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PCIC recently underwent a very successful five-year review, a part of UVic's normal oversight process for its research centres and entities. As part of this process, PCIC produced a self-assessment report summarizing its progress and achievements of the past five years. That report provides the basis for this year's corporate report, which is presented as a five-year retrospective of our achievements. It begins with an overview of PCIC, and our history, strategy and governance structure. It continues with a discussion of PCIC's climate services and how they have been developed over the past five years. Climate service delivery has taken on considerable importance across Canada over that time, with the example that has been set at PCIC being influential in that development. Following that, this report provides a synopsis of PCIC's outreach efforts and then emphasizes PCIC's achievements in climate science, including achievements in the research programs based of the three PCIC research themes (Regional Climate Impacts, Hydrologic Impacts and Climate Analysis and Monitoring). The report concludes with a discussion of PCIC's operational management and a list of publications.

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## A MESSAGE FROM THE DIRECTOR

PCIC is a regional climate service provider that serves stakeholders and the public in BC and more widely. Since its inception in 2005 as a project within the Canadian Institute of Climate Studies, PCIC has been dedicated to ensuring the provision of quantitative, high-quality regional climate services and information. PCIC has continued to strengthen its scientific reputation and service through defining and implementing its strategic scope.

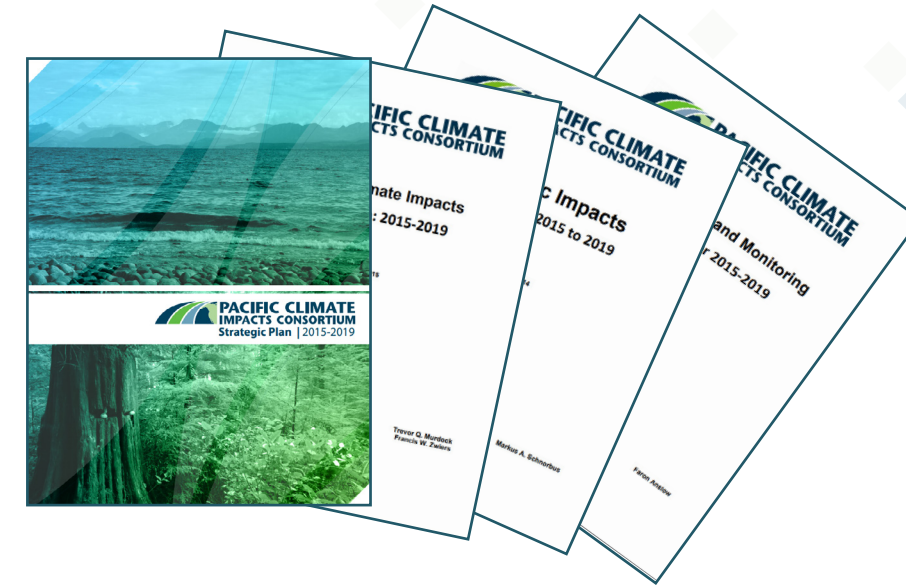
Over the past 5 years, PCIC has focused on regional climate service delivery and user needs as outlined in its Strategic Plan for 2015-2019. PCIC's service objectives have evolved somewhat over the past five years, reflecting the evolution of user needs and their capabilities. PCIC distills relevant findings from the global climate research community, performs applied, regional climate research and enables the uptake of that information to our user community. Because planning for the effects of climate change and variability is an effort that involves a broad spectrum of climate-information users with various needs and goals, PCIC continues to offer an array of quantitative climate information, ranging from high-level regional overviews to raw observational data and climate model output. In new collaborations, PCIC also works to increase the capacity of others to develop and deliver climate services.

Through careful and consistent leadership, PCIC is well-positioned as a competent and reputable climate science provider and has set an example illustrating good practises in climate service delivery that have influenced others in the nascent Canadian network established with the Canadian Centre for Climate Services (CCCS).

Increasingly PCIC has been collaborating with its users to undertake projects in which climate information and its interpretations are co-developed, with the results tailor-made for user needs. In addition, PCIC, with support from the newly established Canadian Centre for Climate Services (CCCS), has recently begun to take a more formal and active role in user training and capacity building.

PCIC's continuing success in delivering regional climate services, highlighted in this report, is thanks to the support and commitment of all our partners. With this support, we continue to grow in our ability to address the important questions in regional climate science and hydrology and expand our capacity to meet the needs of our user base.

## PCIC'S MISSION



Above, left to right, covers of: The PCIC Strategic Plan 2015-2019; Regional Climate Impacts, Research Plan for 2015-2019; Hydrologic Impacts, Research Plan for 2015-2019; and Climate Analysis and Monitoring, Research Plan for 2015-2019.

To adapt to climate change, PCIC's regional stakeholders require easily accessible, high-quality data, credible climate projections and guidance on their use. PCIC's goals are to provide high-quality climate services and information in an increasingly comprehensive form, and to continually strengthen the underlying scientific basis for those products. PCIC has carefully defined the strategic scope of the organization to help guide it towards these objectives.

The PCIC Strategic Plan 2015-2019, one of the principle documents that guides PCIC's work, clearly prioritizes climate service delivery and user needs. The plan lays out a concise and focussed set of service objectives for PCIC together with a number of strategic objectives that describe the key activities that are to be undertaken to enable the effective delivery of quality climate services.

PCIC's service objectives have evolved since the publishing of the 2015 plan in order to better engage with its users. Objectives that reflect PCIC's engagement with its users are:

1. To provide and enable analysis of the impacts of climate variability and change on the regional climate and water resources.
2. To provide and enable interpretation of regional climate information specific to user needs.
3. To provide and enable the use of recent data and future climate projections.

This evolution is consistent with a broad understanding of what constitutes a climate service, wherein capability building via user engagement and training is an important part of the scope of services that our users hope for.

## PCIC'S MISSION

These services are supported by our dedication to three strategic objectives, which are to

1. Build partnerships that enable service delivery and support our applied science program.
2. Ensure that PCIC has the scientific and information resources that are necessary to support its service delivery objectives.
3. Maintain operational and managerial excellence.

It is these objectives (service and strategic) that guides the work of PCIC in its research and service delivery and informs all of the projects that will be discussed in what follows.

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## PCIC OVERVIEW

From its beginnings as a project within the Canadian Institute for Climate Studies, the Pacific Climate Impacts Consortium has grown into a climate services centre capable of serving the needs of a diverse group of users across the BC Yukon region and more broadly. PCIC is proud to be part of a network of climate service providers who are helping people prepare for and adapt to the changing climate.

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## PCIC OVERVIEW

### HISTORY



The Sedgewick Building on the campus of the University of Victoria was the first home of the Canadian Institute for Climate Studies, the predecessor organization of the Pacific Climate Impacts Consortium.

UVic has hosted a climate services organization of some form for at least the last 25 years, beginning with the Canadian Institute for Climate Studies (CICS), which was established in 1994. CICS successfully delivered a suite of climate services and managed a comprehensive climate research program on behalf of Environment and Climate Change Canada (ECCC) that involved partners across Canada. In 2005 there was a shift in focus at the federal level, resulting in withdrawal of federal funding to CICS. At the same time, the BC Government was becoming increasingly concerned with the regional impacts of climate change. Recognizing the potential value of CICS's products, its human capital and the benefits of being able to draw upon the substantial amount of climate expertise that is available at UVic, the University, the British Columbia Ministry of Environment and Climate Change Strategy (MoE), BC Hydro, and other regional stakeholders along with a number of regional scientists held a workshop to explore ways to capitalize on CICS' value. The workshop concluded that there was an opportunity to pool resources, focus them on serving climate information needs in the Pacific and Yukon Region of Canada, and that this could best be done through an organization that bridges the gap between the international climate science community and regional users of climate information. This 2005 meeting marked the inception of PCIC as a project within CICS.

PCIC grew in regional importance and built upon its predecessor, initiating products such as downscaled regional climate analyses and hydroclimate modelling for the major BC river basins. As PCIC grew, it fostered enduring relationships with key stakeholders and partners such as BC Hydro, BC Ministries

## PCIC OVERVIEW

(Environment; Transportation and Infrastructure; and Forests, Lands, Natural Resource Operations & Rural Development; Agriculture) and the Ouranos Consortium. PCIC's association with BC Hydro was initiated in 2005, at PCIC's organizing meeting, and continues to this day. BC Hydro formalized its relationship in a four-year research agreement in 2007. BC Hydro reaffirmed its commitment to PCIC by renewing the agreement in 2011 and 2015, and has again done so very recently by an additional four year commitment in an agreement that will extend to the end of the 2022-2023 fiscal year. PCIC's growing regional value and its 2007 Strategy and Plan had an influence on the 2008 BC Government (via the MoE) announcement of an endowment, granted to UVic, that provided sustained support to PCIC and created PICS. PICS and PCIC both receive funding from the Endowment, share facilities, and work on complementary aspects of the climate change issue, with PCIC providing climate services and expertise, detailing our understanding of the changing climate and its impacts, and PICS providing insights and advice on the development and implementation of potential adaptation, mitigation and policy solutions.

PCIC's user base has grown steadily over the past 5 years to include an even broader range of stakeholders at all levels of government, publicly- and privately-owned industries and the general public. An increasingly important aspect of PCIC activities is its deepening involvement with the infrastructure engineering sector, both within our region and nationally. In several cases, PCIC has collaborated on a succession of projects with the same partner over the period, thereby substantially deepening the relationship with that partner in the process. It has also extended its services to partners beyond its regional borders in cases where PCIC's expertise and capacity have allowed such expansion to occur. This has brought considerable impact and recognition to PCIC at a national scale. Also, the broader user base and greater level of implied responsibility has enhanced the value of PCIC's services and information for users within our region. With the development of both our expertise, capacity and user-base, PCIC continues to roll-out new products and more powerful tools for the public, the private sector and research communities, and provide ever greater, more detailed and better-documented data.

### ROLE

PCIC is a regional climate service provider serving stakeholders and the public in BC and more widely. As a part of this, we are dedicated to ensuring the provision of quantitative, high-quality climate information. Motivated by our stakeholders' needs, PCIC both distils relevant findings from the global climate research community and performs applied, regional climate research. Because planning for the effects of climate change and variability is an effort that involves a broad spectrum of climate-information users with various needs and goals, PCIC offers an array of quantitative climate information, ranging from high-level regional overviews to raw observational data and climate model output. It also works to increase the capacity of others to develop and deliver climate services. Increasingly, PCIC and its users undertake projects in which climate information and its interpretations are co-developed. Also, PCIC, with support from the newly established Canadian Centre for Climate Services (CCCS), has recently begun to take a more formal and active role in user training.

## PCIC OVERVIEW

### GOALS

PCIC's goals are to provide high quality climate services and information that are increasingly comprehensive, and to continually strengthen the underlying scientific basis for those products. We have carefully defined the strategic scope of the organization to help guide it towards these objectives. To this end, five principal documents, consisting of a strategic plan and three research plans act as our guide:

- The PCIC Strategic Plan 2015-2019
- Regional Climate Impacts, Research Plan for 2015-2019
- Hydrologic Impacts, Research Plan for 2015-2019
- Climate Analysis and Monitoring, Research Plan for 2015-2019

The PCIC Strategic Plan 2015-2019 (PCIC, 2015) was developed building on the strength of PCIC's founding Strategy and Plan 2007 and the subsequent 2009-2013 and 2012-2015 PCIC Strategic Plans. The 2015 plan also further focused PCIC's strategic scope, clearly prioritizing climate service delivery and user needs. The plan lays out a concise and focussed set of service objectives for PCIC together with a number of strategic objectives that describe the key activities that are to be undertaken to enable the effective delivery of quality climate services.

PCIC's service objectives as defined in the 2015 plan are:

1. To provide analysis of the impacts of climate variability and change on the regional climate and water resources.
2. To provide interpretation of regional climate information specific to user needs.
3. To provide recent data and future climate projections specific to the PCIC study region.

These objectives have evolved somewhat over the past 5 years, reflecting the evolution of user needs and their capabilities. As a consequence, it would now be reasonable to replace with verb "provide" in these three objectives with the verbs "provide and enable". An updated set of objectives that better reflects PCIC's engagement with its users might therefore be:

1. To provide and enable analysis of the impacts of climate variability and change on the regional climate and water resources.
2. To provide and enable interpretation of regional climate information specific to user needs.
3. To provide and enable the use of recent data and future climate projections.

This evolution is very much consistent with a broad understanding of what constitutes a climate service, wherein capability building via user engagement and training is an important part of the scope of services that our users hope we will deliver.

## PCIC OVERVIEW

These services are supported by our dedication to three strategic objectives, which are to

1. Build partnerships that enable service delivery and support our applied science program.
2. Ensure that PCIC has the scientific and information resources that are necessary to support its service delivery objectives.
3. Maintain operational and managerial excellence.

It is against these six objectives (service and strategic) that the remainder of this report weighs PCIC's progress over past five years.

