that will be used to assess uncertainty in these climate maps is given in section 3.3.

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

Objective	Description	Timescale of Interest	Priority
1	**Development of the PCDS:** Update and maintain the database of historical station data. Implement near-real-time data ingestion with quality control and station homogenization. Maintain the data base as the custodian of the province's climate data and develop a user interface for routine, facile access.	Short to Long-term	1
2	**PRISM Climatology Mapping:** Application of the PRISM technology to the generation of 30 arc second resolution climatological maps of maximum, minimum, and mean temperature and precipitation in British Columbia on a monthly and annual basis.	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 1971 to present. Future work will explore production of monthly maps into the early and mid 20th century with eventual focus on producing maps at a daily temporal resolution.	Long-term	2
5	**Develop Seasonal Climate Reviews:** Deliver regular, routine reports at three month intervals analyzing the previous season's weather anomalies in the context of long-term trends, including extreme events, using data in the CRMP database, PRISM climate maps, and publically available atmospheric analyses.	Short-term	2

2.2.3 PRISM Uncertainty and Sensitivity Analysis

The utility of PRISM climate maps will be greatly increased if an estimate of the uncertainty associated with the mapping can be provided. To meet this need, the uncertainty associated with the generation of PRISM climate maps will be estimated along with an assessment of the parameter sensitivity of the model. This work is also useful to the PRISM climate group, who have expressed interest in performing such an analysis.

2.2.4 **PRISM Time-series Mapping**

To generate a picture of the historical evolution of monthly weather anomalies in British Columbia, time-series maps of the same variables as for the PRISM climate mapping will be constructed. This will yield a set of maps for each month analyzed for the variables mean daily maximum temperature, mean daily minimum temperature, mean daily mean temperature, and mean total precipitation. Time-series maps will be used internally within PCIC for analysis of climate variability and for forcing of PCIC's hydrological models. However, wider use is foreseen externally such as for driving process models or for assessing potential ranges of conditions in areas of the province not served by station observations. The temporal coverage of this map set will depend on the spatial and temporal coverage and the quality of data for each time slice. Within the first two years of the research plan, these maps will be created for the period from 1971 to present. This is the nominal period for the PRISM climate mapping as outlined in the agreement between PCIC and OSU. However given the capabilities of PRISM to handle relatively sparse data, these maps will be extended substantially further backward in time. A cursory look at the data availability suggests that these maps can be made from 1950 onward, if not longer. When real-time data ingestion is running smoothly, production of monthly maps will be done as part of the SCR process. This activity will benefit from the uncertainty and sensitivity analysis which is a part of objective 2. Over the long-term, this approach can be extended toward the production of daily maps.

2.2.5 **Seasonal Climate Reviews**

The data from the PCDS, especially that which is incorporated in real time, will be used to issue reports on weather anomalies from the preceding three month period at intervals corresponding to the ends of 3 month seasons. These reviews will include details on selected stations distributed throughout the ecoprovinces along with maps of the distribution of anomalies. Station and regional descriptions will be accompanied by a description of atmospheric circulation and connections will made between circulation and observed seasonal weather. Research activities will include investigating whether known links between seasonal weather in western North America, atmospheric circulation anomalies, and SST variability in the Pacific Ocean were important in determining the observed anomalies. Generating spatially interpolated anomalies and uncertainty estimates on those maps will be another important area of research and development.

2.3 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 of objective 5 will be described for the province as a whole and also by the 9 ecoprovinces. As the process becomes established, these efforts may include Yukon and the Rocky Mountains lying within Alberta. However, broad extension of these efforts is somewhat precluded by the lack of an agreement between these provinces/territories analogous to the CRMP Agreement. Subregional break-down of weather reviews will be made following the eco-provinces as shown in Figure 1. Descriptions of regional details will enable users of Seasonal Climate Reviews to quickly focus on the locations that they are most interested in. It's important to note, especially for the Seasonal Climate Reviews that the inferences that can be made for more remote regions will be far less detailed than those for the south of the province owing to the much lower station density in the north and along the coast. While much of CAM's focus is province wide, some aspects of the Seasonal Climate Reviews 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 MoE, 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 work to support the formation of station climate normals for PRISM variables is a part of the agreement with the PRISM Climate Group (PRISM/PCIC agreement, 2010b), as is the transfer of knowledge relating to the operation of PRISM. Furthermore, collaborations are expected between the various British Columbia Ministries for the purpose of data sharing and transfer of meta data.

The Ministry of Environment (MoE) is responsible for tracking progress of the CRMP Program, and for reviewing and interpreting results for planning and policy applications. Furthermore, the MoE will insure that the collaborating British Columbia ministries and cooperating organizations who have contributed observational data and site meta data will also receive the benefits from climate analysis and monitoring by PCIC; e.g., access to datasets (PCDS), climate maps and time series.

