PACIFIC CLIMATE IMPACTS CONSORTIUM

Regional Climate Impacts

Research Plan: 2015-2019

15 January 2015

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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

Regional Climate Impacts is one of several themes of the Pacific Climate Impacts Consortium (PCIC). PCIC was founded in 2005 as 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 (PYR; Figure 1 from PCIC 2014a). This research plan is a companion document to the PCIC Strategic Plan as well as research plans in the Hydrologic Impacts (HI; Schnorbus 2015) and Climate Analysis and Monitoring (CAM; Anslow 2015) themes; the three PCIC themes are additionally supported by the Computational Support Group (CSG) which, among other things, implements electronic climate information delivery.

The work undertaken within the RCI theme upon formation of PCIC in 2005 was initially guided by project-level user feedback only. The first RCI research plan added definition and focus (Murdock and Bürger 2010). This document is one of a series that will be updated roughly every two years (see also Murdock and Zwiers 2012). A key source of user feedback since the previous plan occurred in the form of an RCI theme user workshop (PCIC 2014b). This plan also reflects the input of the PCIC Program Advisory Committee and extensive experience that has been gained by the RCI theme through ongoing interaction with users in the context of numerous RCI projects.

The overarching goal of the RCI theme is to improve the availability and relevance of climate change and impacts scenarios in the PYR and to support their use in decision-making and long term planning. For this reason, our previous plan concentrated on developing a comprehensive foundation of climate information and downscaling capability (Appendix 1). In this update, we transition our focus towards making use of this information base.

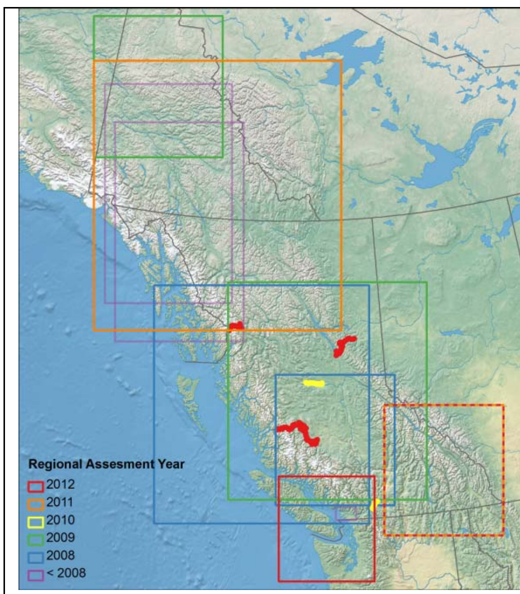

Figure 1: Spatial domain of PCIC focus. Boxes outline spatial extents of regional and community analyses conducted during the past 5+ years (PCIC 2014a).

Indeed, each source of climate information has recently undergone major updates. First, we have begun using climate model projections from the latest the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project Phase 5, (CMIP5), which was undertaken by the WCRP in support of the IPCC 5th Assessment Report. CMIP5 climate projections are based on a new set of forcing scenarios called Representative Concentration Pathways (RCPs; Moss et al. 2010) that replace the SRES scenarios (e.g., B1, A1B, A2; Nakicenovic et al. 2000).

Second, a similar shift is taking place in the source of Regional Climate Model (RCM) simulations for North America in that the so-called NARCCAP project (North American Climate Change Assessment Program), which provided RCM simulations driven by CMIP3 GCMs with SRES forcing scenarios, is being supplanted by CORDEX (COordinated Regional climate Downscaling EXperiments) RCM simulations that are driven by CMIP5 GCMs with RCP forcing scenarios.

Third, together with the Pacific Institute for Climate Solutions and provincial government collaborators, PCIC has made an extensive effort to update and enhance the historical climate database for the region (see CAM research plan; Anslow 2015).

Finally, we have continued to invest in documenting and researching the performance of a range of statistical downscaling tools through an extensive intercomparison project (see 1.1.1). Thus we possess insights and knowledge that allow a more informed choice of tools than previously, and consequently a new source of high spatial and temporal resolution statistically downscaled climate scenarios.

This plan outlines how the RCI theme will exploit these recent advancements in data sources to provide our users with climate information to meet their planning and decision-making needs. Specifically, we will focus on assessment of projected changes to extremes and on facilitating the assessment of impacts. We will also work closely with users to assist them in interpreting the information so that it can be accounted for in their planning processes. The remainder of this document provides details of the RCI research plan, how it will be implemented, and dependencies on other work at PCIC and in the climate research community more broadly.

1.1 Progress since 2012-2016 plan

This section provides a succinct summary of RCI theme progress following the previous RCI theme plan (Murdock and Zwiers 2012), which covered 2012-2016.

