CORPORATE REPORT
2019 - 2020

PACIFIC CLIMATE IMPACTS CONSORTIUM

THE PACIFIC CLIMATE IMPACTS CONSORTIUM

The Pacific Climate Impacts Consortium is a regional climate service provider that serves stakeholders in British Columbia and surrounding regions. Since its inception, PCIC has been dedicated to ensuring the provision of high-quality regional climate services and information to support planning that reduces the risks associated with climate variability and change.

TABLE OF CONTENTS

A MESSAGE FROM PCIC'S CORPORATE LEADERSHIP

Climate change, future climate variability, extreme precipitation and adaptation to those changes remain amongst the most complex and pressing scientific and social challenges that we face. PCIC is a organization whose work responds to a consistent and growing need for comprehensive and authoritative climate information to support adaptation planning and decision making in B.C. and nationally.

In the 2019/2020 fiscal year, PCIC continued to pursue its goals to provide high quality climate services and information to stakeholders and the public. PCIC keeps building capacity and producing increasingly comprehensive climate service products and works to continually strengthen the underlying scientific basis for those products.

This report highlights many achievements in the consortium's delivery of regional climate services in the past year. For example, we have added to our data portals, renewed our Plan2Adapt tool, advanced the science on extreme precipitation and drought and improved modelling of rivers important to hydro electric production and freshwater salmon habitat. These, and many other new and ongoing projects, are helping the public and PCIC's stakeholders to assess the impacts of climate change and variability in their regions and account for climate in their planning.

With the help of our partners, many as part of relationships that have extended back a decade or more, as well as the continuing strong commitment of the University of Victoria, we have developed and maintained an impressive capability to deliver climate services in multiple forms to broad audiences across the province, in the broader Northwestern Region and nationally.

We would like to thank all our partners and the staff at PCIC for their efforts and commitment this past year and recognize their efforts in light of the challenges brought by COVID-19 this past spring.

Dr. Lisa Kalynchuk
Chair, Board of Directors

Tina Neale
Chair, Program Advisory Committee

Dr. Francis Zwiers
PCIC Director

GOVERNANCE, STAFF AND PARTNERS

PCIC'S GOVERNANCE

Board of Directors 2019-2020

Lisa Kalynchuk (Chair), Vice-President Research, University of Victoria

David Castle (Chair), Vice President Research, University of Victoria

James Barnes, Manager, Corporate Engineering Initiatives, BC Ministry of Transportation & Infrastructure

Don Barnhardt, General Counsel, University of Victoria

Alain Bourque, Directeur Général, Ouranos

Lo Cheng, Executive Director, Canadian Centre for Climate Services, Environment and Climate Change Canada

Johannes Feddema, Professor and Chair, Department of Geography, University of Victoria

Heather Matthews, Director, Generation Resource Management, BC Hydro

Adam H. Monahan, Professor, School of Earth and Ocean Sciences, University of Victoria

Colleen O'Keefe, Senior Legal Counsel, University of Victoria

Terry Prowse, Professor and Chair Emeritus in Climate Impacts on Water Resources, Department of Geography, University of Victoria

Sybil Seitzinger, Executive Director, Pacific Institute for Climate Solutions, University of Victoria

Laird Shutt, Director General, Atmospheric Science and Technology Directorate, Environment and Climate Change Canada

Francis Zwiers, Director, President & CEO, Pacific Climate Impacts Consortium, University of Victoria

Programme Advisory Committee 2019-2020

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

Yapo Allé-Ando, Water Resources Engineer, Teck Resources Ltd.