### APPROACH

PCIC's applied research activities, which support its service objectives, are organized into three themes. To deliver climate services from these research areas, PCIC maintains a small and highly qualified team of professionals with significant experience, both in their specific fields of expertise, and in climate research and analysis more generally. PCIC's in-house expertise includes climatology, the development of climate change scenarios, hydrology, scientific computing and communications.

We are part of a larger informal network of climate research and information-providing institutions. The structure of this network in Canada is now beginning to benefit from the organizational and coordination efforts of the recently established CCCS. It also benefits from a growing private sector and international interest in climate service development and delivery, including the World Meteorological Organization's Global Framework for Climate Services, the Copernicus climate service delivery initiative, many national services that have been established in Europe and elsewhere, and the growing importance of climate change adaptation in the context of the UN Framework Convention on Climate Change. We rely on the strengths of this community through collaborations and partnerships. We also give back to this community by releasing software, providing data, developing user capacity and by participating in the peer-reviewed research community, both as reviewers and authors. These strong ties keep PCIC researchers conversant with the leading edge of regional climate science research and service delivery. Our services are delivered to users via a variety of online tools, seasonal climate reviews, data portals, plain-language articles, webinars, public presentations, reports, peer-reviewed journal articles and custom projects, many of which are undertaken in a co-production mode.

## PCIC OVERVIEW

### GOVERNANCE & USER ENGAGEMENT

PCIC has a transparent, comprehensive and effective system of governance. PCIC is a legally incorporated not-for-profit corporation that is registered with Industry Canada under the Canada Not-for-profit Corporations Act and is governed by a Board of Directors (PCIC BOD). The PCIC BOD meets four times per year to provide direction on the affairs of the organization to ensure its development and enhance the value of its programs, services and financial sustainability. The Board also has ultimate responsibility for the stewardship of PCIC's financial and human resources. It approves PCIC's annual work and financial plans, provides financial oversight, and appoints and oversees the PCIC Director, who also serves as President and Chief Executive Officer of the corporation. The Board ensures that PCIC maintains the quality, depth, and continuity of oversight required for attaining the Corporation's major strategic and service objectives. Dr. David Castle, the University of Victoria Vice-President of Research, served as Chair of the PCIC Board from 2014 to 2019. Under his leadership, the PCIC BOD and PCIC Management maintained a regular reporting system that provides the PCIC BOD with regular quarterly updates on PCIC's progress against its annual budget and work plan.

The President and Chief Executive Officer, who is also the Director, is responsible for the day-to-day conduct of organizational activities and the execution of PCIC's Strategic and Research Plans. PCIC has enjoyed the leadership of Prof. Francis Zwiers since 2010. In that time, Prof. Zwiers has strengthened PCIC's scientific reputation and our service face through defining and implementing its strategic scope.

PCIC receives scientific and strategic advice concerning the PCIC program via a Program Advisory Committee (PAC), which also meets three to four times per year. The PAC is made up of both scientists and stakeholder users. Mr. Thomas White, in his role with the MoE Climate Action Secretariat, served as Chair of the PAC between 2010 and 2018, and the PAC is now chaired by Tina Neale, Director of Climate Risk Management, BC Ministry of Environment and Climate Change Strategy. Each Research Theme provides the PAC with a periodic update on its progress, seeking advice on the pertinence of the work for stakeholders and users. This allows the PAC to offer advice on each of PCIC's themes. PCIC also consults with the PAC on the development of its Strategic Plan. In addition, PCIC receives much scientific and strategic advice directly from its users and partners through the many research and service agreements that it has developed with its stakeholders. The conversations and negotiations that define the scope of these agreements, the agreements themselves, the conversations (both formal and informal) that takes place in the course of the implementation of the agreements, and the final reporting process for each agreement, all constitute part of the user engagement process that provides PCIC with continual and valuable advice that complements the more formal process involving the PAC.

## PCIC OVERVIEW

### PCIC GOVERNANCE

#### Members of the PCIC Board of Directors 2014-2019

##### Current Members:

Jim Barnes, Manager, Corporate Engineering Initiatives, - Engineering Services, BC Ministry of Transportation and Infrastructure (2017 – present)

Don Barnhardt, General Counsel, University of Victoria (2009 – present)

Alain Bourque, Directeur Général, Ouranos (2013 – present)

Johannes Feddema, Professor and Chair, Dept. of Geography, Uvic (2017 – present)

Cheng, Lo, Executive Director, Canadian Centre for Climate Services, Environment and Climate Change Canada (2018 – present)

Heather Matthews, Director, Generation Resource Management (2016 – present)

Adam H. Monahan, Professor, School of Earth and Ocean Sciences (2013 – present)

Terry Prowse, Research Scientist, Environment Canada/UVic (2009 – present)

Sybil Seitzinger, Executive Director, Pacific Institute for Climate Solutions (2015 – present)

Laird J. Shutt, Assistant Deputy Minister, Science and Technology Branch, Environment and Climate Change Canada (2017 – present)

Francis Zwiers, Director, Pacific Climate Impacts Consortium (2010 – present)

##### Past Members:

David Castle, Vice-President Research, University of Victoria (Chair, 2014 – 2019)

Howard Brunt, Vice-President Research, University of Victoria (Chair 2008 – 2014)

Charles Lin, Director General, Atmospheric Science and Technology Directorate, Environment and Climate Change Canada (2016 – 2017)

Renata Kurschner, Generation Resource Management, BC Hydro (2009 – 2016; Vice-Chair 2011 – 2016)

Paul Knowles, Director, Competitiveness & Innovation Branch, Ministry of FLNR (2013 – 2016)

Asit Mazumder Professor, Dept. of Biology, University of Victoria (2009 – 2015)

Tom Pedersen, Executive Director, Pacific Institute for Climate Solutions (2009 – 2015)

Carol Pendray, Controller, University of Victoria (2013 – 2015)



## PCIC OVERVIEW

### Treasurer:

Kathleen Veldhoen, Lead, Planning & Operations, Pacific Climate Impacts Consortium (2015 –present)

Cassbreea Dewis, Lead, Planning & Operations, Pacific Climate Impacts Consortium (2008 –2015)

### Secretary:

Jamie Millin, Assistant to the General Counsel, University of Victoria (2010 – present)

### Members of the PCIC Program Advisory Committee 2014-2019

#### Current Members:

Tina Neale, Director, Climate Risk Management, BC Ministry of Environment and Climate Change Strategy (Chair, 2019 –present)

Yapo Alle-Ando, Water Resources Engineer, Teck Resources Limited

David Campbell, Head, River Forecast Centre, Water Management Branch, BC Ministry of Forests, Lands and Natural Resource Operations

Nathan Gillett, Manager, Canadian Centre for Climate Modelling & Analysis, Environment and Climate Change Canada

Adelana Gilpin-Jackson, Specialist Engineer, Transmission Lines Strategy & Standards, BC Hydro

Cathy LeBlanc, Senior Planner, Intergovernmental Relations and Planning Branch, BC Ministry of Community, Sport and Cultural Development

Kate Miller, Manager, Environmental Initiatives Division, Cowichan Valley Regional District

Stephanie Smith, Manager, Hydrology and Technical Services, BC Hydro

Dave Spittlehouse, Research Climatologist, BC Ministry of Forests, Lands and Natural Resources Operations

Tim Takaro, Professor, Faculty of Health Sciences, Simon Fraser University

Stephanie Tam, Water Management Engineer, BC Ministry of Agriculture and Lands

#### Past Members:

Wendy Avis, Manager, Environmental Strategy, BC Hydro

Daniel Caya, Science du climat, Ouranos

Sean Darling, Director, Innovation and Governance Branch, Ministry of Agriculture

Greg Flato, Manager, Canadian Centre for Climate Modelling and Analysis, Environment Canada

Brenda Goehring, Manager, Regulatory and Relationship Management Corporate Safety, Health and Environment, BC Hydro

## PCIC OVERVIEW

Ben Kangasniemi, (Past Chair), Climate Science Specialist, Climate Change Branch, BC Ministry of Environment

Douglas McCollor, Manager, Meteorology and Climate Services, BC Hydro

Dirk Nyland, Chief Engineer, BC Ministry of Transportation and Infrastructure

Tom Pedersen, Dean, Faculty of Science, University of Victoria

Leigh Phillips, Science Writer, Pacific Institute for Climate Solutions, University of Victoria

Lawrence Pitt, Associate Director, Pacific Institute for Climate Solutions

Gerry Still, currently retired from BC Ministry of Forests and Range

Lee Thiessen, Executive Director of Climate Change Policy, Climate Action Secretariat, BC Ministry of Environment

Andrew Weaver, Professor, School of Earth and Ocean Sciences, University of Victoria

Thomas White (Chair), Manager, Science and Adaptation, Climate Action Secretariat, BC Ministry of Environment

Paul Whitfield, Head, Environmental Sciences Section, Meteorological Service of Canada

## PCIC OVERVIEW

### PCIC STAFF

PCIC's applied research activities, which support its service objectives, are organized into three themes. To deliver climate services from these research areas, PCIC maintains a small and highly qualified team of professionals with significant experience, both in their specific fields of expertise, and in climate research and analysis more generally. PCIC's in-house expertise includes climatology, the development of climate change scenarios, hydrology and scientific computing. PCIC also maintains a talented group of support staff who take care of the day-to-day operations of PCIC, do communications and outreach, and maintain the computer infrastructure that is used for serving up data, scientific modelling and performing calculations on the data sets that PCIC's researchers use.



PCIC Staff, front rows, left to right: Trevor Murdock, Stephen Sobie, Michael Shumlich, Francis Zwiers, Nicolaas Annau, Shelley Ma, Kari Tyler, Qiaohung Sun, Matthew Benstead, Yanping He, Rod Glover, Charlotte Ballantyne, Seoncheol Park, Yaqiong Wang and Kathy Veldhoen. Third row on stairs, left to right: Arelia Schoeneberg and Samah Larabi. Fourth row on stairs, left to right: Dhouha Ouali and Mohamed Ali Ben Alaya. Top row on stairs, left to right: Markus Schnorbus and Charles Curry. Not shown in this photo: Faron Anslow, James Hiebert, Nikola Rados, Kai Tsuruta and Lee Zeman.

## DELIVERING QUALITY CLIMATE SERVICES TO USERS

PCIC serves its users by providing data, guidance, user training and making site-specific assessments of potential climate impacts.

## DELIVERING QUALITY SERVICES TO USERS

### DELIVERING QUALITY SERVICES TO OUR USERS

PCIC seeks to achieve its service objectives by delivering regional climate information in a comprehensive way to a complex and diverse user base. Those objectives have been achieved by ensuring that users can access a variety of tools and sources of climate information. Many projects undertaken at PCIC include strong stakeholder participation, and it is frequently the case that projects have outcomes that result in more than one mode of service delivery.

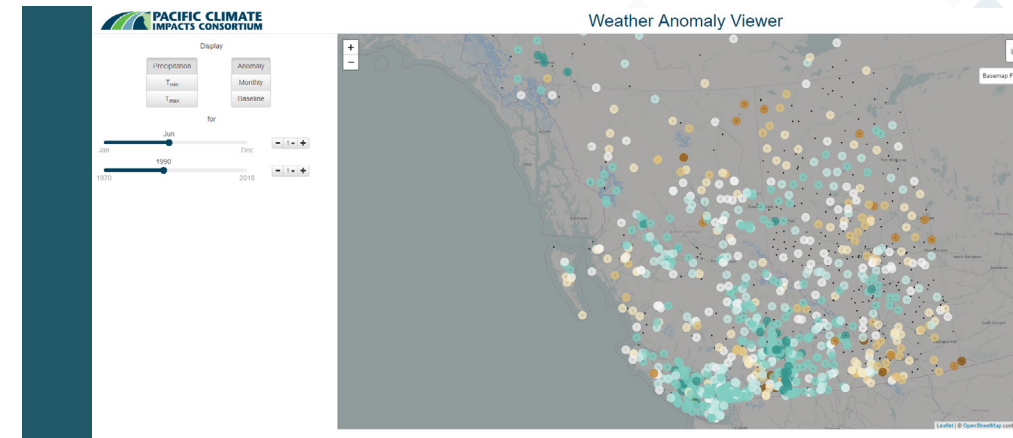
The primary modes of service delivery over the past five years include:

1. Public, openly accessible delivery to regional and national audiences via web-based self-service tools (data and information portals);
2. Direct delivery to stakeholders via user commissioned and supported projects;
3. A spectrum of user training and engagement activities;
4. The publication of research, project reports, and other materials.

The following sections summarize some of our key accomplishments in the first three modes of service delivery.