1.1.1 Statistical Downscaling

The top priority identified in 2012 RCI research plan was statistical downscaling. Since then, we have continued to invest in downscaling by testing several quantile-based statistical downscaling methods against each other and by developing a hybrid method that performs well in representing climate and weather extremes. This has been used to produce an ensemble of high spatial (10 km) and temporal (daily) resolution statistically downscaled climate projections. In particular, the full suite of CMIP5 GCM projections was obtained and a method was developed to objectively choose a subset that spans the range of CMIP5 climate change projections. As a result, ensembles of daily time series of downscaled minimum and maximum temperature and precipitation are now available for an ensemble of GCMs following RCPs 2.6, 4.5, and 8.5.

1.1.2 Climate Analyses: Regional and Sectoral

One of the key products to be produced by the RCI theme since its inception has been reports that provide regional assessments of climate impacts. Several new regional projects have been undertaken (Figure 1). Following the goals of the 2012 RCI theme plan, each of these projects included an analysis of extremes. In particular, through a process of iterative user feedback, we have learned which of the dozens of potential indices of extremes tend to be the most useful for different users within British Columbia (Murdock and Sobie 2013; Murdock et al. 2014a; Nodelman 2014).

In addition, climate analyses were undertaken following a sectoral approach (specifically, for agriculture, transportation, and mining). In these cases, our role was to provide maps, analysis, and interpretation for climate impacts sections of reports led by sectoral experts rather than leading the development of the reports ourselves (BCAC 2013; Nodelman 2014). This is a useful evolution of the way in which PCIC provides climate services to users since the sector-specific expertise required to produce authoritative evaluations of the potential impacts of climate change generally resides outside PCIC.

1.1.3 Extreme precipitation

Many impacts result from extreme precipitation (landslide, flooding, human health hazards, etc.). As a step towards the assessment of impacts from extreme events, several projects were undertaken to gain an in depth understanding of projected changes in extreme precipitation in British Columbia. This includes contributions (along with the CAM theme) to the assessment of atmospheric rivers (Pinna 2014), assessments of extreme precipitation at three case study locations for BC Ministry of Transportation (Nodelman 2014), and an investigation into the scaling behaviour of extreme precipitation projections (Murdock et al. 2014b). The latter led to finding improved methods of statistical downscaling for precipitation (Cannon et al. 2014).

1.1.4 Products and Services

The most widely used product of the RCI theme (in collaboration with CSG) is the Plan2Adapt online tool. Early into the previous plan, the tool was updated with an improved mapping interface and an expanded, more heavily reviewed, impacts tab (a feature that provides a rough list of possible impacts to consider for a region based on the projected climate change associated with it). Since that time, an additional sector has been added to the impacts tab (health impacts).

To meet a need for climate information in regions that may not have been covered by a recent regional analysis (Figure 1), and to provide a consistent set of regional analyses for all parts of the Province, climate summaries were produced for all eight BC Government "resource regions" with support from the BC Ministry of Forests, Lands, and Natural Resource Operations (BCMFLNRO). These four page summaries include succinct analyses of historical trends and projected future change, for temperature and precipitation only.

1.1.5 User Engagement

Much of the activity of the RCI theme now falls under a more operational role in user support and engagement. Nevertheless, these activities do contribute to our research objectives by deepening our understanding of users' needs for information. The scope of these activities ranges from modest support such as a review of a short section in a user-produced document that makes use of publicly available PCIC climate information to extensive multi-year collaboration on educational materials. A representative subset of the user groups that have been engaged in this way since the last plan include the Metro Vancouver Regional Engineers Advisory Committee, Pacific Institute for Climate Solutions, BC Centre for Disease Control, BC Oil and Gas Commission, Fraser Basin Council, Columbia Basin Trust, Teck Resources Limited, and BC Hydro as well as several local governments, BC Ministries, professional associations, and consulting firms.

2. Research Plan

2.1 Purpose

The purpose of this document is to describe how PCIC's Regional Climate Impacts (RCI) theme will undertake applied research that meets the planning and decision-making needs of users in the PYR for regional information about projected climate change and its impacts. The plan defines the main objectives for RCI to invest time and resources in during 2015 to 2019.

2.2 Collaboration

Projects undertaken by PCIC staff will often be scoped and managed within PCIC. However, activities will also often depend on collaboration with researchers elsewhere, users, or extension agents. Objectives 1 and 3 in particular require peer review by and collaboration with academic and government researchers in physical sciences. Objective 2 depends directly on impacts researchers to a degree that may include project definition, shared data, and collaborative projects.

2.3 User needs

The focus of the RCI theme is to improve the usefulness of information on regional climate change and related impacts within PYR, striving to provide "actionable science", which is defined in Kerr (2011) as "data, analysis, and forecasts that are sufficiently predictive, accepted, and understandable to support decision-making". To do this, an understanding of users' planning and decision-making processes is necessary. In other words, we must know how regional climate change information could be used, what additional information is needed, and in what form it would be most useful. Obtaining this knowledge requires a two-way collaboration with users, whereby PCIC gains insights into user requirements and objectives, and the user gains insights into the types of climate information that may reliably be provided to help inform their planning and adaptation processes.