3.2 The Provincial Climate Data Set

The PCDS is the foundation of the research activities of the CAM theme. These station observations provide the most direct indicator of climate and climate variability in the province of British Columbia. The success of the CRMP agreement will produce an unprecedented resource of climate data from more than 6000 locations in the province and spanning almost 140 years of observations in a few locations. The range and diversity of the PCDS bring some challenges: quality control standards vary from network to network; the sheer quantity of data makes analyzing and correcting data based on metadata difficult; the measurement techniques or instrumentation for a given variable differs between networks. Because of these difficulties, bringing the data to a scientifically useful state is foreseen to be a long-term challenge. However, even in a raw state, the data are useful. For example, departures of long-term averages of mean daily temperature from climatology have been shown to be relatively insensitive to station siting problems when sufficient numbers of stations are incorporated in the analysis (Menne et al. 2012, Fall et al., 2011). This research activity will cover all three temporal scales. Station data that comes in near real time will address short term needs, while the longer station records contain information on the multidecadal scale.

Presently, the majority of the historical data has been ingested into the PCDS. PCIC's computational support team has inserted these observations into a PostgreSQL database which facilitates extraction of variables and integration with the PRISM Climate Group's database structure. Observations from the PCDS will be made available to the public via a web-based data portal that will include mapping capabilities to enable user selection of stations based on proximity to sites they are familiar with.

Quality control (QC) of the data is the first responsibility of the originating network coordinators. Subsequently, PCIC will perform additional QC and identify outliers and data gaps after the data has been entered into the database. Finally, additional QC will be applied during the process of preparing the data for PRISM mapping, and the PRISM Climate Group at Oregon State University will oversee this work, following the PRISM Collaborative Agreement (PCIC, 2010b).

3.2.1 Quality Control/Quality Assurance

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. We define climate normals as the description of the mean and the variability of a particular measurement. The assessment of means is typically done over standard 30 year averaging periods whereas the characterization of variability benefits from the full length of station records. The first stage of quality control involves performing simple range checks and tests for “sticky” sensors. This will eliminate many spurious measurements that arise when sensors fail, become snow covered, or have other difficulties. Further quality control will incorporate more sophisticated, machine learning based methods for 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.

Another quality control method involves comparing measurements at one station with those from a nearby station. These so-called buddy checks are performed as part of the PRISM climate mapping process which is what intertwines the two research activities. This iterative loop is schematically demonstrated in Figure 3 through the ASSAY program of PRISM. By proceeding with climate mapping, better quality controlled station data will arise iteratively. Where possible and for stations with long records, careful attention will be paid to the station meta data to track changes to sensors, siting, or other factors that may influence the homogeneity of the data. As part of its program to develop the Adjusted Homogenized Canadian Climate Dataset, EC has described efforts to create “clean” records of precipitation, temperature, sea level pressure, and wind for suitable stations in their networks (Mekis and Hogg, 1999; Vincent et al., 2001; Wan et al., 2007; Wan et al., 2009). Homogenization of precipitation records is more difficult than other variables due to the short spatial correlation length which limits the use of neighbouring stations for quality assurance. Overall, the description of these practices will serve as a useful starting point for efforts to homogenize the PCDS data.

3.2.2 **Dataset Maintenance and Expansion**

The PCDS in its current state is a snap-shot of a best-effort for data collection for periods prior to roughly 2010 inclusive. The accumulation of data and maintenance of the data set is foreseen to be a long-term effort at storing, performing quality control and serving climate related meteorological measurements. Doing so will require implementing real-time or near real-time data ingestion. Environment Canada issues hourly station measurements within an hour of their observation for stations with automatic recording. These data may be easily imported into the PCDS. Furthermore, several of the networks operated by BC ministries such as the Ministry of Transportation and Infrastructure, the snow pillow network, stations in the Ministry of Agriculture, and stations in the Ministry of Environment report data in real time. A pilot project is under way to put these data feeds into a common, quality controlled stream. Once this stream is established, data can be imported into the PCDS as they arrive at PCIC and be used as part of the Seasonal Climate Review process described below. Finally, observations from EC recorded manually will be inserted into the PCDS at regular intervals once they become available typically on a monthly basis. Regular updates will be received from the BC ministries. Altogether, once the PCDS is established, data streams will be maintained to keep the dataset as comprehensive as possible.

3.3 Climate Mapping

Updating the PRISM climate maps that were constructed for the 1961-1990 climate normal period is a crucial part of the efforts of CAM. The currently-available PRISM climatology has been used widely in PCIC for the production of forcing data for hydrologic modelling as well as for assessment of changes in BC’s climate, forest cover, and other impacts studies. The new maps are foreseen to be more widely used by all other themes in PCIC for the purposes of downscaling, distribution to stake holders, and for the generation of forcing data for the hydrologic modelling conducted by the Hydrologic Impacts theme among other applications. The currently-available PRISM climatology is relatively low resolution and was constructed for the (1961-1990) climate normal period. However, it has been used widely in PCIC for the production of forcing data for hydrologic modelling as well as for assessment of changes in occurrence of extremes in future climate. Climate mapping activities are facilitated by a pre-existing agreement between PCIC and the PRISM Climate Group at OSU. The work will be long-term in nature especially when the monthly maps are created extending back 60 or more years into the past.