## DELIVERING QUALITY SERVICES TO USERS

### PUBLIC DELIVERY VIA SELF-SERVICE WEB TOOLS



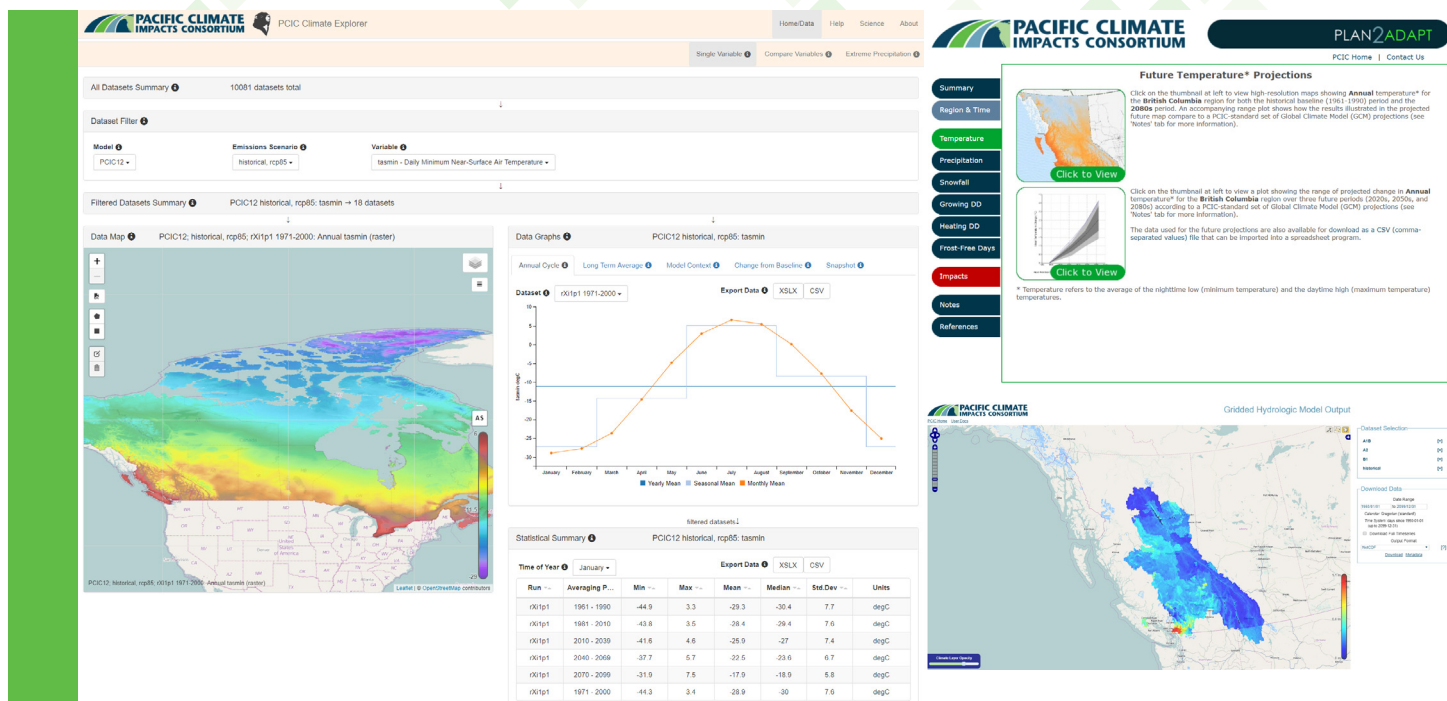
This figure shows a screenshot of PCIC's Seasonal Anomaly Maps tool, which provides maps of departures of average monthly temperature and total precipitation from the long-term climatology at weather stations.

PCIC's use of public facing web-based self-service tools has grown considerably in importance and scope over the review period. Our website now offers 6 kinds of data portals, with multiple products on several of those portals. They offer both point data, such as from PCIC's extensive station data archive, and a range of gridded data products. We will soon be adding further products, including a recently completed suit of hydrologic simulations performed with the VIC-GL model. In addition, we offer a range of interactive tools. One of these is a climate anomaly viewer that can be used to examine recent climate conditions in BC. Another is our newly released PCIC Climate Data Explorer (PCEx), which is aimed at technically sophisticated users. One further tool is Plan2Adapt, which is aimed at a more general audience. A further tool that is in development will allow users to evaluate streamflow projections at arbitrary points on the drainage networks of the river basins that we have simulated, essentially by allowing them to run the stream flow routing scheme that is incorporated in the VIC-GL model offline.

The volume of data that is user downloadable has quadrupled over the review period, and we have seen increases in volumes of data that have been transferred to users and in the number of visits to our website. The development approach that we have used has relied on tools that are openly available in the public domain, thus minimizing both cost and the need to develop large volumes of code from scratch. Further, we have followed a design philosophy that enables simple, intuitive user interfaces that can be navigated by both humans, and in the case of our data portals, by machines. We offer users flexibility in their choice of domain of interest, and in the format of data downloads. Further, we ensure, through the provision of permalinks, that user choices are repeatable.

This evolution and expansion of our self-serve electronic service delivery capabilities has meant that PCIC's strategy for developing and hosting our online products and services has also had to evolve. We have moved from running all of our services on a single, dedicated application server, to a more flexible approach that utilizes multiple providers and a wide range of resources for maximal efficiency. The primary drivers of change have been increases in demand from users, the volume of data that we

## DELIVERING QUALITY SERVICES TO USERS



This figure shows screenshots of the user interfaces of the PCIC Climate Explorer (left), the Plan2Adapt tool (top right) and the Gridded Hydrologic Model Output Data Portal page (bottom right).

have had to serve and the even larger volumes that we need to anticipate in the coming years. Over the last five years we have doubled the number of users of our data portal and are currently logging more data requests than ever before. We have expanded the geographic range of the services that we offer, providing downscaled climate scenarios across all of Canada (rather than simply BC). The volume of data that is available for users to download has increased by nearly a factor of four (from approximately 10 TB to 40 TB).

In the last five years, we have also modestly increased in the number of services and applications that we have been providing. We have developed and released the Climate Anomaly View tool, which displays monthly climate anomalies on an ongoing basis for all of the weather stations in BC. We have also developed and released the PCIC Climate Explorer (PCE), which is a sophisticated, modern, successor to the Regional Analysis Tool. Currently, we are running them both in parallel during a six-month transition period. Creating PCE, which incorporates a host of features that respond to our user's requirements, and developing and implementing the supporting backend, was a major undertaking but has created a flexible and expandable service delivery infrastructure that will serve us well in coming years. We are already exploiting this investment by updating Plan2Adapt so that it functions with the same backend and data resources. Additionally, we have added numerous gridded data sets and portal pages to the PCIC Data Portal and there are plans to add additional station data portals.

Our services and applications have heterogeneous software requirements. They employ application specific software stacks and have radically different resource requirements. For example, the PCIC web page, <https://www.pacificclimate.org>, has quite modest computational and storage requirements (2 CPU,

## DELIVERING QUALITY SERVICES TO USERS

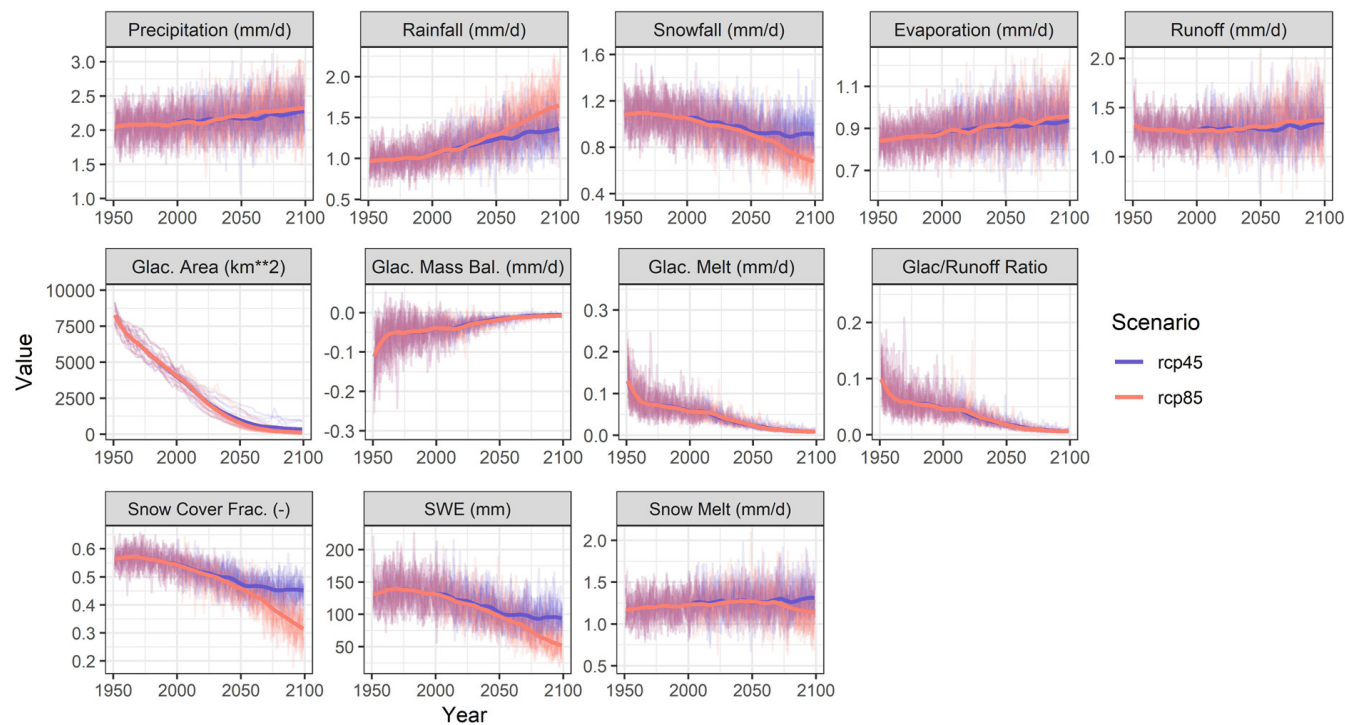
3 GB of RAM, 9 GB storage), while our Data Portal requires tens of terabytes of online storage at all times. Most applications fall somewhere in the middle.

The increase in the level of heterogeneity in our applications made it evident that we could not continue to rely on our single application server to support our electronic delivery of self-serve climate services. This application server was purchased in 2011 and has been beyond its reasonably expected end-of-life date for some time. Fortunately, PCIC is far from the only organization that has been faced with similar challenges. There have, therefore, been numerous developments in the technology and resources over the last 5 years that target these exact problems.

In addition to the advancements in technology, there have been further advancements in the availability of advanced computing resources to the university research and applied science "enterprise". Both Compute Canada and Uvic have introduced virtualization services over the review period that PCIC has been able to utilize. Compute Canada has started a Research Platforms and Portals program that targets teams like PCIC that are providing services to other researchers. We have been able to migrate our data portal and its 40TB of data from our single application server and externalize those costs, while at the same time substantially improving the reliability of the services offered through our data portal. Additionally, we have been able to externalize PCIC's website to Uvic, taking advantage of Uvic's VMware virtualized hosts.

There are many other applications at PCIC that support the development of our services, both self-service and user specific, that require modest-yet-substantive resources. These applications often require timely access to computational resources that are not subject to external competition in job queues. We have been able to meet these needs by using our own small "cloud" (also a new development in the last five years). This provides us with maximal flexibility, rapid deployment and the ability to scale resource to the size of the problem. This also gives us the opportunity to provide a "high-availability" backup resource for deployments of the data portal, in order to execute zero-downtime rolling upgrades.

## MODELLING HYDROLOGIC IMPACTS OF CLIMATE CHANGE



Annual average hydrologic fluxes and states for the Fraser River basin (upstream of tidewater) for the period 1950 to 2100 based on an ensemble of 32 climate experiments using 6 global climate models and two emissions scenarios (RCP4.5 and RCP8.5) (16 members each for RCP4.5 and RCP8.5). Each experiment represented by a thin line and each scenario represented by the ensemble average (thick line). All values (except Glacier Area, the Glacier/Runoff Ratio and Snow Cover Fraction) are presented as mass per unit area (in liquid water equivalent depth).

Since 2007, BC Hydro has been engaging PCIC on the development of improved tools and methods for the analysis of hydro-climatic changes. The focus during the review period has included extremes and the explicit representation of glacier processes and glacier influences on hydrology. An important outcome of this research partnership has been the development of the VIC-GL hydrologic model, by coupling the VIC hydrologic model to a regional glacier model so as to explicitly account for the evolution of glacier mass, area and runoff changes through time in hydrologic change projections. Coupling glaciers required a substantial redesign of VIC, resulting in a model that is much more computationally efficient and much more suitable for quasi-operational use. The model development work was a collaborative effort involving the University of Northern British Columbia (UNBC) and BC Hydro that was led by PCIC. PCIC also developed a new trans-boundary gridded observational climate data set for northwestern North America for driving VIC-GL.

## A Closer Look: Annual Average Hydrologic Fluxes and States for the Fraser River Basin

## Water Balance Changes:

Precipitation is projected to increase slightly by end-century, although ensemble variability is very high and no difference is apparent between RCP4.5 and RCP8.5. Nevertheless, in future the proportion of annual precipitation expected to occur as Rainfall and Snowfall will increase and decrease, respectively, owing to increasing temperature (not shown). Of note, past mid-century this change in precipitation phase is anticipated to be greater for RCP8.5 than RCP4.5. Owing to increasing precipitation, Evapotranspiration is also expected to increase in future, although there are no discernible differences between the RCPs. This is indicative of the water-limited nature of the basin; as precipitation increases, more of the available energy will be used for evaporation and transpiration. The net results of the projected changes in precipitation and evapotranspiration is a negligible change in annual Runoff.