David Campbell, Section Head, River Forecast Centre, BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development

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

Adelana Gilpin-Jackson, Specialist Engineer, BC Hydro

Cathy LeBlanc, Senior Planner, BC Ministry of Community, Sport and Cultural Development

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

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

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

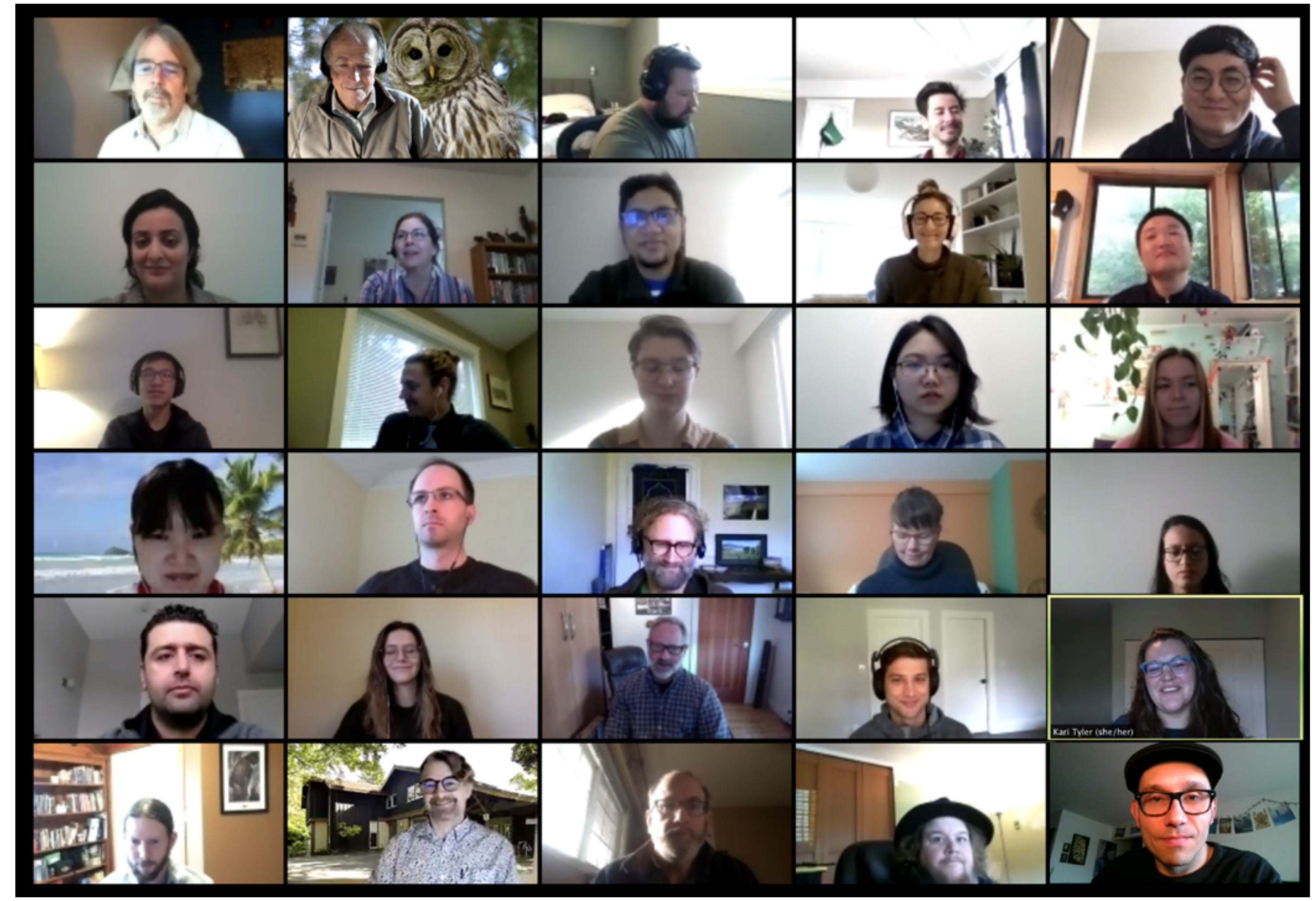
Dave Spittlehouse, Research Climatologist, BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development