3.3.1 PRISM

At its core, PRISM is a multiple regression model that determines the relationship between the predictand climate variable and an underlying topographic or other spatial data set (for example, in the monthly time-series, the predictor field is the monthly climatology). For each pixel in the distributed modelling domain a linear regression is computed between the data in the underlying map (typically elevation) and the climate variable of interest extracted from stations that meet particular criteria regarding distance, topographic orientation, proximity to coastlines, influence of cold air pooling etc. The regression equation is used to compute the mapped value of the climate variable at the pixel of interest. Then PRISM moves to the next pixel and repeats the process. The refinement to the linear regression approach which is at the heart of simplistic, lapse rate based downscaling approaches is what makes PRISM capable of simulating sharp lateral climate gradients that are not a function of elevation such as the influence of coastal cooling, rainshadow effects, and winter or nocturnal temperature inversions. PRISM was chosen for the purposes of mapping the climatology of BC because it is the method most capable of handling the varieties of climate influences as well as the sometimes sparse station coverage in British Columbia.

The initial mapping of the 1971-2000 climate normals will use station data and a topographic map of British Columbia as predictors. The process of generating these maps iterates between parameter adjustment and assessment of map quality through statistics and the user's knowledge base of the climate of BC. The maps produced through this process can be termed "*alpha*" in quality. Once this iterative process has been completed to the satisfaction of the PRISM operator, a "*beta*" quality map will be released. The penultimate stage in the PRISM climate mapping process is the review stage. Climate maps will be made available to scientists who, collectively, have an understanding of the landscape and climate of BC such that identification of major flaws in the climate maps can be made. In the final stage of the mapping, these flaws will be addressed and then final maps will be released.

3.3.2 Time Series Maps

After climate normal maps are generated, time series maps may be produced. This stage relies on the climate maps produced above to serve as the predictor maps upon which the climate anomalies are mapped. Nominally, these maps will be produced at a monthly temporal resolution for temperature and precipitation over the period from 1971 to present. However, station density should be high enough, far enough back in time to extend the map set from the 1950s through to the present. These maps will serve either as precursors to the model forcing and analysis input for the Regional Climate Impacts and Hydrologic Impacts themes. Once daily maps are produced, these may be used as direct inputs to hydrologic models. At later stages in the course of CAM research, such maps can be generated at a daily time step, which is an application of PRISM that the PRISM Climate Group is already using. However, mapping daily weather variables requires a substantial expansion of the work spent on climate mapping. So, the trade off between the time spent doing this and the benefit to PCIC and users in the province will need to be assessed. Mapping daily weather variables will also lead to much greater uncertainty in the map products. The number of stations contributing to the analysis will be far fewer given that, for any time, there are likely to be only a few hundred reporting stations whereas in the monthly application there will typically be many more. Furthermore, the relationships between topography and climate variables are often not as clear at short timescales due to such processes as transient inversions (for temperature) and changes in orographic effects on precipitation with changing circulation patterns. Finally, the distance at which station data are correlated is much smaller for daily variables than monthly resulting in less reliable regression relationships in the PRISM mapping process.

The quality of the climate mapping that can be accomplished with PRISM is limited by the quality of the underlying stations observations. The PRISM climate mapping process benefits from rigorous quality control of the stations data, and the process will feedback on the quality control efforts of the PCDS. Figure 3 demonstrates the interaction between the CRMP data and PRISM mapping. Because of the extensive quality control that must be undertaken to generate these maps, the timeline for these activities appears unusually long. This leeway is intended to allow careful cleaning of the station data and accommodation of any unforeseen data quality issues.

3.3.3 Assessing 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 parameter selection for the PRISM model.
3. 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 jack-knife cross validation technique in which stations are randomly removed and the influence of the removal on mapped climate is assessed. This process can be extended to removal of multiple stations to assess PRISM's ability to obtain the same mapped climate for sparser and sparser observational networks. 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 cross validation could also be used to establish uncertainty estimates on mapped weather anomalies as well, so this activity will benefit other CAM research aims. Uncertainty due to model parameter selection 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.

3.3.4 Alternatives to PRISM

In the long term it's critical for CAM and PCIC to remain objective regarding the choice of method for generating high-resolution climatology and climate data time series. PRISM has the advantage of being directly rooted in surface station observations whereas dynamical downscaling may be more holistic for the entire atmosphere, but fail to represent surface properties well. However, within the 5 year span of this research plan, it's likely that dynamical downscaling will evolve to the point where the method can be applied province-wide for long timescales sufficient for generating climatologies and high resolution time series maps. At present the Atmospheric Sciences department at the University of Washington runs the WRF regional model operationally at a spatial resolution of 1 1/3 kilometre over a domain roughly 100000 km^2 in size. It is not foreseen that PCIC will be performing dynamic downscaling in the near future, but the research involving downscaling and production of climate and monthly weather maps should be state-of-the-art and aware of the developing capabilities of available methods. An active research collaboration between Ouranos, Uvic's Climate Modelling Lab, and PCIC is aimed at developing a high resolution (15 km) dynamical downscale of climatology and climate projections for western Canada. Furthermore, there are currently available downscaling methods such as that of Jarosch et al. (2010) which will be objectively compared to PRISM.