## Glacier Changes:

There is strong consensus among all ensemble members that Glacier Area has been declining since the 1950s, and will continue to decline such that glaciers will be almost entirely absent from the basin by 2100. This decline in glacier area is driven by the fact that glaciers in the Fraser basin have been in a state of negative Glacier Mass Balance since 1950. As glaciers shrink and retreat to higher elevations, the overall basin-wide mass balance will become progressively less negative. Nevertheless, because of decreasing glacier melt, the contribution of glaciers to runoff (the Glacier/Runoff Ratio) has been declining from approximately 10% in 1950 to approximately 5% by the 2000s, and will continue to decline throughout the coming century.

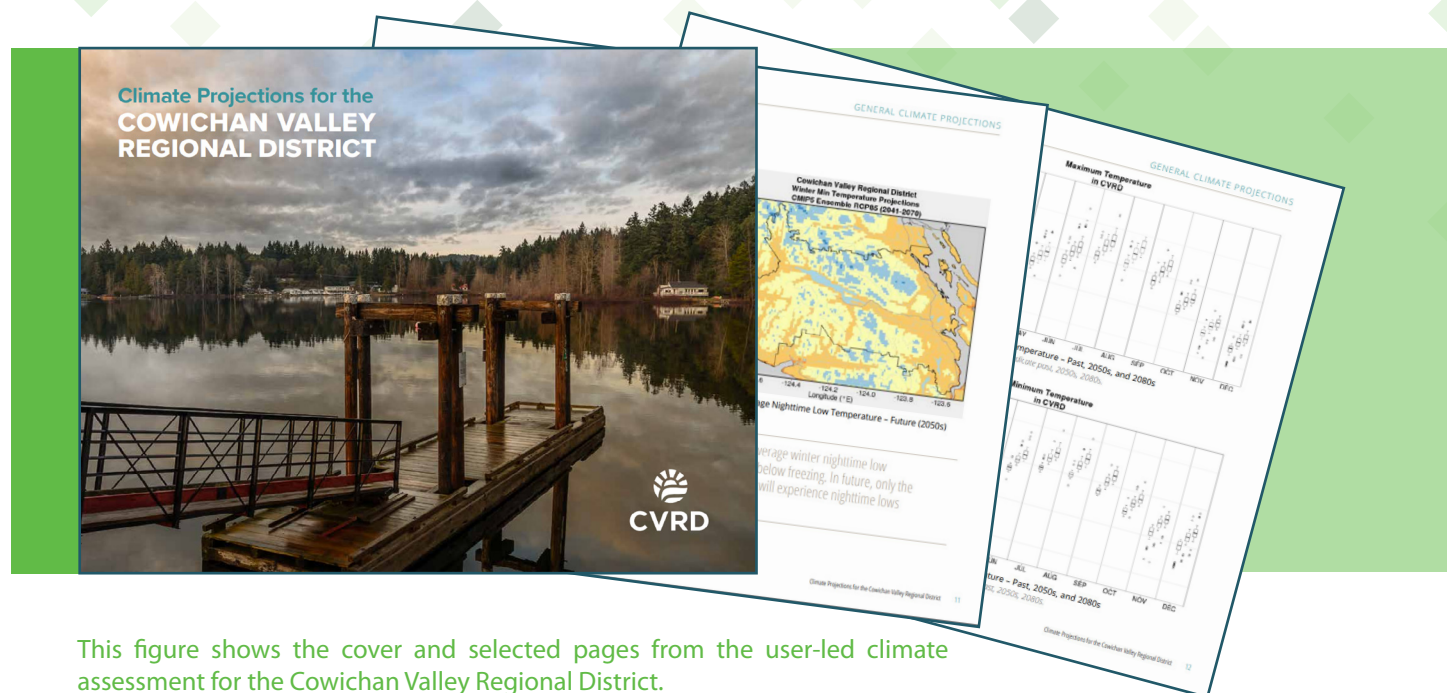
## Snow Changes:

As a result of decreasing snowfall, the annual average Snow Cover Fraction and basin-wide Snow Water Equivalent (SWE) are expected to decline throughout the current century, although the rate of decline slows considerably for RCP4.5 after mid-century (as per the projected temperature and snowfall changes). Although the overall amount of snow accumulation is projected to decline, the snowpack that does remain will experience steadily increasing melt rates, such that the basin-average Snow Melt rate will experience negligible change throughout the first half of the current century. After mid-century, the RCP4.5 scenario will experience higher basin-average melt rates than RCP8.5 (as RCP4.5 will retain more snow than RCP8.5).

VIC-GL has now been applied over a substantial part of northwestern North America, including the Columbia, Fraser and Peace River drainage basins, and smaller watersheds on the mainland and Vancouver Island. Hydro-climatological projections have been used to inform BC Hydro license renewal applications and energy planning projects for project sites in the Bridge, Shuswap and Alouette River basins, to assess climate change impacts on hydrology for large and small watersheds throughout the province, and to study future changes in flood hazard. Recent projects include a study of climate change impacts on the hydrology of the Comox Lake watershed for the Comox Valley Regional District, and the study of future changes in flood hazard for the Fraser River, including climate change scenario modelling of the Fraser River watershed for the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). Hydrological assessments have also been provided for several regional and sectoral assessments described in the following section.

## DELIVERING QUALITY SERVICES TO USERS

## REGIONAL AND SECTORAL ASSESSMENTS



This figure shows the cover and selected pages from the user-led climate assessment for the Cowichan Valley Regional District.

PCIC works extensively with governments and other organizations to provide interpretation of regional climate information to inform adaptation planning. Over time, PCIC has covered nearly the entire province, as well as regions beyond its borders. PCIC prioritizes those projects that allow further development of its tools or the application of results in regions or sectors not recently studied. Since 2014, new regional assessments associated with agreements have included services for 12 municipalities and regional districts, 10 BC agricultural and forestry regions, 4 health authorities, 4 BC-Washington transboundary projects, the Northwest Territories, 3 First Nations communities, and many more regions. Assessed regions vary in size from very specific locales (e.g. an area surrounding a hospital or a forest service road), to larger areas (e.g. Cowichan Valley Regional District, Capital Regional District, Metro Vancouver, Northeastern BC), and to studies that encompassed the entire Province of BC, the Northwest Territories, as well as Canada-wide assessments. These user-led projects typically include a combination of PCIC's services, including data provision, data quality control, data gap analyses, trend analyses, high-resolution climate mapping, statistical downscaling, climate extremes analysis, storm impacts, interpretation and training via participation in presentations, workshops, and co-produced report development.

## DELIVERING QUALITY SERVICES TO USERS

## ADVISING THE ENGINEERING COMMUNITY



This figure shows sample pages from the collaborative report that PCIC produced with Vancouver Coastal Health.

PCIC has been increasingly active in its engagement with the engineering community, aiding in the development of guidance documents, providing data and interpretation, and participating in dialogues with the engineering community about approaches for including climate change in the planning of engineering projects.

Supported by a series of contracts with PCIC, the BC Ministry of Transportation and Infrastructure (MOTI) released Technical Circular T-06/15 dated June 22, 2015 and revised August 11, 2016 and March 27, 2019 entitled Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design. The circular requires that climate change be considered in all MOTI infrastructure projects, such as roads and bridges. PCIC's role included contributing climate science expertise to a committee organized by the BC Association of Consulting Engineers, which reviewed a draft of the Technical Circular, as well as to Engineers and Geoscientists of BC (EGBC), which produced a guidance document to assist engineers in following the mandate to consider future climate information in all MOTI design and construction projects. In addition, PCIC has played a role in helping EGBC design and deliver training events for engineers on the circular.

MOTI has also engaged PCIC from fall of 2015 until present to develop online climate information tools specifically to meet the needs of engineers in BC. This ongoing project has been and continues to be synergistic with a large PCIC effort to reengineer its interactive climate analysis tools and the recently released PCEX in particular.

## DELIVERING QUALITY SERVICES TO USERS

Another facet of our interaction with the engineering community, which is also focused on transportation infrastructure, is a series of PIEVC case studies for forestry service roads with FLNRORD, MOTI and FPIInnovations to determine how climate change may affect forestry service roads in the future. Several of these studies have involved forest road infrastructure in the Prince George area.

In addition, PCIC has been working with engineers on topics that pertain to built infrastructure more broadly. At the national scale, the National Research Council (NRC) is supporting PCIC in a collaboration with ECCC that will contribute to the development of updated guidance to the engineering community for infrastructure design that takes recent climate observations and projected climate change into account. This 3-year project will contribute to updating the National Building Code of Canada and the Canadian Highway Bridge Design Code CSA S6.

Within this region, PCIC has worked directly with regional users to provide site-specific analysis and data to assist engineers with building design. A project with the Vancouver Island Health Authority, for construction and renovation projects at the Nanaimo Regional General Hospital, led to significant interest and the work was presented at meetings for Engineers and Geoscientists BC, BC Hydro, the Canadian Health Engineering Society, and others. Since then, PCIC has worked with Vancouver Coastal Health, Interior Health and Fraser Health to help produce regional climate impacts reports that will inform several health care infrastructure projects in their regions. PCIC is also working with UBC, MoE and consulting engineers to develop an online interface for providing “future-shifted” weather files that incorporate future climate projections into weather files that are widely used in the energy modelling that is carried out to inform building design. In addition, PCIC is providing interpretation and support to a BC Housing-led project that is seeking to develop training materials to inform engineers and other buildings professionals on how to incorporate future conditions into design.

### DIRECT DELIVERY VIA USER-COMMISSIONED REPORTS

Users often require more detailed interpretation of climate information than is afforded via PCIC’s online data and analysis tools, or require that climate information be tailored to their particular regions, sectors or circumstances. Because the impacts of climate change are broad, PCIC works with a diverse set of stakeholders and since 2014 has provided services under 69 agreements with key accomplishments highlighted throughout this report.

## DELIVERING QUALITY SERVICES TO USERS

### CURATION OF THE REGION’S CLIMATE DATA RESOURCES

Many projects that PCIC undertakes support the development of materials and understanding required in turn to support service delivery for its broad user base.

PCIC has continued to develop the Provincial Climate Dataset (PCDS), which is enabled by its agreement under the provincial Climate Related Monitoring Program (CRMP), creating a unique resource for the Province in the form of “one stop shopping” for meteorological station data collected by participating agencies in the province. PCIC has worked to develop approaches to PCDS quality control and homogenization, through support provided by the MoE and ECCC. In 2015, PRISM climate maps for the 1981-2010 period that were developed at PCIC were made available on PCIC’s PRISM data portal. These high-quality maps, which are now available at 800-meter spatial resolution, update 4-km resolution maps offered earlier by PCIC for the 1971-2000 period. The work to update these maps was supported by partnerships with the Bonneville Power Administration and the National Oceanic and Atmospheric Administration. More recently, PCIC has entered into a relationship with FLNRORD to develop a new generation of PRISM maps for BC utilizing further improved data and forest ecological information to flag locations where the estimated climatology is inconsistent with the ecology. At the same time, PCIC has partnered with the Government of the Northwest Territories to expand climate data collection and PRISM climate mapping in the North, which will also improve PCIC’s data portal and PRISM climate mapping tool.

A three-year Grants-and-Contributions agreement with ECCC, as well as support from three externally-funded research grants, has significantly advanced our understanding of precipitation extremes. In another partnership with ECCC, PCIC substantially enhanced its statistical downscaling capability, and used that capability to statistically downscale a large collection of CMIP5 climate change simulations to 10 km spatial and daily temporal resolution for all of Canada. The resulting product, based on the BCCAQv2 method developed at PCIC, has been made available to users from the PCIC website and via ECCC data portals and is having very high national impact. Finally, a project to study the impacts of storm activity on power outages based on an analysis of BC Hydro’s own power outage data, is contributing to our understanding of storms and their impacts.

PCIC’s service delivery under its user-supported projects has contributed new and updated data, maps, tools, regional summaries and projections quantifying the impacts of climate change on regions within and beyond BC. Each project has contributed to the growing body of knowledge on the impacts of climate variability and change on regional climate and water resources within and beyond BC.

## DELIVERING QUALITY SERVICES TO USERS

### USER TRAINING & ENGAGEMENT

User training and engagement is a component of most projects with our users, either directly as part of our service, or indirectly as part of a co-development process. PCIC takes an iterative user-led approach to its projects, in which projects are initially scoped, further developed and ultimately reported on collaboratively. Training and engagement also occur through workshops, online instructional videos and webinars for PCIC's tools, user surveys, and written materials (e.g. PCIC co-developed a primer in collaboration with MOTI that educates engineers about terms that may lead to confusion because they are used differently in climate science than in engineering).