The RCI theme seeks to continually improve its understanding of user needs in four main ways (see also communication activities in the PCIC strategic plan):

1. Actively participating in user-led projects such as vulnerability and adaptation assessments.
2. Collaborating with users on the delivery of products and services including reports, guidelines, online tools, educational courses, and presentations.
3. Participating in user-led workshops (regional, professional association meetings, etc.).
4. Holding bi-annual RCI theme workshops (PCIC 2014b) to solicit input from users explicitly on our current research plan.

2.4 Motivation

As a result of the outreach described above, the RCI theme is continually exposed to the kinds of questions that users seek to answer. Some examples include:

- How can I obtain an Intensity-Duration-Frequency curve for extreme precipitation for my area that takes climate change into account?
- How much will peak energy demand in winter decrease in the future due to climate change? At what point might British Columbia shift to summer peak demand?

- Are gastrointestinal illnesses, vector-borne diseases, or heat stress likely to become more prevalent as climate changes?
- What wildlife corridors will help maintain optimal ecosystem function under climate change?
- Do storm water drainage culverts need to be larger? By how much?
- Can my municipality expect more power outages from more frequent and intense storms?
- How long will the wildfire season be? What is the optimal tree species to plant in a given location and should its seeds be sourced from a different location?
- How much will year-to-year variability change here?
- Will there be more frequent avalanches? Rain on snow events? Freeze-thaw cycles? Landslides?
- How will agricultural crops be affected by warmer temperatures and changing precipitation?

Many of these questions cannot be answered by the RCI theme, at least not directly or immediately. Our intention with this research plan is to describe investments of time and resources into activities that will improve our ability to inform user driven questions such as these and also increase the capacity of our users to do so on their own. Answering these questions often requires using approaches that range from the development of *downscaled* climate model projections to providing estimates of potential future climate conditions to process-based or spatially explicit *impacts* models. Others may be addressed directly through the analysis of indices of *extremes*. Recognizing that many user questions revolve around the interpretation of downscaled scenarios and output from impacts models provides the basis for the three applied research objectives below that are currently envisioned for the RCI theme. However, it should be recognized that conversations with users will play a critical role in identifying the specific objectives of RCI activities over the period covered by this plan.

2.5 Applied research objectives

While assessments of regional climate change, extremes, and impacts in PYR based on CMIP3 results (which have been available for use since 2005) continue to be published, the more recent CMIP5 results are increasingly being used. The RCI theme has made use of these new GCM results in conjunction with the availability of ANUSPLIN high spatial (10 km) and temporal (daily) resolution historical climate data, as well as a thorough and extensive investment in quantile-based statistical downscaling methods, to produce an ensemble of (10 km, daily) statistically downscaled climate model projections from RCMs and CMIP5 GCMs.

This new data source presents an opportunity for meeting user needs that we have not been afforded previously. This data source is available for direct download by advanced users from the PCIC Data Portal even as the switch over from CMIP3 to CMIP5 results is just beginning. The daily temporal resolution in particular is needed for the analysis of extremes and impacts. Therefore, RCI will focus on the use of the recently downscaled CMIP5 results, as reflected in Objectives 1 and 2 listed in Table 1: assessment of extremes and impacts. As a third objective, it will also continue to pursue advancements in downscaling, particularly exploiting insights on the representation of extremes that are obtained from the pursuit of Objectives 1 and 2. These objectives are motivated as described in the previous section and arise out of completed and ongoing work. We intend to significantly improve our ability to provide relevant future projections within each objective, as described in Sections 3 and 4.

Table 1: RCI Research Objectives

Objective	Description	Priority
1	**Extremes:** extend the analysis of projected future climate change to include regional extremes.	1
2	**Impacts**: extend the analysis of projected future change to include regional impacts relevant to ecosystems, resource management, infrastructure, and local government.	2
3	**Downscaling:** increase the resolution of the most recent future climate change projections to relevant regional scales, with a particular focus on improving the ability of statistical downscaling schemes to faithfully represent extremes.	2

2.5.1 Objective 1 – Extremes

The purpose of Objective 1 is to include indices of rare or extremely rare events in climate analyses (as in 1.1.2), now with the benefit of an ensemble of statistically downscaled CMIP5 GCMs for three emissions trajectories. Assessment of extremes is aimed at improving the relevance of climate information to users (Tyler 2012). We will draw upon recent experience selecting, in collaboration with users, the most useful and appropriate indices for PYR from the ETCCDI/CLIMDEX indices (Zhang et al. 2011; Appendix 3) and related extreme value statistics, such as return values for periods of different durations.