This research plan intends to utilize PRISM to the full extent of the PRISM/PCIC agreement (2010). Much of the methodology from quality controlling the PCDS to developing inputs to hydrological models used by the Hydrologic Impacts theme are slated to be derived from PRISM. Although PRISM's knowledge-based system for mapping climate variables is uncomfortable to some scientists, PRISM products have been utilized in many impacts studies and shown to be superior to the Daymet (Thornton *et al.*, 1997) and WorldClim (Hijmans, et al., 2005) interpolation schemes in representing Olympic Mountains water balance, winter temperature inversions in Colorado, and the influence of maritime air near the California coast (Daly *et al.*, 2008). However, the greater objectivity of Daymet and WorldClim is beneficial. A cited reference search reveals 87 citations of Daly *et al.*, 2008 many of which cite the use of PRISM products in impact studies. PCIC is aware of the alternatives to PRISM, but given the broad, practical use of the method, PRISM will be used for the foreseeable future.

3.4 Seasonal Climate Reviews

The seasonal Climate reviews are intended to inform the public of anomalies in seasonal weather as they relate to normal climate. Where identifiable modes of climate variability have influenced the season, these will be identified and explained in lay terms. The Seasonal Climate Reviews will be written to address the lay person, but they will contain enough information and links to the data used in the analysis for them to be useful to researchers and industrial users as well. The initial CAM effort at a SCR describing the occurrence of an unusually cool and wet spring and summer was well received by members of the scientific and consulting communities indicating the demand for these products. SCR will address past weather in the near term although comparisons will be made to near- and long-term station data.

SCRs will be constructed by analyzing province-wide anomalies in temperature and precipitation first as a broad-brush description of station averages relative to their respective 1971-2000 climate normals. When the 1981-2010 climate normals are calculated, SCRs will be referenced to those normals. Subsequent descriptions at a more regional scale will also be provided. These regional descriptions are necessary to address the large spatial scale of BC in light of the often shorter spatial scales of temperature and especially precipitation anomalies. The observational anomalies presented in the Seasonal Climate Reviews will initially be based on data from Environment Canada who makes monthly averages of surface observations available within two weeks of the end of a given month. The timeliness of these data releases enables calculation of seasonal anomalies rapidly at the end of 3 month "seasons". For the purposes of the SCRs the seasons will be defined as three calendar month periods beginning in December for the winter season, March for spring, June for summer, and September for fall. Point anomalies will be used to generate spatially interpolated anomalies along with an uncertainty estimate for the mapped fields. An example is given in figure 4. Mapping seasonal anomalies will initially be done using geostatistical methods such as splines or kriging (Luo et al., 2008). When the PRISM climate mapping is completed, it will be possible to associate spatial variation in climatology with anomalies and use the PRISM products to generate high spatial resolution seasonal anomalies.

The second component of the SCR will be a description of the mean atmospheric circulation that explains the observed anomalies or lack thereof. Mean values in the synoptic scale field of variables such as sea level pressure, 500 hectopascal geopotential height, and wind anomalies allow the diagnosis of the atmospheric circulation anomalies that lead to anomalous station observations. These fields can be gathered from analysis and reanalysis products produced by forecasting centers such as the Canadian Meteorology Centre, The United States National Center for Environmental Prediction, and the European Center for Medium Range Weather Forecasting. These centers provide timely access to mapping tools capable of plotting desired variables and their anomalies as well as the data behind the plots to enable analysis within PCIC. The circulation anomalies will be tied to dominant modes of seasonal scale weather variability in western North America such as the El Niño Southern Oscillation where such ties exist.

Finally, the Seasonal Climate Reviews will address the occurrence of extremes in the climate records by placing the observed anomalies in the context of the statistical distribution of the anomalies throughout the history of the climate record for a given station or region. When extremes are identified, the SCR will provide a special analysis of the large-scale weather pattern that prevailed at the time of the occurrence of the extreme. This analysis will be similar to that done for the seasonal anomalies, but focused on synoptic scale conditions. Development of the SCRs will benefit from a two-way transfer of data and model output between the Hydrological Impacts Program and Regional Climate Impacts (RCI). While station records are a good indicator of the occurrence of many anomalies, stake holders may bring to light unusual conditions in a region that may otherwise escape detection. The efforts to describe regional climate anomalies will have useful applications for RCI and can be made available to stake holders of this theme. In the longer term, inclusion of an analysis of hydrological anomalies and extremes would be a valuable addition to the SCR process. This would require expertise from the HI to identify noteworthy streamflows and their causes. This activity will be limited by the capacity of the HI to review seasonal mean and extreme streamflows.

Prior to their release, reviews of SCRs will be solicited from climate scientists at CCCMA and other colleagues. Research groups at the University of Washington (JISAO/CIG) and Oregon State University (OCCRI) produce similar reviews of weather anomalies in Washington and Oregon respectively. The CAM Lead will work with to coordinate the SCR process with these centers and to ensure that a consistent mechanistic story is told when large scale forcing merits it. Because BC is influenced by continental and even Arctic conditions, much of the anomalous weather in BC will be unique within the rest of western North America.