In addition, PCIC has recently made a formal commitment, in collaboration with the CCCS, to further invest in this aspect of its activities. Through this long-term project PCIC will enhance its capacity to regularly engage with other climate service providers (i.e. climate expert organizations in other regions and the CCCS), share expertise and information (operating and strategic) that can inform coordinated climate service delivery, contribute to setting a shared vision for climate services in Canada, and coordinate priorities and plans to implement that vision. This project will ultimately enhance the collective capacity of providers to deliver climate services in Canada. PCIC will also enhance its own capacity to provide users (e.g. provincial government departments and agencies, municipal governments, Indigenous organizations, consultants, industry and the public) in British Columbia and elsewhere, with quality, coordinated and regionally tailored climate services, in the form of user engagement, user support and user training.

In maintaining a two-way dialogue with its users, and taking a co-production approach whenever possible, PCIC is able to deliver the interpretation of regional climate information specific to user needs, make its services more accessible, and help to direct its research such that it will be most useful to these regions. End-users are also able to actively consider the impacts of climate change on their operations and planning and to include the findings in reports that are tailored for their audiences.

## DELIVERING QUALITY SERVICES TO USERS

### OUR USERS & THEIR CONTRIBUTIONS

PCIC has benefitted from sustained and enthusiastic user involvement and support throughout the review period. The breadth and depth of user involvement is clearly evident from the extensive list of collaborators and partners and the large number of user funded agreements that we have entered into over the review period. A few statistics that give an impression of the extent of user engagement and commitment to PCIC's work include the following:

- PCIC entered into 69 agreements with its users during the review period as opposed to 32 in the previous review period. The number of active agreements in any one year has ranged from 12 to 20 during the review period.
- Agreements with users have involved all parts of the organization, including
- 6 agreements focused on Hydrologic Impacts
- 12 Climate Analysis and Monitoring agreements
- 42 agreements dealing with Regional Climate Impacts assessments and downscaling
- 9 agreements for tools and services development that were led by the Computational Support Group
- The corresponding distribution for the previous review period was 2 HI, 2 CAM, 26 RCI and 2 CSG.

It is interesting to note that balance between short term (1-year or less) and longer-term agreements has shifted significantly since the last review period, indicating that our users and collaborators are increasing paying sustained attention to climate related issues. Over the prior 5-year period, the short term agreements contributed from 9-19% of total revenue depending on the year and long term agreements provided 19-27% revenue. During the current review period, short term agreements have continued to provide a similar proportion of revenue as previously, 13-21%, whereas there has been substantial growth in long term contracts, which contributed 23-47% of annual revenue, highlighting their growing number and the strength of the user commitment to PCIC.



# SCIENTIFIC OUTREACH

## SCIENTIFIC OUTREACH

An important aspect of PCIC's work is to communicate what it does, and on topics related to climate science more generally, to its users and the general public in British Columbia. PCIC's approach to science communications is to provide information to users and the public in a neutral and objective manner, maintaining a low, but authoritative and trusted public profile. This approach leads to relatively low levels of media attention, although PCIC does communicate via the media on specific occasions, such as the recent announcement of the new collaboration between the CCCS and PCIC. The following subsections briefly review communications approaches that are used by PCIC.

## SCIENTIFIC OUTREACH

PCIC communicates with its users through plain language summaries and reports, its website, and in person at workshops and conferences..

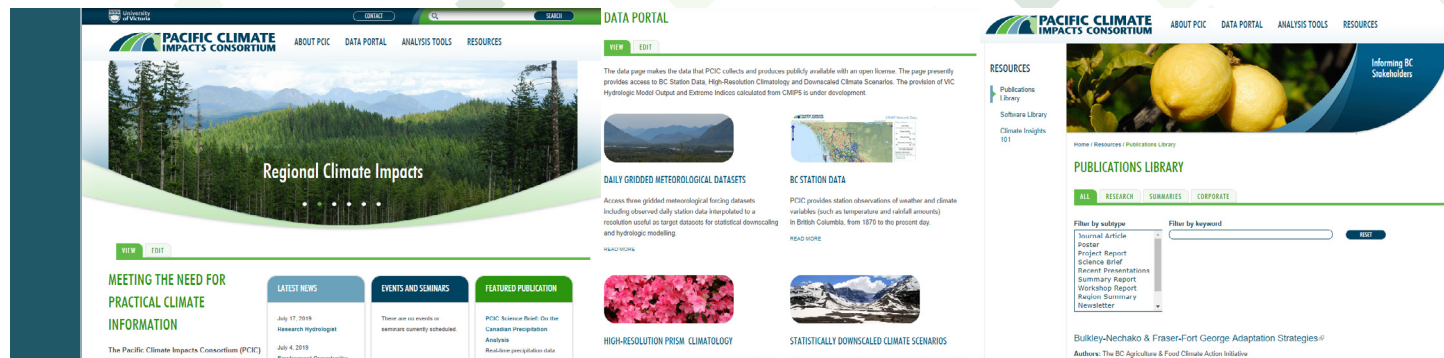


## PLAIN-LANGUAGE SUMMARIES & SCIENCE BRIEFS

PCIC strives to produce documents that are easily understood by audiences from a variety of backgrounds. We make a concerted effort to ensure that user reports, which are often highly technical, are accompanied by plain language documents that distil the main results and findings in an accessible format. Where possible, these are produced jointly with the user. When necessary we do not hesitate to engage the services of professional consultants, such as Pinna Sustainability, to help with the task of producing clear, plain language synthesis documents. A list of our summary and project reports is found in the Publications section at the end of this report. Also, PCIC produces a regular series of Science Briefs; short reports on recent climate science literature relevant to stakeholders in the Pacific and Yukon Region of Canada. Other ongoing plain language communications include our regular PCIC Updates newsletter and our annual corporate report.

## SCIENTIFIC OUTREACH

## WEBSITE



The PCIC website is our primary point of contact with many of our users. We work diligently to keep its content current and to incorporate the innovations in electronic climate services delivery that are described in Section 3a. The site was updated in 2014 to improve navigation, better accommodate our growing selection of self-serve online tools, present our growing online documents library in a more organized manner, and ensure that PCIC's tools and products can easily be found. That update continues to serve PCIC well, and thus there are no immediate plans to further update the look and feel of the site. In the background, however, there have been significant developments in the where and how the site is hosted and in the methods that are employed to host and deploy new services on the site.

## WORKSHOPS, EVENTS &amp; MEETINGS

PCIC has, at several times, used workshops, events, meetings, surveys and webinars as a means of communicating with and receiving input from its user community and scientific collaborators. This includes events that were organized by PCIC and events to which PCIC was invited. These opportunities allow us to communicate PCIC and its services to a broad, interested audience and to further raise PCIC's profile and recognition amongst users and its scientific peers.

Examples of the types of opportunities that we have pursued include

- An invitation to PCIC hydrologists to lead a workshop for the BC branch of the Canadian Water Resources Association (Vancouver, 2014).
- Organizing and hosting the 13th International Meeting on Statistical Climatology (IMSC), which attracted about 200 participants from all of the globe (Canmore, 2016)
- Organizing a workshop on Uncertainty Modelling in the Analysis of Weather, Climate and Hydrological Extremes at BIRS, the Banff International Research Station for Mathematical Innovation and Discovery (Banff, 2016).
- An invitation to provide one of the two Canadian Meteorological and Oceanographic Society (CMOS) tour speakers for 2017, enabling PCIC Director Francis Zwiers to make presentations on changing climate extremes across eastern Canada (9 locations, 2017).

## SCIENTIFIC OUTREACH

- An invitation to present a public lecture at the CMOS Annual Congress, an event which drew an audience of several hundred people. A podcast related to the event is available at <https://www.hipcast.com/podcast/HxqXsBVQ> (Toronto, 2017).
- Climate change adaptation dialogues with First Nations communities, which have led to PCIC participation in projects with the Cowichan First Nation, Splitsin First Nation and Toquaht First Nation. PCIC jointly presented a webinar with Indigenous and Northern Affairs Canada's (INAC) First Nation Adapt Program, to share the types of climate change information and services PCIC can offer to communities preparing to adapt, and helped promoted funding opportunities for First Nation communities to assess, prepare and plan for climate change impacts (2018).
- An invitation to present two webinars to Global Television weather presenters across Canada that introduced the rapidly growing science of extreme event attribution (2018).
- An opportunity to co-organize a session at the annual meeting of the American Association for the Advancement of Science highlighting event attribution science as an emerging activity that is at the juncture between mathematics, statistics and climate science (Washington, DC, 2018)

Communication and engagement with our users is an ongoing activity that occurs continuously via regular meetings. Examples include quarterly meetings of the participants in BC's CRMP program, meetings of the coordinating and collaboration mechanisms that have been established by the CCCS (more frequently than monthly), the NRC Climate Resilient Infrastructure project (3-4 times per year), our ongoing interaction with BC Hydro on hydrologic modelling and climate change impacts issues affecting their transmission and distribution systems (weekly to monthly), ongoing interaction with MOTI on the development and implementation of PCEX to ensure that it meets the needs of the engineering community (roughly monthly), and many others.

In addition, many regional projects involve PCIC participation in one or more community workshops or meetings, with PCIC often providing presentations and input on their development.

## SCIENTIFIC OUTREACH

### PRESENTATIONS & WEBINARS

PCIC is well known for its willingness to share its expertise with others. Over the past 5 years, PCIC has made well over 300 presentations to user groups from professional associations and government agencies, scientific workshops and conferences, and public events. The presentations are geared directly at the user-specific audience and facilitate the communication and interpretation of climate science at the level that is appropriate to the objectives of the event and the nature of its participants.

### MEDIA INTERACTIONS

PCIC is careful with its interactions with the media in that we limit our dealings to those topics in which we are expert and that provide opportunities to inform and educate the public. Prof. Francis Zwiers is our primary media contact; however other PCIC staff members also interact with the media where appropriate. Some notable recent instances where PCIC had occasion to interact with the media include:

- A Vancouver Sun op-ed published late in 2018 placing the impact of climate change on wildfire risk in the context of other factors that are also increasing wildfire risk in BC's forests
- Extensive media interest in a paper on BC's intense 2017 and 2018 wildfire seasons that was published in Earth's Future in 2018 (Prof. Zwiers was co-author)
- Extensive interest in a paper on the increasing frequency of hot summers and the corresponding rising levels of heat stress in Earth's Future in 2017 (Prof Zwiers was co-author)
- Canadian Broadcasting Corporation [Trevor Murdock, PCIC's Lead for Regional Climate Impacts, Contributor and Interviewee] 2017: 2050s-Degrees of Change, Podcast Mini-Series.
- Requests to comment in the media on the current climatic conditions in BC that are usually handled by Dr. Faron Anslow, PCIC's Lead for Climate Analysis and Monitoring, several times per year.

## HIGH-CALIBRE APPLIED RESEARCH

PCIC's research programme carries out the fundamental scientific work that forms the foundation of PCIC's climate services .

## HIGH-CALIBRE APPLIED RESEARCH

### PCIC'S RESEARCH PROGRAM

Achieving our service objectives has required a research program focused around three strategic objectives:

- Build partnerships that enable service delivery and support our applied science program.
- Ensure that PCIC has the scientific and information resources that are necessary to support its service delivery.
- Maintain operational and managerial excellence.

PCIC's applied research program is the foundation for the successful delivery of regional climate services to the public and is realized both by PCIC and in partnership with our collaborators and stakeholders. Strategic objective number 3 is discussed in Section 6 of this report; the first two objectives are addressed in the following Section.

PCIC's research program has been focussed by research plans that were established for each of our three Research Themes in 2015: Hydrologic Impacts, Regional Climate Impacts and Climate Analysis and Monitoring. They evolved from earlier plans that, together, have guided applied science at PCIC since its inception.

## HIGH-CALIBRE APPLIED RESEARCH

### HYDROLOGIC IMPACTS THEME

Our Hydrologic Impacts Research program has resulted in the publication of 3 reports and a subsequent 27 journal articles. A major consequence of the research program was that the VIC hydrologic model (has been reengineered to substantially improve its computational efficiency and to enable the inclusion of coupled glacier mass balance and glacier dynamics components. The resulting model, which is dubbed VIC-GL, has so far been used to model hydroclimate projections for several BC river basins (Peace, Columbia, Fraser, Campbell and Comox) and is now also being used for studies of the Stikine River basin by colleagues at UNBC. In addition, we have also successfully coupled a water temperature module to VIC-GL and have used that capability to produce simulations of historical and future water temperature changes in the Fraser basin. These developments will enable us to simulate past and future hydrologic change in BC's heavily glaciated basins, where changes in flow regimes and water temperature are important for both the future management and use of these resources and for the protection and management of key ecological resources, such as BC's wild salmon populations.