One challenge facing the analysis of extremes is that, by definition, they are rare. Statistical science provides a strong theoretical foundation for the analysis of rare events, either on the basis of the analysis of series of annual extremes (the block-maximum approach, which has been extensively applied in operational hydrology, for example), or on the basis of the analysis of exceedances across a high threshold (the peaks-over-threshold approach). We will address this challenge by using climate model simulations to test some of the assumptions that are often made during analysis of extremes. Building on experience assessing the spatial scaling behaviour of precipitation and the effect of downscaling on projected changes in extremes, we also intend to investigate the temporal scaling of precipitation, an important aspect to address before attempting to produce Intensity-Duration-Frequency curves of extreme precipitation that incorporate future conditions.

2.5.2 Objective 2 – Impacts

The purpose of Objective 2 is to undertake and/or support analyses of climate change impacts based on temperature, precipitation, and related extremes (as in 1.1.3). The ultimate objective is to facilitate the production of a suite of projections of different impacts. For example, active projects in this area currently include atmospheric rivers, storminess, heating and cooling demand, health impacts, and wildlife corridors. The role of the RCI theme in these projects is not only to provide future climate scenarios, but also to work with decision-makers and impacts researchers on the non-trivial task of incorporating climate model projections into other modelling tools that usually were not designed with a changing climate in mind. This process involves two-way communication and learning by PCIC about the assumptions and data needs of impacts tools as well as by users about the limitations and assumptions that accompany the use of downscaled climate scenarios.

Some impacts for which demand has been expressed but for which opportunities to take on projects have not yet been forthcoming include wind, wildfire, landslides, erosion, freeze-thaw cycles, and the development of Intensity-Duration-Frequency curves. In the long term, successful analysis of a range of impacts is the foundation upon which regional impacts assessments such as Miles et al. (2010) and BACC (2008) may be produced.

Although this objective is as important as Objective 1, our plans to address impacts depend on collaboration opportunities and funding because PCIC's primary expertise on impacts is in hydrology (resident in the HI theme), whereas user needs for information on impacts are wide-ranging, as shown by the range of impacts described above that are being pursued currently and for which there is user demand.

2.5.3 Objective 3 – Downscaling

The purpose of Objective 3 is to improve the regional utility of future climate change projections through downscaling to higher resolution and a continuing focus on the ability of statistical downscaling to well represent extremes. The appropriate spatial scale depends on the application. Recent downscaling from CMIP5 includes:

- dynamical downscaling (daily and sub-daily) with regional climate models at approximately 25 km resolution as undertaken by regional climate modelling groups participating in CORDEX-NA,
- statistical downscaling (daily) at 10 km resolution for general purposes and at 1/16° (~ 6km) resolution mainly for hydrological applications as performed at PCIC, and
- semi-empirical downscaling that uses reconstructed observations (at 800 m; Daly et al. 2009; Anslow 2015) to adjust global climate model output with bias and elevation corrections, as performed at PCIC (www.Plan2Adapt.ca) and elsewhere (Hamann et al. 2013).

The next major components of the RCI downscaling efforts will be to:

- assess the robustness of both dynamical and statistical downscaling,
- produce statistical downscaling from CORDEX-NA runs as they become available, and
- consider producing statistically downscaled results using synchronous (variables paired in time) transfer function statistical downscaling to complement quantile-based (asynchronous) statistical downscaling where variables are paired by rank or percentile that has been completed to date.

Note that PCIC does not undertake its own dynamical downscaling, but rather will continue to make use of dynamical downscaling results that are produced elsewhere as community projects, such as CORDEX-NA. PCIC will contribute to the value of these projects, and to the understanding of the value added by downscaling, by evaluating CORDEX-NA simulations and by further downscaling the simulations to higher spatial resolutions.

3. Approach

3.1 Objective 1 – Extremes

We will expand upon recent projects (e.g., Murdock and Sobie 2013; Murdock et al. 2014b; Nodelman 2014) in which we have assessed ETCCDI/CLIMDEX indices (Zhang et al. 2011) in collaboration with users, to refine the most relevant subset of indices (Appendix 3). We will also use extreme value theory to analyse return values for defined return periods, which represent events with a given likelihood of occurrence per year. Although 100- and 200-year return values are often needed as design parameters, data limitations render estimates of changes in return values for shorter periods more reliable. We will investigate ways of computing longer return periods (e.g., van den Brink and Können 2011).

Specialized indices have also been developed in collaboration with users (BC Ministry of Transportation and Infrastructure, Engineers Canada, and City of Castlegar) to address issues of particular concern in PYR such as rain on frozen ground, and a demand for further analysis of custom indices has been expressed by users (PCIC 2014b). We will develop specialized indices where the user need requires it, but we will also focus attention on the subset of basic temperature and precipitation indices that have proven most informative thus far (Appendix 3), to facilitate comparison between projects and more in depth analyses of a smaller number of indices.

3.2 Objective 2 – Impacts

Producing projections of future impacts requires expertise with climate model projections and downscaling, and thus is a natural extension of the experience gained in the RCI theme. However, it also requires expertise in the specific impacts of interest, which is generally not resident at PCIC, with the exception of hydrological impacts in the HI theme. Progress under this objective is thus contingent on the interest and collaboration of PCIC users and partners who are impacts experts.