3.5 Dissemination

An underlying current in the CAM theme is the development of dissemination opportunities to make these products known to the researchers, stake holders in industry and government, and the general public. These efforts will foster research opportunities within the wider climate research community and are likely to help network CAM as a valuable research partner to outside agencies. The PCDS will be made accessible through a web based data portal which will allow any person to download any variable from any station in the PCDS. Stations will be plotted on a dynamic web map, so user selection of a station can be made based on proximity to known landmarks. This portal will also host the PRISM climate maps for both the normals and the time-series. Seasonal Climate Reviews will be published and announced on PCIC’s web site and in regular, routine public reports. These reports are expected to garner attention in the Pacific region and from other climate centers that also monitor climate in their respective regions such as the Climate Impacts Group at University of Washington, USA. Finally, scientific publications of CAM research activities when possible will help to raise the awareness of PCIC as a strong research institution in addition to its current profile as an expert provider of societally relevant climate impacts data.

4. Applied Research Activities

The research approaches outlined above can be broken down into individual applied research projects which together will accomplish the broader research goals outlined in this plan. This section breaks apart the research path into the individual research components that will be required and indicates which PCIC themes will contribute toward the accomplishment of these goals (CSG = Computational Support Group; CAM = Climate Analysis and Monitoring; RCI = Regional Climate Impacts; HI = Hydrological Impacts).

4.1 Developing the PCDS

4.1.1. Establishment of a database to interface with the PRISM Climate Group's database and to allow easy access to the CRMP data. CSG/CAM. Completed and ongoing.

4.1.2. Calculate initial station normals for CRMP network stations. CAM/CSG. 2012.

4.1.3. Serving the CRMP data in each stage of quality control through a public web browser based data portal. CSG/CAM. 2012 and ongoing**.**

4.1.4. Develop real-time data ingestion. This will start with the EC daily data and move toward what's made available through the various BC ministries. CAM/CSG. 2012.

4.1.5. Quality control station data. Work toward homogenization where applicable. CAM/CSG. 2012 and ongoing. Target for 3^{rd} generation dataset by end of 2016**.**

4.2 PRISM Mapping

4.2.1. Perform uncertainty and parameter sensitivity analysis of the PRISM. CAM. 2012-2013.

4.2.2. Apply PRISM technology to the station normals to develop maps of the climatology of the province. CAM. 2013.

4.2.3. Apply PRISM technology to develop monthly time series of temperature and precipitation variables for as many months as station coverage in the CRMP data allow for. CAM. 2014.

4.2.4. Build on the monthly timeseries and near real-time station data ingestion to produce monthly temperature and precipitation maps in near real-time. Once methods for producing daily maps are established, daily PRISM maps may be released. These will be highly experimental within the temporal context of this research plan. CAM. 2016.

4.2.5. Apply PRISM technology to develop daily time series as before. This requires generation of daily station climatologies as well. CAM. 2015-2016.

4.2.6. Compare PRISM climate maps and time series maps with those developed through other statistical methods as well as dynamic downscaling of climate reanalysis. CAM/RCI/HI. 2015

4.3 Seasonal Climate Reviews

4.3.1. Develop spatial interpolation methods for anomalies with uncertainty estimate. CAM. 2012.

4.3.2. Develop tools to rapidly access and analyze atmospheric analysis and reanalysis data for interpreting climate anomalies. CAM. 2012.