### REGIONAL CLIMATE IMPACTS THEME

PCIC's Regional Climate Impacts program has focused on downscaling and understanding user needs, and has resulted in a wide range of products and services, as well as the publication of 19 reports and 18 journal articles. The RCI theme focuses much of its efforts on delivering statistically downscaled regional climate projections and applying these data to the assessment of impacts in different parts of the Province. A major scientific achievement of this program was the downscaling of a suite of CMIP5 climate change simulations via a state-of-the-science statistical downscaling scheme, Bias Correction/Constructed Analogues with Quantile mapping reordering, version 2 (BCCAQv2) that was developed at PCIC. The resulting climate change scenarios of daily minimum and maximum temperature and daily precipitation amounts cover the range of emissions scenario uncertainty that was considered by the Intergovernmental Panel on Climate Change in its 5th Assessment, and span model and internal variability sources of uncertainty amongst models that performed reasonably well in representing the climate of western North America as judged via a suite of indices of climate extremes. The resulting daily temporal resolution downscaled climate change scenarios are available with national Canadian coverage at ~6 km x 10 km spatial resolution. They have been used extensively at PCIC to study projected impacts that are of concern to our users, are delivered to the general public via PCIC's data portal and via an ECCC website and through the CCCS data portal that is shortly to be released. They also form the basis of the Climate Change Atlas developed by the Prairie Climate Centre at the University of Winnipeg. In addition, they are widely recognized amongst municipal government users as a key source of localized information about future climate change. Over the past year the RCI theme has been preparing for the pending availability of CMIP6 climate change simulations by investigating potential enhancements to the BCCAQv2 downscaling scheme and the potential for using a higher resolution observationally based gridded training data set. PCIC has also developed a novel approach to the gridding of relatively sparse, high quality station data at high resolution.

## HIGH-CALIBRE APPLIED RESEARCH

### CLIMATE ANALYSIS AND MONITORING THEME

PCIC's Climate Analysis and Monitoring program has focused on three key areas. The first is the assembly, organization, dissemination and routine analysis of climate monitoring data gathered all over BC as PCIC's contribution to the Climate Related Monitoring Program (CRMP) that is led by the MoE. PCIC has a key role in this program as the integrator and host of the Pacific Climate Data Set (PCDS), which contains observations from networks that are operated by the partners to the governing CRMP Memorandum of Understanding. The CRMP MOU was established in 2010 and renewed for a further 6 years in 2018 with the involvement of an expanded number of partners. PCIC maintains the PCDS and supporting metadata, has established automated near real-time data feeds from a number of observing networks and periodically ingests data in batch mode from other networks. It also has developed an intuitive and flexible web-based data portal that provides convenient user access to the PCDS. As a consequence, PCIC is able to host and make freely available historical meteorological observations from over 7200 locations across BC. The inclusion of additional partners in the CRMP program will lead to the availability of even more station data in the province. The PCDS is, in turn, the basis for a regular, automated, climate monitoring product that PCIC produces and disseminates monthly. PCIC has also undertaken the homogenization of a substantial fraction of the temperature data in the PCDS, thereby gaining significant experience in station data quality control and improvement.

A second key activity of the theme is the use of the PCDS to develop very high resolution (800m) temperature and precipitation climatologies for BC using the PRISM expert system that is developed at Oregon State University, which PCIC is licensed to use. These climatologies are used extensively throughout the province and more widely, for example, through their inclusion in ClimateWNA (Wang et al., 2012), which integrates high resolution climatologies across the western North America region. PCIC's high resolution climatologies reflect the current WMO climatological period (1981-2010) and are accompanied by time series of monthly maps for 1950-2007. Work is currently underway to further improve the climatologies as described previously.

A third key area in the CAM program has focused on the estimation of engineering design values as part of a large project that PCIC is undertaking in collaboration with the NRC and its partners. Initial effort has focused on the estimation of extreme snow loads based on snow data from both national and provincial observing networks across Canada. This work has benefited considerably from our experience with snow data in BC and its innovative application in the development our high-resolution precipitation climatologies for BC. It should be noted that thanks to strengthening user support for the work taken on

## HIGH-CALIBRE APPLIED RESEARCH

### CONTRIBUTIONS TO THE CLIMATE SCIENCE COMMUNITY



Scientific creativity and innovation involve the constant exchange of ideas and results. It is therefore important that PCIC scientists work at the cutting edge of regional climate science. PCIC's peer-reviewed publication track record is an indicator of the high calibre of the applied climate research that contributes to the robustness and reliability of the products and services that we deliver. Since 2014, PCIC staff have published 118 articles in high quality scholarly journals. These articles, which appear in national and international journals, including on occasion journals such as Nature Climate Change, Nature Geoscience, and the Nature journal Scientific Data, lend confidence to our users of our scientific credibility while contributing to the greater climate science community.

PCIC also contributed to this community by attending and helping to organize scientific conferences. Over the past five years, PCIC scientists have attended about 20 conferences per year presenting scientific posters and making oral presentations, and our scientists have contributed to, or in some cases have led, the organization of conferences. In addition, PCIC scientists are often asked to serve as peer reviewers of articles, research proposals and other documents, reviewing over 100 documents per year. In addition, Prof. Francis Zwiers serves actively on the editorial boards of well-regarded peer-reviewed scientific journals:

- Co-chief Editor, *Advances in Statistical Climatology, Meteorology and Oceanography* (2018-present)
- Associate Editor, *Journal of Geophysical Research – Atmospheres* (2012-present)
- Associate Editor, *Journal of Climate* (2005 – present)

In addition, Prof. Zwiers serves on a variety of boards and panels with scientific assessment, advisory or management responsibilities. Examples include

- the US National Academies of Science committee on event attribution (NAS, 2016),
- the International Science Panel that supports New Zealand's Deep South National Science Challenge – a large, multidisciplinary project that seeks to provide New Zealand with information that it can use to support climate change adaptation in that country (2015—present),
- the Regional Coordinating Committee of the CCCS (2018—present), and
- the Board of Directors of the Ouranos Consortium (2011—present).

## HIGH-CALIBRE APPLIED RESEARCH

### CONTRIBUTIONS TO CLIMATE SERVICE DELIVERY

PCIC is part of a larger, informal tiered network of climate research and information-providing institutions and we rely on, and contribute to, the strengths of this community through collaborations and partnerships. The community includes national government institutions, other regional climate service organizations, and climate researchers from Canada and around the world.

We have contributed throughout the 5-year review period to an ongoing national discussion concerning the coordination of climate service delivery. PCIC promotes the coordination of regional climate service delivery in Canada by developing our reputation and influence as a credible and reliable regional climate service provider. PCIC does this by contributing at professional meetings, coordinating actively with Ouranos at the Board of Director's level (PCIC's Director and CEO serves as a member of Ouranos' Conseil d'Administration, and by informal reciprocal arrangement, the Director General of Ouranos serves on PCIC's Board of Directors) and by collaborating with ECCC and other Federal Government departments on projects that contribute to climate service delivery in Canada. Indeed, it can be argued that PCIC, which under Prof. Zwiers' guidance has carefully and consistently positioned itself as a competent and reputable climate service provider, has set an example illustrating good practices in climate service delivery that have influenced others, including the establishment of ECCC's Canadian Centre for Climate Services (CCCS).

## HIGH-CALIBRE APPLIED RESEARCH

### RESEARCH COLLABORATION

PCIC's applied climate research involves both institutional and individual scientific collaborations. These research collaborations, which enable productive two-way exchanges of information, have fostered many long-term partnerships. Presently, PCIC is actively involved in institutional collaborative projects with BC Hydro, the BC Ministry of Transportation and Infrastructure, the BC Ministry of Environment and Climate Change Strategy, the BC Ministry of Agriculture, the BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development, Environment and Climate Change Canada (Canadian Centre for Climate Modelling and Analysis; Climate Data Analysis Section; Canadian Centre for Climate Services), the Government of the Northwest Territories, the National Research Council and Natural Resources Canada.

In addition to our institutional collaborations, PCIC has numerous scientific collaborations with individual researchers or research groups. Some examples of important research collaborations of this kind include:

- **Climate Analysis and Monitoring Theme:** Dr. Chris Daly and the Oregon State University PRISM Group; Dr. Joseph Licciardi, University of New Hampshire; Dr. Anders Carlson, Oregon State University; Dan Parrakis, Canadian Forest Service; Dan Sugar, University of Washington now University of Calgary.
- **Hydrologic Impacts Theme:** Drs. Daniel Peters and Rajesh Shrestha, W-CIRC; Dr. Alex Cannon, CDAS/ECCC; Drs. Vivek Arora, John Fyfe and Yiran Peng, CCCma/ECCC; Drs. Brian Menounos, Stephen Déry and Siraj Ul Islam, UNBC; Prof. Dan Moore, UBC; Global Water Futures, USask.
- **Regional Climate Impacts Theme:** Dr. Stewart Cohen, Environment Canada; Prof. Damon Mathews, Concordia; Prof. Stephen Dery, UNBC; Mr. Colin Mahony and Profs. R. Dan Moore, Sally Aitken, Tongli Wang, UBC Forestry; Prof. Adam Monahan, UVic; Profs. Ralph Evins, Phalguni Mukhopadhyaya, UVic Department of Civil Engineering; Dr. Robin Cox, Royal Roads University; Profs. Tim Takaro, Bimal Chhetri, and Jordan Brubacher, Simon Fraser University; Prof. Belgin Cavka, UBC Department of Civil Engineering; Prof. Sean Smukler, UBC Faculty of Land and Food Systems; Drs. Meade Crosby, Heidi Roop, and Guillaume Mauger, University of Washington.
- **PCIC Director (Dr. Francis Zwiers):** Profs. David Atkinson and Adam Monahan, University of Victoria; Profs. Paul Kushner and Steve Easterbrook, University of Toronto; Prof. Laxmi Sushama, McGill University; Prof. Ron Stewart, University of Manitoba; Prof. Yanping Li, University of Saskatchewan; Prof. Stephen Dery and Dr. Siraj Ul Islam, UNBC; Prof. Andre St. Hilaire, L'Institut national de la recherche scientifique; Profs. Diana Allan and Kirsten Zickfeld, Simon Fraser University; Dr. Budong Qian, Agriculture and Agri-foods Canada; Drs. Nathan Gillett, Slava Kharin, Megan Kirchmeier-Young, Xiaolan Wang and Xuebin Zhang, Environment and Climate Change Canada; Mr. Steven Taylor, Pacific Forestry Centre; Prof. Gabi Hegerl, University of Edinburgh; Dr. Philippe Naveau, LSCE/IPSL, France; Dr. Aurelien Ribes, CNRM/Meteo France; Drs. Peter Stott and Nikos Christidis, UK Met Office; Prof. Hans von Storch, Universität Hamburg; Dr. Jana Sillmann and Prof. Gunnar Myhre, University of Oslo; Prof. Song Yang, Sun Yat-sen University; Dr. Chao Li, East China Normal University; Dr. Ying Sun, National Climate Center, China Meteorological Administration.

## HIGH-CALIBRE APPLIED RESEARCH

A further approach that Prof. Zwiers has used to develop research collaborations that have resulted in important developments in our scientific capacity has been to engage in a number of academic research networks with objectives that align with PCIC's objectives. These include:

- The Marine Environmental Observation, Prediction and Response Network (MEOPAR) NCE based at Dalhousie University (2012—2018);
- The Canadian Sea Ice and Snow Evolution (CanSISE) Network lead by Prof. Paul Kushner, University of Toronto (2013—2018; part of the NSERC Climate Change and Atmospheric Research Program);
- The Canadian Network for Regional Climate and Weather Processes (CNRCWP) Network lead by Prof. Laxmi Sushama, then at UQAM (2013—2018; part of the NSERC Climate Change and Atmospheric Research Program);
- The Climate Related Precipitation Extremes project lead by Prof. Francis Zwiers and Ron Stewart (2017—present; part of the Global Water Futures Program based at the University of Saskatchewan). This project includes a postdoctoral research position that is jointly supported by the Canadian Statistical Sciences Institute (2019—2021; CANSSI);
- The Short-duration Extreme Precipitation in Future Climate project lead by Prof. Yanping Li (2017—present; part of the Global Water Futures Program based at the University of Saskatchewan);
- Participation in the Global Water Futures Modelling Core (2017—present);
- A postdoctoral research position focused on compound extremes that is supported jointly by the US Statistical and Applied Mathematical Sciences Institute (SAMSI) and the Canadian Statistical Sciences Institute (CANSSI) (2017-2019);
- An NSERC CRD project entitled Adaptation to minimize the joint impacts of climate change and the management of hydraulic infrastructures on fish and fish habitat lead by Prof. Andre St. Hilaire of INRS and supported by Rio Tinto Alcan (2018—2021);
- The Data Analytics for Canadian Climate Services (DACCS) CFI project that is lead by Prof. Steve Easterbrook at the University of Toronto (2019-2022).

These networks generate considerable research activity at PCIC, produce results that often contribute directly to PCIC objectives, strengthen the organization's expertise base and generate a pool of people from whom PCIC can draw when opportunities for additional staffing arise. Highly Qualified Personnel (HQP) who have been trained at PCIC also end up in other locations where they contribute to the generation of climate knowledge and the delivery of services. This includes 3 former HQP who now hold faculty positions, several who are currently employed as research scientists in government laboratories including one in the Netherlands at KNMI, one in France at Meteo-France in Toulouse and 4 who now have indeterminate positions as Research Scientists at ECCC, and at least two individuals who now work in the consulting industry. Altogether, 3 graduate students and 11 other HQP have held positions at UVic as part of these networks over the review period and have actively worked in collaboration with PCIC. The networks that are currently active presently support 6 HQP at PCIC, and include plans to engage 1-2 additional HQP within the coming year.