An example of an impact that we intend to continue to investigate is projected changes in storminess. Changes in the frequency and intensity of storms are of particular interest to BC Hydro, BC Ministry of Transportation and Infrastructure, and coastal communities. The PCIC Director (Zwiers) has previously collaborated with scientists at Environment Canada (Toronto) and others on historical and future changes in storminess indicators, based on reanalyses and climate model simulations. Further expertise is available at Environment Canada and in the UVic Department of Geography that would help to make investigation in this area feasible. Complementary work is also taking place at PCIC with support from the MEOPAR (Marine Environment Observation, Prediction And Response) NCE (Network of Centres of Excellence), in which Zwiers is a participant. Work since the previous plan on this subject includes assessment of impacts of extreme precipitation on transportation (Nodelman 2014) and contributions to an assessment of atmospheric rivers (Pinna 2014).

Other active projects on impacts include preliminary assessments of heating and cooling demand, health impacts, and (transboundary) wildlife corridors. Another possible impact to explore is future climatic suitability for crops and invasive species, which is important to the BC Ministry of Agriculture, the BC Grower's Association, BCMFLNRO, and BC Hydro.

3.3 Objective 3 – Downscaling

We have successfully tested and developed a quantile-based statistical downscaling method that we are confident in applying on an operational basis as new climate model results become available (see 1.1.1). While this allows us to shift a larger portion of our workload towards the assessment of extremes and impacts (Objectives 1 and 2), we will continue to pursue improvements in statistical downscaling, while publishing results of work thus far in journals and guidelines (e.g., update to Murdock and Spittlehouse 2011). Next steps that we will take under this activity, described in more detail below, are:

1. choose or develop a synchronous method for statistical downscaling to point locations and conduct downscaling at selected locations,
2. quantify downscaling uncertainty, and
3. prepare for a new suite of GCM projections from CMIP6 .

We will investigate the use of a synchronous (variables paired in time) method such as eXpanded DownScaling (XDS) which generally provides more skill at the cost of more comprehensive data requirements and manual intervention (Bürger et al. 2012). We intend to use site-specific case studies to investigate the potential added benefits of a synchronous method, if user demand aligns with this investigation. We will also consider gridding synchronously downscaled results if a suitable method can be found that can be automated without sacrificing the improved skill such methods may provide.

The assessment of uncertainty is complex and demanding, and because resources are limited, we will take a pragmatic approach to identify those aspects of uncertainty that will most improve our ability to deliver user-driven “actionable science” as described in Section 2.3. For example, keen user interest in updated Intensity-Duration-Frequency curves for extreme precipitation that take into account climate change leads us to prioritize investigation of scaling relationships between daily and sub-daily precipitation change between the past and future in climate models.

Toward the end of the time frame covered by this research plan, a new set of climate model projections from CMIP6 will likely be nearing completion. We will ready ourselves for operational production of statistical downscaling and updated online tools when CMIP6 simulations become available.

4. Applied research

This section describes the specific requirements to meet each of the research objectives in section 3 with approximate timelines. These are the necessary tasks required to accomplish the goals of each objective laid out in the previous section. Actual timing will depend upon PCIC staff capacity, evolving user needs, opportunities for collaboration, and funding opportunities. The requirements are listed in the order in which activities build upon each other, not in order of priority.

4.1 Requirement 1 – Data requirements

Most subsequent activity for RCI depends on first obtaining historical climate observations and climate model simulations, as described in the introduction. The majority of the period covered by this plan is between the major GCM data releases of CMIP5 and CMIP6. Thus, the main activity will be to obtain RCM results from CORDEX-NA driven by CMIP5 GCM projections to replace the suite of NARCCAP RCM results driven by CMIP3 GCM projections.

4.1.1 **Historical observations** – Obtain and assess gridded data sets for the Pacific and Yukon region as they become available, including new datasets created by the CAM theme ▪ *Timeline*: ongoing ▪ *Lead*: RCI ▪ *Support*: CAM

4.1.2 **Obtain RCM results** – Download and quality control CORDEX data as they continue to be made available and as opportunities arise. Make use of RCM results in downscaling, regional climate change assessment, and exploration of uncertainty. ▪ *Timeline*: ongoing ▪ *Lead*: RCI ▪ *Support*: CSG ▪ *Data:* CCCma + Ouranos + CORDEX-NA

4.1.3 **Prepare for CMIP6 results** – Become informed of details regarding a new suite of CMIP6 simulations that may impact PCIC use of them for regional analysis, computation of extremes, statistical downscaling, etc. ▪ *Timeline*: 2016/18 ▪ *Lead*: RCI

4.2 Requirement 2 – Statistical Downscaling

Producing a region-wide set of downscaled future projections requires choosing synchronous or asynchronous methods, as described above. In addition, downscaling is either performed on a grid or to stations followed by using geospatial methods to produce gridded results (Murdock and Bürger 2010). A practical approach has been chosen of first conducting gridded downscaling using asynchronous methods. Next we will consider complementing this resource with selected downscaling to stations using synchronous methods (see 3.3; subject to alignment with specific user projects).