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Figures

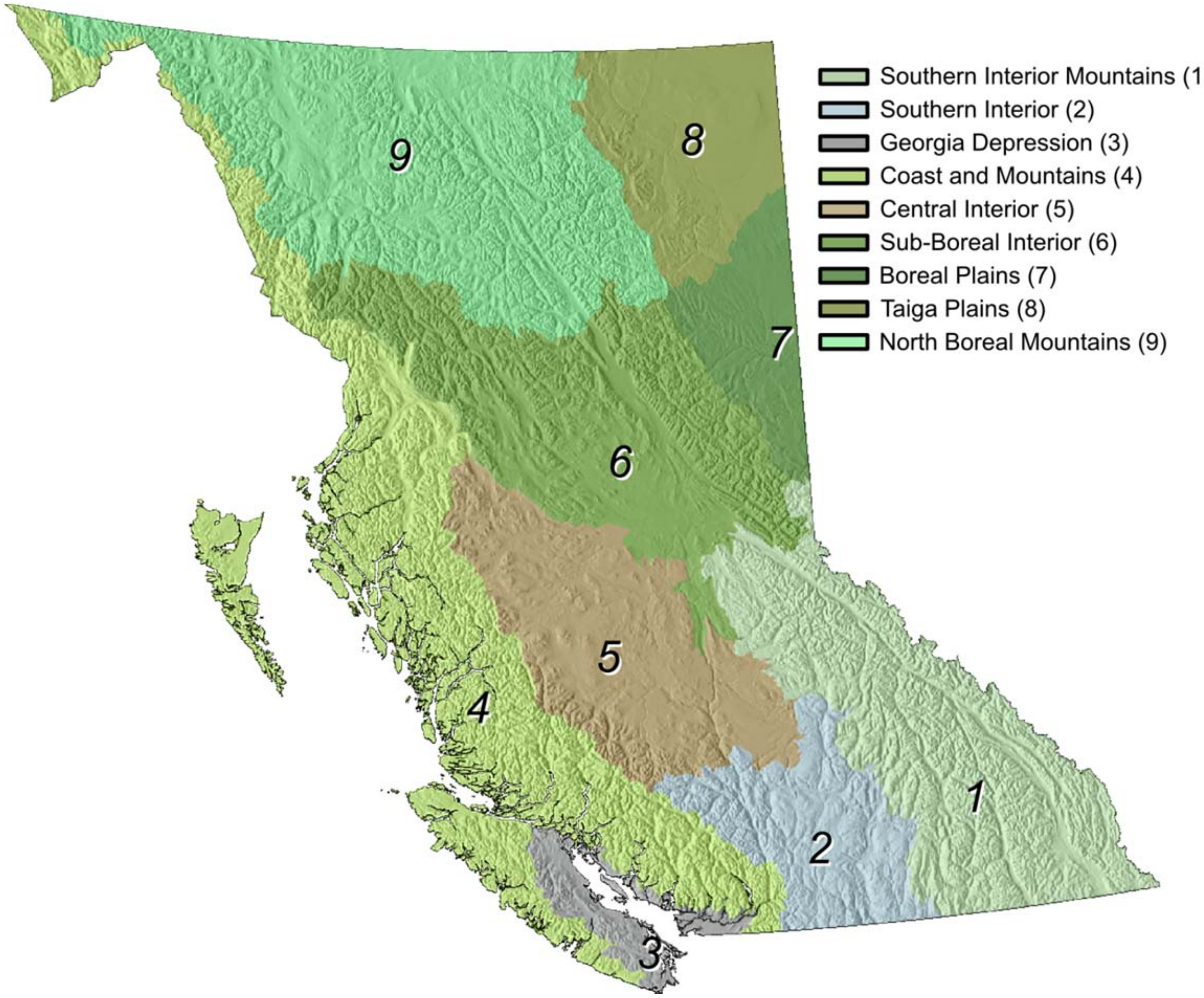

Figure 1: Map of British Columbia showing the eco provinces which will be the focus for the regional descriptions of seasonal climate in SCRs. Underlying the eco provinces is the shaded relief of the topography demonstrating the diversity of landscapes with relatively flat plains in the northeast and 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.