An informal way that PCIC builds collaborations and contributes to the climate science and university community is by hosting short and longer-term visits to PCIC. The longer-term scientific visitors include

## HIGH-CALIBRE APPLIED RESEARCH

collaborators who are directly involved in our work and students from overseas academic institutions who are required to include an experience working in a foreign applied research setting to complete their degree requirements. The latter visits, ranging in length from a number of weeks to a year, have provided PCIC with access to very well trained and talented young people who have contributed substantially to PCIC's objectives at minimal cost. The longer-term visits are complemented by short visits, often of only a day or two in duration, that bring fresh perspectives to the work undertaken at PCIC.

**FINANCIALS & PARTNERS**

**FINANCIALS, 2018-2019**

Over the past five years, PCIC has enjoyed a stable funding and operational environment, thanks to the ongoing support and collaboration of our valued partners.

Sustained funding from the endowment has provided leveraging opportunities, such that PCIC has continually grown and diversified its user and stakeholder base and maintained long-term partnerships. Direct leveraging of endowment resources has attained a level at or above 100% in recent years – that is, PCIC is able to invest more than \$2 in the provision of regional climate services and applied science for every \$1 received from the endowment. Indirect leveraging (in the form of the time and effort of PCIC’s partners and collaborators) and external research funding from academic sources substantially increase those levels, such that conservatively, total leveraging is now in excess of 200%.

Our strong service ethic combined with the commitment to do high quality work for regional stakeholders has also contributed to our success in attracting funding and projects.

The most recent 2018-2019 fiscal year saw a 48% growth in funding from our partners, with users and stakeholders contributing resources under 20 separate agreements.

As a not-for-profit corporation, 100% of PCIC’s funding supports its programs and service delivery. PCIC’s most important resource is its staff. Accordingly, most of our financial resources are dedicated towards our staff salaries. We limit other costs by ensuring budgetary efficiency through careful planning, and keeping a frugal eye on operational expenses. In 2018-2019, 89% of PCIC’s expenditures supported staff salaries. Of the remaining 11%, about 2% supported external partnerships and 9% supported operational expenses such as financial accounting and auditing services, computing resources, travel to conferences and staff professional development.

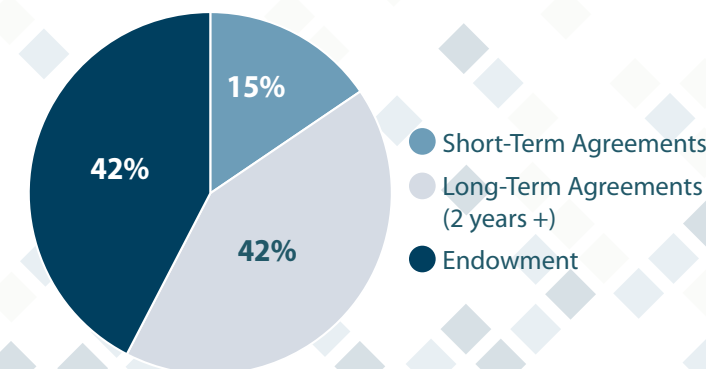
Fiscal accountability is ensured at PCIC through quarterly reporting on revenue and expenditure variances and through a rigorous annual external audit. PCIC maintains systems for project accounting and financial tracking to ensure the effective use of the resources under its stewardship and also to ensure audit compliance.

PCIC remains steadfast in its commitment to ensuring investment in its programs is effectively managed.

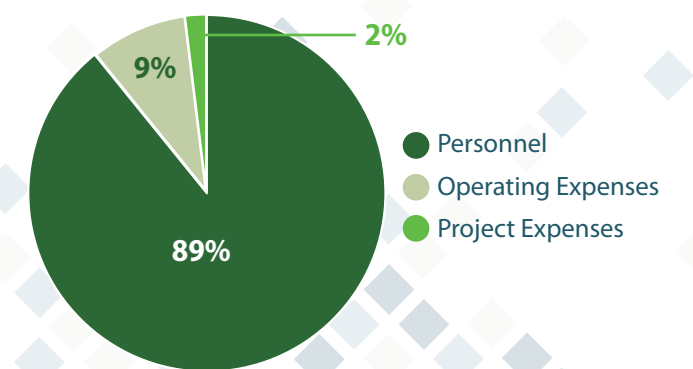
**FINANCIALS & PARTNERS**

PCIC’s research programme is supported by financial stability that comes from a commitment to responsible financial management and through our diverse network of partners. Through delivering high-quality climate service while utilizing strategic budgeting and partnerships, PCIC has grown in its budget, research and services offered to the present day.

**2018-2019 Revenue**



**2018-2019 Expenses**





## FINANCIALS & PARTNERS

### PCIC PARTNERS, 2014-2019

#### PCIC Collaborators and Partners 2014-2019

Adaptive Resource Management, Ltd.  
 Agriculture and Agri-Food Canada  
 Alberta Rural Development Ministry  
 BC Agriculture and Food Climate Action Initiative  
 BC Agricultural Climate Adaptation Research Network  
 BC Agricultural Research and Development Corporation  
 BC Blueberry Council  
 BC Hydro  
 BC Ministry of Agriculture  
 BC Ministry of Environment and Climate Change Strategy  
 BC Ministry of Health  
 BC Ministry of Municipal Affairs and Housing  
 BC Ministry of Community, Sport and Cultural Development  
 BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development  
 BC Ministry of Transportation and Infrastructure  
 Bonneville Power Administration  
 Environment and Climate Change Canada, Canadian Centre for Climate Modelling and Analysis  
 Environment and Climate Change Canada, Canadian Centre for Climate Services  
 Environment and Climate Change Canada, Climate Research Division  
 Environment and Climate Change Canada, W-CIRC  
 Canadian Meteorological and Oceanographic Society  
 Canadian Network for Regional Climate and Weather Processes  
 Canadian Sea Ice and Snow Evolution Network  
 Canadian Statistical Sciences Institute  
 Capital Regional District  
 Centre de Recherche Informatique de Montréal  
 City of Prince George  
 City of Surrey  
 City of Vancouver  
 City of Victoria  
 Columbia Basin Trust  
 Comox Valley Regional District  
 Compute Canada  
 Corporation of Delta  
 Cowichan First Nation  
 Cowichan Valley Regional District  
 Dalhousie University  
 District of North Vancouver  
 Engineers and Geoscientists BC  
 Engineers Canada  
 Fisheries and Oceans Canada  
 FPIInnovations  
 Fraser Basin Council  
 Fraser Health  
 Global Water Futures  
 Government of Northwest Territories Environment and Natural Resources  
 Great Northern Landscape Conservation Council  
 Indigenous and Northern Affairs Canada  
 Interior Health  
 Marine Environmental Observation Prediction and Response Network

## FINANCIALS & PCIC PARTNERS

Metro Vancouver  
 Municipality of Whistler  
 National Oceanic and Atmospheric Administration  
 National Research Council  
 Natural Resources Canada  
 Natural Sciences and Engineering Research Council  
 North Pacific Landscape Conservation Council  
 Okanagan Basin Water Board  
 Ouranos Inc.  
 Oregon State University, PRISM Climate Group  
 Pacific Institute for Climate Solutions  
 Pacific Salmon Foundation  
 Partnership for Water Sustainability in BC  
 Regional District of North Okanagan  
 Resort Municipality of Whistler  
 Rio Tinto  
 Simon Fraser University  
 Splantsin First Nation  
 Statistical and Applied Mathematical Sciences Institute  
 Teck Resources Limited  
 Toquaht First Nation  
 University of British Columbia  
 University of New Hampshire  
 Université du Québec à Montréal  
 University of Northern British Columbia  
 University of Saskatchewan  
 University of Toronto  
 University of Washington, Climate Impacts Group  
 Vancouver Coastal Health  
 Vancouver Island Health Authority  
 World Climate Research Programme

## PCIC PUBLICATIONS

### PCIC PUBLICATIONS & CO-PRODUCED PUBLICATIONS

#### Project and Summary Reports

##### 2018

Chandler, P.C., S.A. King and J. Boldt [Contributing Author], 2018: State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. *Canadian Technical Report of Fisheries and Aquatic Sciences*, 3266, 245 pp.

**The Pacific Climate Impacts Consortium**, 2018: *Climate Change Scenario Modelling for the Fraser River Watershed Phase 1*. Final Report, The Pacific Climate Impacts Consortium, 37pp.

RDH Building Science, 2018: *NRGH Climate Change Vulnerability Assessment Report*. RDH Building Science, 108 pp.

Vancouver Coastal Health, 2018: *Moving Towards Climate Resilient Health Facilities for Vancouver Coastal Health*. Vancouver Coastal Health, 68 pp.

Wilson, T. and Eco-Logical Resolutions, 2018: *Enhancing Runoff and Drainage Management in the Fraser Valley Agricultural Sector*. BC Agriculture and Food Climate Action Initiative, 47pp.

##### 2017

The Capital Regional District, **The Pacific Climate Impacts Consortium** and Pinna Sustainability, 2017: *Climate Projections for the Capital Region*. The Capital Regional District, 66 pp.

The Cowichan Valley Regional District and **The Pacific Climate Impacts Consortium**, 2017: *Climate Projections for the Cowichan Valley Regional District*. The Cowichan Valley Regional District, 52 pp.

**The Pacific Climate Impacts Consortium**, 2017: *Climate Extremes in the Georgia Basin: Summary Report*. The Pacific Climate Impacts Consortium, 12 pp.

Pouliotte, J. and **T. Murdock**, 2017: *Historical and Projected Climate Trends in the Georgia Basin. Project report for Environment and Climate Change Canada*. The Pacific Climate Impacts Consortium, 29 pp.

##### 2016

**Anslow, F.S.** and **Y. Wang**, 2016: *Statistical Homogenization of Temperature Data from the Williston Basin and Campbell River Regions of British Columbia*. The Pacific Climate Impacts Consortium, 38 pp.

Krosby, M., Michalak, J., Robbins, T.O., Morgan, H., Norheim, R., Mauger, G., and **T. Murdock**, 2016: *The Washington-British Columbia Transboundary Climate-Connectivity Project: Climate impacts and adaptation actions for wildlife habitat connectivity in the transboundary region of Washington and British Columbia*. Climate Impacts Group, University of Washington, 23 pp.

Metro Vancouver, **The Pacific Climate Impacts Consortium** and Pinna Sustainability, 2016: *Climate Projections for Metro Vancouver*. Metro Vancouver, 80 pp.

## PUBLICATIONS

To share its research findings and practices, and provide guidance on climate data and projections, PCIC publishes a wide variety of material, from summary reports and high-level overview material to peer-reviewed journal articles. A list of these and many full-text articles is available on in PCIC's online Publications Library.

## PCIC PUBLICATIONS

**Murdock, T.Q., S. R. Sobie,** H. D. Eckstrand and E. Jackson, 2016: *Georgia Basin: Projected Climate Change, Extremes, and Historical Analysis*. The Pacific Climate Impacts Consortium, 69 pp.

**Murdock, T.Q., S. R. Sobie,** H. D. Eckstrand and E. Jackson, 2016: *Williston Basin: Projected Climate Change, Extremes, and Historical Analysis*. The Pacific Climate Impacts Consortium, 69 pp.

**The Pacific Climate Impacts Consortium,** 2016: *City of Vancouver Climate Impacts Summary 2016*. The Pacific Climate Impacts Consortium, 3 pp.

The Resort Municipality of Whistler and **The Pacific Climate Impacts Consortium,** 2016: *Summary of 2050s climate projections for Whistler Area*. The Pacific Climate Impacts Consortium, 2 pp.

### 2015

**Anslow, F.,** 2015: *2015: A Year in Review*. The Pacific Climate Impacts Consortium, 8 pp.

**Murdock, T.Q., A.J. Cannon, S.R. Sobie, B. Veerman, F. Anslow** and **F.W. Zwiers,** 2014: *Workshop Primer: Projected precipitation extremes for Coastal British Columbia*. The Pacific Climate Impacts Consortium, 8 pp.

**Shrestha, R.R., M.A. Schnorbus, A.J. Cannon** and **F.W. Zwiers,** 2015: *Simulating the Effects of Climate Change on Fraser River Flood Scenarios – Phase 2 – Final Report*. The Pacific Climate Impacts Consortium, 60 pp.

### 2014

The BC Ministry of Forests, Lands and Natural Resource Operations [Contributing Author], 2014: *Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios: Final Report*. The BC Ministry of Forests, Lands and Natural Resource Operations, 202 pp.

**The Pacific Climate Impacts Consortium,** 2014: *Climate Extremes in the Columbia Basin Summary Report*. The Pacific Climate Impacts Consortium, 12 pp.

**The Pacific Climate Impacts Consortium,** 2014: *Testing the Monthly Drought Code as a Metric for Fire Weather in Southeast BC – Project Summary Report*. The Pacific Climate Impacts Consortium, 8 pp.