We will seek ways to capitalize on the different strengths of dynamical and statistical downscaling methods. Long term improvement in statistical downscaling will include investigating the *components* of different methods that contribute to skill and uncertainty, including new baseline historical datasets. For example, instead of assessing three different methods with arbitrarily different bias correction schemes, the differences between which confound the ability to compare results, we will move towards development of methods by assessing the influence of one component at a time. In conjunction with projects on impacts (3.2), we may consider downscaling derived variables (such as humidity) directly rather than relying on their computation from downscaled temperature and precipitation. Downscaling of derived and other variables such as wind will assist in addressing wildfire impacts and facilitate the HI theme running the VIC hydrological model in energy balance mode (Schnorbus 2015).

4.2.1 **Downscale RCMs** – Conduct further statistical downscaling of RCMs for use in regional assessments of climate change, extremes, impacts, and quantifying uncertainty. ▪ *Timeline*: 2015/17 ▪ *Lead*: RCI ▪ *Support*: CSG

4.2.2 **Downscaling development** – Continue to evaluate downscaling methods, concentrating on the importance of different components separately such as bias-correction, predictor variables, spatial domains, and historical data sets. Consider development of a synchronous method and derived variables. ▪ *Timeline*: ongoing ▪ *Lead*: RCI

4.3 Requirement 3 – Impacts Modelling and Assessment

Facilitating the production of future impacts scenarios requires investments by PCIC in two areas: first, data provision, which is primarily within the purview of CSG (e.g., through the development of appropriate data portals), and, secondly, in understanding enough about the use of climate scenarios by impacts modellers to provide guidance on their use and interpretation.

4.3.1 **Support use of scenarios and interpretation** – pursue opportunities in collaboration with users and impacts researchers for production of impacts scenarios; determine impacts modelling requirements; provide guidance on use of downscaled climate scenarios in conjunction with impacts models, and on interpretation of results. ▪ Timeline: 2015/17 ▪ Lead: RCI

4.3.2 **Respond to lessons learned** – as the application of (downscaled) climate model scenarios to impacts models and assessments in many cases involves novel applications, lessons learned about impacts modelling requirements must be incorporated into future versions of this plan. The imperative to respond to lessons learned cuts across each one of the other requirements listed in this section. ▪ Timeline: 2017 ▪ Lead: RCI

4.4 Requirement 4 – Quantify Uncertainty

A good understanding of the uncertainty inherent in future climate scenarios from various sources is a key element for interpreting future projections and providing guidance to users. Assessment and communication of uncertainty is important but non-trivial. For example, the difference in impacts between higher and lower greenhouse gas emissions or concentrations matters for long-term planning because adaptation and mitigation planning are relatively integrated at the regional and local level. Five sources of uncertainty to address are listed in Appendix 2.

4.4.1 **RCM uncertainty** – compare simulated historical climate to observations for CORDEX-NA RCMs with and without statistical downscaling. ▪ *Timeline*: 2016/18 ▪ *Lead*: RCI

4.4.2 **Statistical downscaling uncertainty** – investigate the effect of downscaling on climate projections; investigate spatial and temporal scaling of extremes; compare uncertainty from synchronous methods to each other and to asynchronous methods; assess uncertainty arising from components of methods. ▪ Timeline: 2015/18 ▪ *Lead*: RCI

4.4.3 **Observed data uncertainty** – assess uncertainty in historical datasets and compare to climate model and statistical downscaling uncertainty. ▪ Timeline: 2016/19 ▪ *Lead*: RCI *Support*: CAM

4.4.4 **Multimodel ensembles** – determine methods, benefits and limitations of combining projections from GCMs and RCMs (e.g., Kendon et al. 2010) including those driven by different emissions scenarios and from regional climate model emulators. ▪ Timeline: 2015/17 ▪ *Lead*: RCI

4.5 Requirement 5 – Delivering results

Carrying out the three research objectives in this document promises to produce a large volume of information. An important aspect of delivering results about the projected future climate is to provide context with historical trends and variability. A focus on extremes as our top priority (Objective 1) brings a need to assess historical trends and variability *of extremes* (Zhang et al. 2011). Because of the rare nature of extremes, by their very definition, trends of extremes will present additional challenges to assess, and may not be feasible to assess for all indices.

Another key aspect of communicating results is the online display of spatial information and statistical summaries. When upgrading online tools with new features and new model results, we will strive to integrate them with the PCIC Data Portal and other available online tools whenever possible. We will focus our own development on tools that provide added value for regional users in PYR and will attempt to ensure complementarity with tools available from other information providers (e.g., Environment Canada, Ouranos, etc.).