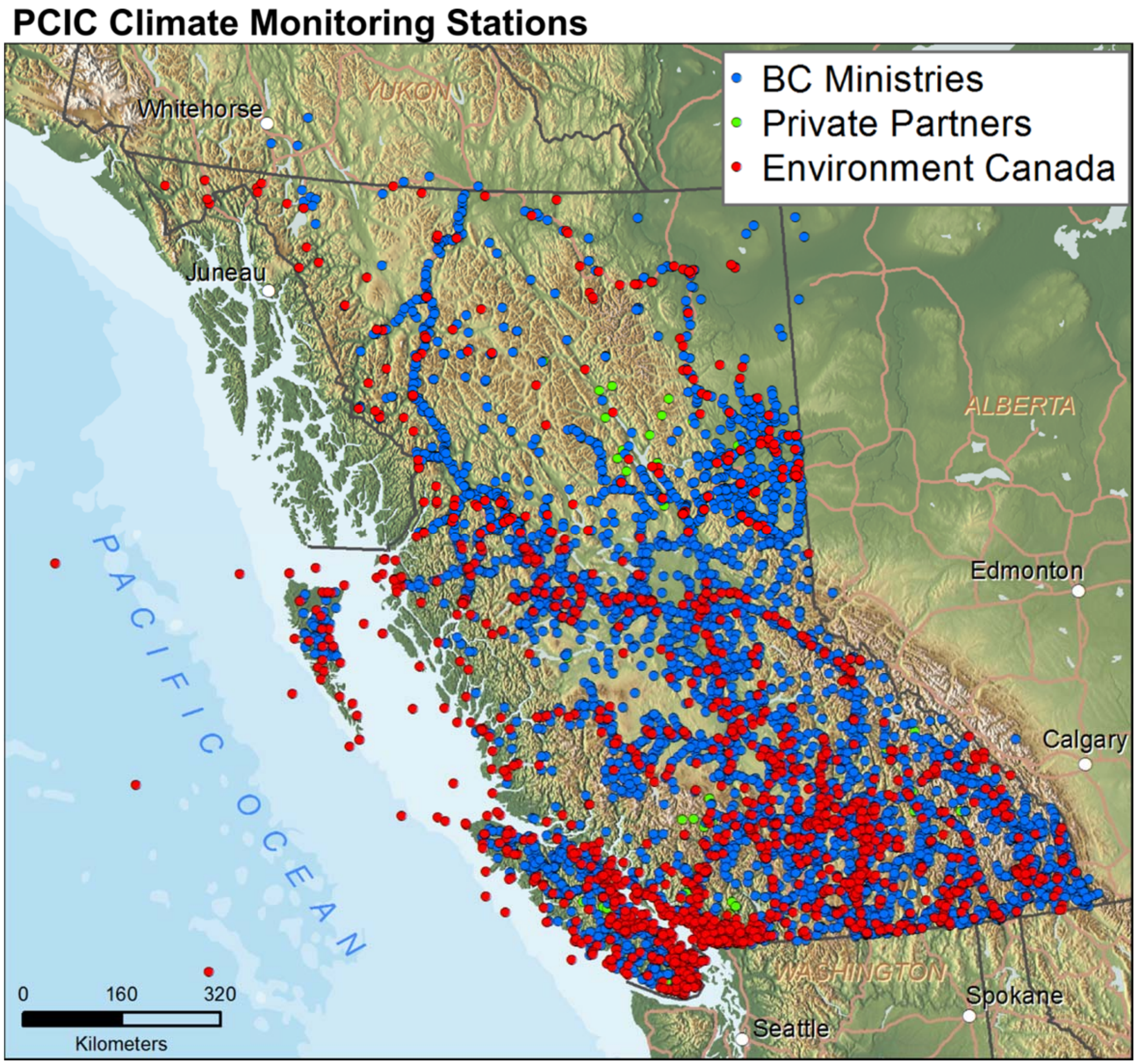

Figure 2: Map depicting the distribution of stations that form the PCDS. Environment Canada stations are in red, provincial networks in blue, and private stakeholder stations in green. This map is somewhat misleading in that it includes all stations with any length of record. The number of stations capable of contributing climatologically useful information will be fewer and less well distributed.