**Murdock, T.Q., A.J. Cannon** and **S.R. Sobie,** 2014: *Statistical Downscaling of Future Climate Projections for North America*. The Pacific Climate Impacts Consortium, 39 pp.

**Sobie, S.R.** and **T.Q. Murdock,** 2014: *Analysis of climate change projections for the Ministry of Transportation and Infrastructure highways risk assessment*. The Pacific Climate Impacts Consortium, 27 pp.

**Sobie, S.R., R.R. Shrestha, T.Q. Murdock** and **M.A. Schnorbus,** 2014: *Columbia Basin regional climate change analysis for Teck Resources Limited*. The Pacific Climate Impacts Consortium, 130 pp.

## PCIC PUBLICATIONS

### Research and Strategic Plans

**Anslow, F.,** 2015: *Climate Analysis and Monitoring Research Plan: 2015-2019*. The Pacific Climate Impacts Consortium, 29 pp.

**The Pacific Climate Impacts Consortium,** 2016: *Hydrologic Impacts Research Plan: 2015-2019*. The Pacific Climate Impacts Consortium, 30 pp.

**Murdock, T.Q.** and **F.W. Zwiers,** 2015: *Regional Climate Impacts Research Plan: 2015-2019*. The Pacific Climate Impacts Consortium, 27 pp.

**The Pacific Climate Impacts Consortium,** 2015: *Pacific Climate Impacts Consortium Strategic Plan 2015-2019*. The Pacific Climate Impacts Consortium, 24 pp.

**Schnorbus, M.,** 2015: *Hydrologic Impacts Research Plan: 2015 to 2019*. The Pacific Climate Impacts Consortium, 30 pp.

### Corporate Reports

**The Pacific Climate Impacts Consortium,** 2018: *PCIC Corporate Report 2017-2018*. The Pacific Climate Impacts Consortium, 23 pp.

**The Pacific Climate Impacts Consortium,** 2017: *PCIC Corporate Report 2016-2017*. The Pacific Climate Impacts Consortium, 21 pp.

**The Pacific Climate Impacts Consortium,** 2016: *PCIC Corporate Report 2015-2016*. The Pacific Climate Impacts Consortium, 38 pp.

**The Pacific Climate Impacts Consortium,** 2015: *PCIC Corporate Report 2014-2015*. The Pacific Climate Impacts Consortium, 19 pp.

**The Pacific Climate Impacts Consortium,** 2014: *Looking Back: 5 Years of Regional Climate Services*. The Pacific Climate Impacts Consortium, 99 pp.

### Science Briefs and PCIC Updates

**The Pacific Climate Impacts Consortium,** 2019: *On the Canadian Precipitation Analysis*. The Pacific Climate Impacts Consortium, 3 pp.

**The Pacific Climate Impacts Consortium,** 2018: *Waves and Coastal Sea Level and the Human Influence on Canadian Temperatures*, 6 pp.

**The Pacific Climate Impacts Consortium,** 2018: *Climate Impacts on Specialty Fruit and Grazing in the Pacific Northwest*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium,** 2018: *Sea Level Rise Observations and Acceleration*. The Pacific Climate Impacts Consortium, 5 pp.

**The Pacific Climate Impacts Consortium,** 2018: *On Paris Climate Accord Emissions and Temperature Limits*. The Pacific Climate Impacts Consortium, 7 pp.

## PCIC PUBLICATIONS

**The Pacific Climate Impacts Consortium**, 2017: *Human-Induced Greening of the Northern Extratropical Land Surface*. The Pacific Climate Impacts Consortium, 3 pp.

**The Pacific Climate Impacts Consortium**, 2017: *Projected Changes to Grasslands and Three US Crops*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium**, 2017: *The Evolution of Snowmelt and Drought*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium**, 2016: *On Changes to Glaciers in Western Canada*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium**, 2016: *Storm Surges and Projected Changes to Atmospheric River Events in Coastal BC*. The Pacific Climate Impacts Consortium, 5 pp.

**The Pacific Climate Impacts Consortium**, 2016: *Tropical Pacific Impacts on Cooling North American Winters*. The Pacific Climate Impacts Consortium, 3 pp.

**The Pacific Climate Impacts Consortium**, 2015: *On the Promise of Biomass and Biosphere-Climate Interactions*. The Pacific Climate Impacts Consortium, 5 pp.

**The Pacific Climate Impacts Consortium**, 2015: *Possible Artifacts of Data Biases in the Recent Global Surface Warming Hiatus*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium**, 2015: *Projected Changes to Short-Duration Extreme Rainfall*. The Pacific Climate Impacts Consortium, 7 pp.

**The Pacific Climate Impacts Consortium**, 2015: *Two Questions About the Response of the Earth's Climate to Carbon Emissions*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium**, 2014: *A Model Simulation of Future Oceanic Conditions Along the British Columbia Continental Shelf*. The Pacific Climate Impacts Consortium, 3 pp.

**The Pacific Climate Impacts Consortium**, 2014: *Contrasting the Responses of Mean and Extreme Snowfall to Climate Change*. The Pacific Climate Impacts Consortium, 5 pp.

**The Pacific Climate Impacts Consortium**, 2014: *Climate Model Simulations of the Observed Early-2000s Hiatus of Global Warming*. Pacific Climate Impacts Consortium, 3 pp.

**The Pacific Climate Impacts Consortium**, 2014: *Crop yield under climate change adaptation*. The Pacific Climate Impacts Consortium, 4 pp.

**The Pacific Climate Impacts Consortium**, 2014: *The Poleward Migration of Tropical Cyclone Maximum Intensity*. The Pacific Climate Impacts Consortium, 2 pp.

**The Pacific Climate Impacts Consortium**, 2014: *Spread in Model Convective Sensitivity Traced to Atmospheric Convective Mixing*. The Pacific Climate Impacts Consortium, 2 pp.

PCIC has prepared and published 16 PCIC Updates over the past five years.

## PEER-REVIEWED PUBLICATIONS

### PEER-REVIEWED PUBLICATIONS

#### Peer-reviewed publications prepared by PCIC staff and affiliates while at PCIC (2014 – 2019)

##### 2019

**Curry, C.L.**, S.U. Islam, **F.W. Zwiers**, S.J. Dery, 2019: Atmospheric rivers increase future flood risk in western Canada's largest Pacific river. *Geophysical Research Letters*, **46**, 1651-1661, doi:10.1029/2018GL080720.

Islam, S. U., **C.L. Curry**, S.J. Dery and **F.W. Zwiers**, 2019: Quantifying projected changes in runoff variability and flow regimes of the Fraser River Basin, British Columbia. *Hydrology and Earth System Sciences*, **23**, 811-828, doi: 10.5194/hess-23-811-2019.

**Werner, A.T.**, R.R. Shrestha, A.J. Cannon, **M.S. Schnorbus**, **F.W. Zwiers**, G. Dayon and **F. Anslow**, 2019: A long-term, temporally consistent, gridded daily meteorological dataset for northwestern North America. *Scientific Data*, **6**, 180299, doi:10.1038/sdata,2018.299.

**He, Y.**, N.R. McFarlane and A.H. Monahan, 2019: A new TKE based parameterization of atmospheric turbulence in the Canadian global and regional climate models. *Journal of Advances in Modeling Earth Systems*, doi:10.1029/2018MS001532.

**Seiler, C.**, 2019: A climatological assessment of intense extratropical cyclones from the potential vorticity perspective. *Journal of Climate*, **32**, 8, 2369-2380, doi: 10.1175/JCLI-D-18-0461.1.

**Tsuruta, K.**, M.S. Hassan, S.D. Donner and Y. Alila, 2019: Modelling the effects of climatic and hydrological regime changes on the sediment dynamics of the Fraser River Basin, British Columbia, Canada. *Hydrological Processes*, doi:10.1002/hyp.13321.

##### 2018

**Ben Alaya, M.A.**, **F.W. Zwiers** and X. Zhang, 2018: Probable maximum precipitation: its estimation and uncertainty quantification using bivariate extreme value analysis. *Journal of Hydrometeorology*, doi: 10.1175/JHM-D-17-0110.1.

**Curry, C.L.** and **F.W. Zwiers**, 2018: Examining controls on peak annual streamflow and floods in the Fraser River Basin of British Columbia. *Hydrology and Earth System Science*, doi:10.5194/hess-2017-531.

**Dayon G.**, J. Boe, E. Martin and J. Gailhard, 2018: Impacts of climate change on the hydrological cycle over France and associated uncertainties. *Comptes Rendus Geoscience*, **350**, 4, 41-153, https://doi.org/10.1016/j.crte.2018.03.001.

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

Ji, D., S. Fang, **C.L. Curry**, H. Kashimura, S. Watanabe, J.N.S. Cole, A. Lenton, H. Muri, B. Kravitz and J.C. Moore, 2018: Extreme temperature and precipitation response to solar dimming and stratospheric aerosol geoengineering. *Atmospheric Chemistry and Physics*, **18**, 10133-10156, doi:10.5194/acp-18-10133-2018.

Kharin, V.V., GM. Flato, X. Zhang, N.P. Gillett, **F.W. Zwiers** and K. Anderson, 2018: Risks from climate extremes change differently from 1.5C to 2.0C depending on rarity. *Earth's Future*, **6**, 5, 704-715, doi:10.1002/2018EF000813.

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**Kirchmeier-Young, M.C.**, N.P. Gillett, **F.W. Zwiers**, A.J. Cannon and **F.S. Anslow**, 2018: Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season. *Earth's Future*, doi:10.1029/2018EF001050.

Kushner, P.J., L. Mudryk, W. Merryfield, J.T. Ambadan, A. Berg, A. Bichet, R. Brown, C.P. Dersken, S.J. Dery, A. Dirkson, G. Flato, C. Fletcher, J. Fyfe, N. Gillett, C. Haas, S. Howell, F. Laliberte, K. McCusker, M. Sigmond, R. Sospedra-Alfonso, N. Tandon, C. Thackeray, B. Tremblay and **F.W. Zwiers**, 2018: Assessment of Snow, Sea Ice, and Related Climate Processes in Canadas Earth System Model and Climate Prediction System. *The Cryosphere*, **12**, 1137-1156, doi:10.5194/tc-2017-157.

Li, G., X. Zhang, A. Cannon, **T. Murdock**, **S. Sobie**, **F.W. Zwiers**, K. Anderson and B. Qian, 2018: Indices of Canada's future climate for general and agricultural adaptation applications. *Climatic Change*, **148**, 249-263, doi:10.1007/s10584-018-2199-x.

**Li, C.**, Y. Fang, K. Calderia, X. Zhang, N.S. Diffenbaugh and A.M. Michalak, 2018: Widespread persistent changes to temperature extremes occurred earlier than predicted. *Nature Scientific Reports*, **8**, 1007, doi:10.1038/s41598-018-19288-z.

**Li, C.**, **F. Zwiers**, X. Zhang and G. Li, 2018: How Much Information Is Required to Well Constrain Local Estimates of Future Precipitation Extremes? *Earth's Future*, doi:10.1029/2018EF001001.

Mueller, B.L., N.P. Gillett, A. Monahan and **F.W. Zwiers**, 2018: Attribution of Arctic sea ice decline from 1953 to 2012 to influences from natural, greenhouse-gas and anthropogenic aerosol forcing. *Journal of Climate*, **31**, 19, 7771-7787, doi:10.1175/JCLI-D-17-0552.1.

Naveau, P., A. Ribes, **F.W. Zwiers**, A. Hannart, A. Tuel and P. Yiou, 2018: Revising return periods for record events in a climate event attribution context. *Journal of Climate*, **31**, 9, 3411-3422, doi:10.1175/JCLI-D-16-0752.1.

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Sgubin, G. D. Swingedouw, **G. Dayon**, I.G. de Cortázar-Atauri, N. Ollat, C. Pagé and C. van Leeuwen, 2018: The risk of tardive frost damage in French vineyards in a changing climate. *Agricultural and Forest Meteorology*, **250-251**, 226–242, ISSN 0168-1923, doi:10.1016/j.agrformet.2017.12.253.

Snauffer, A., W. Hsieh, A. J. Cannon, and **M. A. Schnorbus**, 2018: Improving gridded snow water equivalent products in British Columbia, Canada: multi-source data fusion by neural network models. *The Cryosphere*, **12**, 891-905, doi:10.5194/tc-2017-56.

Teufel, B., L. Sushama, O. Huzly, G.T. Diro, D.I. Jeong, K. Winger, C. Garnaud, R. de Elia, **F.W. Zwiers**, J.R. Gyakum, D. Matthews and V.-T.-V. Nguyen, 2018: Investigation of the mechanisms leading to the 2017 Montreal Flood. *Climate Dynamics*, doi:10.1007/s00382-018-4375-0.

**Tsuruta, K.**, M.A. Hassan, S.D. Donner and Y. Alila, 2018: Development and application of a large-scale, physically-based, distributed suspended sediment transport model on the Fraser River Basin, British Columbia, Canada. *Journal of Geophysical Research: Earth Surface*, doi: 10.1029/2017JF004578.

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