4.5.1 **Historical trends and variability** – Extend the computation of historical trends and composites to indices of extremes. ▪ *Timeline*: 2015/16 ▪ *Lead*: CAM+RCI

4.5.2 **Regional climate analyses** – Apply new historical datasets and future projections (including extremes) to regional climate analyses, in collaboration with users. ▪ *Timeline*: 2015 ▪ *Lead*: RCI+CAM

4.5.3 **Online tools** – Develop new features and incorporate CMIP5 results into online data delivery and analysis tools including Plan2Adapt and the PCIC Regional Analysis Tool, using where possible open-source platforms. Incorporate new gridded PRISM baseline. ▪ *Timeline*: ongoing ▪ *Lead*: RCI+CSG ▪ *Support*: CAM

4.5.4 **Face-to-face interaction** – Carry out in-person delivery of climate information at presentations, workshops, and user-organized meetings to enhance both our understanding of user needs and the effectiveness of our products in meeting them. ▪ *Timeline*: ongoing ▪ *Lead*: RCI

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Appendix 1: Schematic of proposed approach

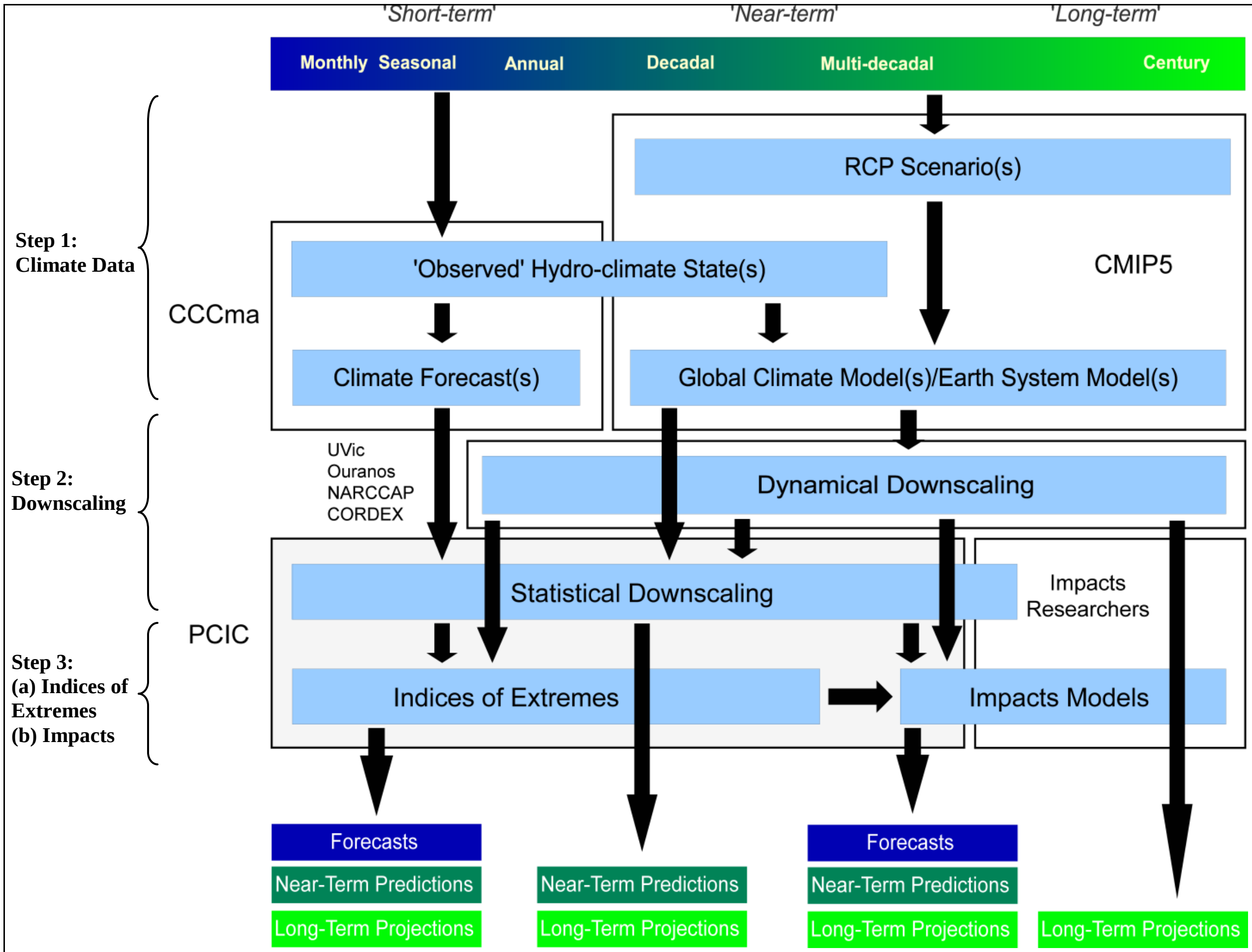

Figure 2: Schematic of proposed approach to improve the availability and relevance of information on climate variability and climate change by means of "short-term" (monthly to annual) forecasts, "near-term" (decadal to multi-decadal) predictions and "long-term" (multi-decadal to century) projections. Global climate data is obtained from external agencies, namely CCCma for monthly, seasonal and decadal forecasts and CMIP5 for decadal climate predictions and multi-decadal and century climate projections (step 1). Dynamical downscaling results are obtained from UVic, Ouranos, NARCCAP, and CORDEX (step 2). The RCI theme's efforts will focus primarily on analysis and diagnosis of dynamically downscaled results and statistical downscaling (step 2) including extremes (step 3a). We will also collaborate on impacts modelling and potentially investigate the feasibility of short term forecasts and near-term predictions (step 3b). Note that the corresponding time scales for the bottom boxes match the colours of the boxes, not the positions underneath the top bar.

Appendix 2: Quantifying and communicating uncertainty

Table 2: Research requirements (Section 4) and possible collaborations related to quantifying uncertainty.

Source	Uncertainty	Requirement	Possible collaborators
1. Imperfect understanding of climate system, climate model parameterizations	How do GCM and RCM projections simulate the past, and how do biases affect projections of impacts?	4.4.1-4	*Climate modellers*: Canadian Centre for Climate Modelling and Analysis, Ouranos, UVic Climate Lab
2a. Non-linear climate system 2b. Sampling challenges for extremes	In PYR, how (un)predictable is the climate system for different variables and times of year?	4.4.3	*Climate researchers*: UVic Climate Lab, Canadian Centre for Climate Modelling and Analysis
3. Communication of complex, interdisciplinary science	How can the complex and subtle messages about uncertainty be expressed clearly?	4.5.1-3	*Educators and extension specialists*: Royal BC Museum, BC Ministry of Environment, Fraser Basin Council, Columbia Basin Trust, Canadian Institute of Planners, APEGBC