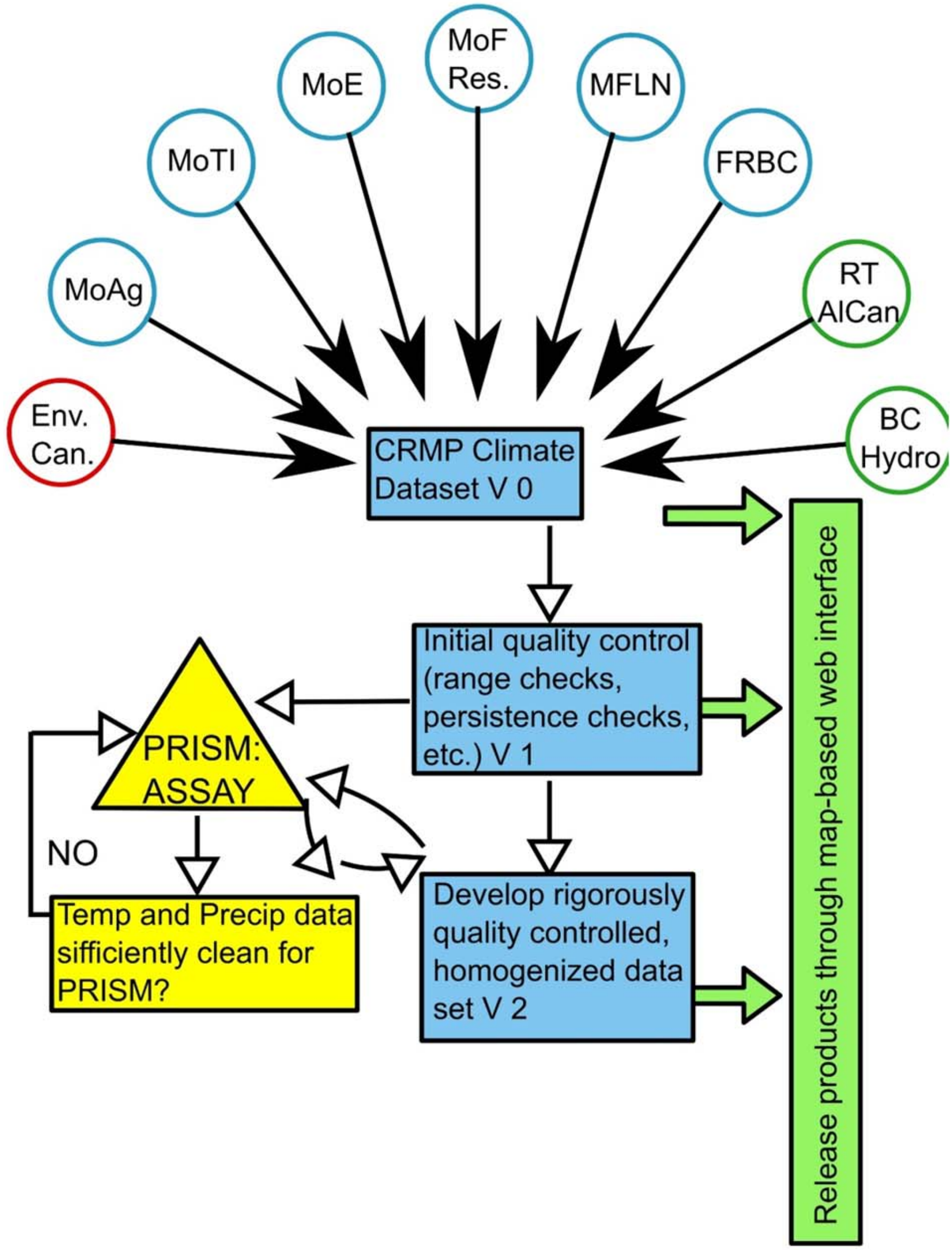

Figure 3: The flow of data from the CRMP networks through quality control, public release, and applications within PRISM. Applications to SCRs will occur at all stages, but initially with EC data only. ASSAY is a quality control program of the PRISM modelling suite. At the top of the flow chart, the circles representing contributing networks are colored such that red indicates federal (namely Environment Canada), blue indicated BC provincial stations, and green indicates private or crown corporation stations.

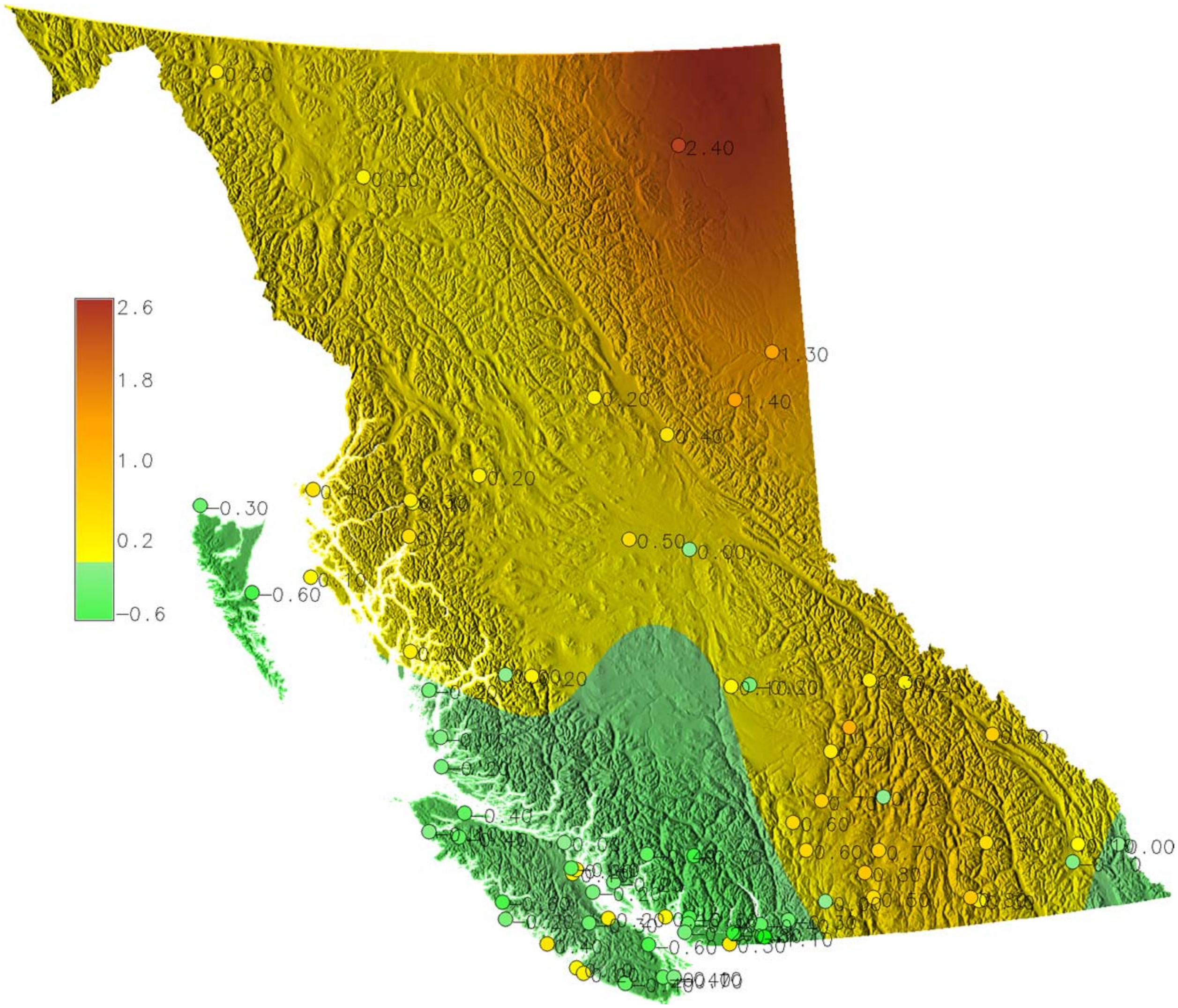

Figure 4: Example of a spatially interpolated temperature anomaly map. This is the anomaly for October, 2011 for Environment Canada stations. The interpolation was performed with a thin plate spline, but no uncertainty estimate was generated.