4. Imperfect downscaling methods, climate impacts models, methods, and data	How does uncertainty introduced by downscaling methods and climate impacts models compound climate and climate model uncertainty?	4.2.1-2, 4.3.2	*Impacts researchers*: BC Ministry of Forests, Lands, and Natural Resource Operations, UBC Forestry, Water-Climate Impacts Research Centre, Canadian Forest Service, BC Hydro
5a. Uncertain greenhouse gas emissions and concentrations 5b. Time scale of impacts compared to time scale of decision-making	How can adaptation take into account the unknown level of success in greenhouse gas mitigation strategies? Are projections of future climate impacts the right tool to inform planning or decision under consideration?	4.5.2	*Policy experts and social scientists*: Pacific Institute for Climate Solutions, ACT, UBC Collaborative for Advanced Landscape Planning, BC Ministry of Community Development

Appendix 3: Indices of Extremes

Table 3: Expert Team on Climate Change Detection and Indices (ETCCDI) CLIMDEX indices of extremes: full set from www.climdex.org with the subset identified as most relevant in British Columbia based on user feedback thus far indicated by *italics*.

Index	Name	Description	Units
FD0	*Frost days*	*Annual count when TN(daily minimum)<0ºC*	*days*
SU25	Summer days	Annual count when TX(daily maximum)>25ºC	days
ID0	Ice days	Annual count when TX(daily maximum)<0ºC	days
TR20	Tropical nights	Annual count when TN(daily minimum)>20ºC	days
GSL	Growing season length	Annual (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between first span of at least 6 days with TG>5ºC and first span after July 1 (January 1 in SH) of 6 days with TG<5ºC	days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	ºC
TNx	Max Tmin	Monthly maximum value of daily minimum temp	ºC
TXn	Min Tmax	Monthly minimum value of daily maximum temp	ºC
TNn	Min Tmin	Monthly minimum value of daily minimum temp	ºC
TN10p	Cool nights	Percentage of days when TN<10th percentile	days
TX10p	Cool days	Percentage of days when TX<10th percentile	days
TN90p	Warm nights	Percentage of days when TN>90th percentile	days
TX90p	Warm days	Percentage of days when TX>90th percentile	days
WSDI	*Warm spell duration index*	*Annual count of days >=6 consecutive days TX>90th percentile*	*days*
CSDI	*Cold spell duration index*	*Annual count of days >=6 consecutive days TN<10th percentile*	*days*
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
RX1day	*Max 1-day precipitation*	*Monthly maximum 1-day precipitation*	*mm*
Rx5day	*Max 5-day precipitation*	*Monthly maximum consecutive 5-day precipitation*	*mm*
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year	mm/day
R10	# heavy precipitation days	Annual count of days when PRCP>=10mm	days
R20	# very heavy precipitation days	Annual count of days when PRCP>=20mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	days
R95p	*Very wet days*	*Annual total PRCP when RR>95th percentile*	*mm*
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
PRCPTOT	*Annual total wet-day precipitation*	*Annual total PRCP in wet days (RR>=1mm)*	*mm*