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

Stephanie Tam, Water Management Engineer, BC Ministry of Agriculture

Francis Zwiers, Director, Pacific Climate Impacts Consortium

PCIC STAFF 2019-2020



From left to right, top to bottom: Rod Glover, Francis Zwiers, Matthew Benstead, Kai Tsuruta, Seoncheol Park, Dhouha Ouali, Kathy Veldhoen, Md. Shahabul Alam, Shayna Thompson, Sangwon Lim, Travis Tai, Nicolaas Annau, Charlotte Ballantyne, Yaqiong Wang, Cairo Sanders, Qiaohong Sun, Stephen Sobie, Faron Anslow, Arelia (Werner) Shoeneberg, Samah Larabi, Mohamed Ali Ben Alaya, Jessie Booker, Markus Schnorbus, Nikola Rados, Kari Tyler, James Hiebert, Trevor Murdock, Charles Curry, Lee Zeman, Michael Shumlich.

2019-2020 staff not pictured: Yanping He, Whitney Huang, Shelley Ma, Nigus D. Melaku,

PCIC'S PARTNERS

BC Agriculture and Food Climate Action Initiative
BC Agricultural Climate Adaptation Research Network
BC Agricultural Research and Development Corporation
BC Housing
BC Hydro
BC Ministry of Agriculture
BC Ministry of Environment and Climate Change Strategy
BC Ministry of Health
BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development
BC Ministry of Municipal Affairs and Housing
BC Ministry of Transportation and Infrastructure
Canada Foundation for Innovation
Canadian Statistical Sciences Institute
Capital Regional District
Centre de Recherche Informatique de Montréal
Compute Canada
École de technologie supérieure
Engineers and Geoscientists BC
Engineers Canada
Environment and Climate Change Canada, Canadian Centre for Climate Services
Environment and Climate Change Canada, Climate Research Division
Environment and Climate Change Canada, Meteorological Service of Canada
Fisheries and Oceans Canada, BC Salmon Restoration and Innovation Fund
Fisheries and Oceans Canada, Pacific Biological Station
Focal Engineering
FPInnovations
Fraser Basin Council
Fraser Health
GHD Limited
Global Water Futures
Government of the Northwest Territories, Department of Environment and Natural Resources
Habitat 7
Indigenous and Northern Affairs Canada
Institut national de la recherche scientifique
Integral Engineering
Interior Health
Island Health
Metro Vancouver
National Research Council Canada
Natural Resources Canada
Natural Sciences and Engineering Research Council
Ouranos Inc.
Oregon State University, PRISM Climate Group
Pacific Institute for Climate Solutions
Prairie Climate Centre
Prism Engineering Ltd.
Province of Nova Scotia
RDH Building Design
Regional District of North Okanagan
Rio Tinto
Simon Fraser University
Statistical and Applied Mathematical Sciences Institute
Toquaht First Nation
Transport Canada
University of British Columbia
University of Manitoba
Université du Québec à Montréal
University of Northern British Columbia
University of Saskatchewan
University of Toronto
University of Victoria
University of Washington, Climate Impacts Group
Vancouver Coastal Health

CLIMATE ANALYSIS AND MONITORING THEME: ACCOMPLISHMENTS AND IMPACTS

UPDATING AND EXPANDING PCIC'S PRISM MAPS

Having high-quality climate data is of key importance for supporting planning and management that accounts for climate change. PCIC is constantly working with its partners to improve the breadth and quality of the data that it can provide. During the past year, the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and PCIC partnered to improve the performance of climate and monthly time series maps. These climate maps use the Parameter Regression on Independent Slopes Method, or PRISM, which integrates multiple sources of information to account for BC's highly complex topography and climate regimes. These data include station data, digital elevation data, snow data, upper atmosphere climatologies, and glacier inventories that are combined with local and expert knowledge in order create a high-resolution climatology. Ultimately, this project will lead to the production of PRISM

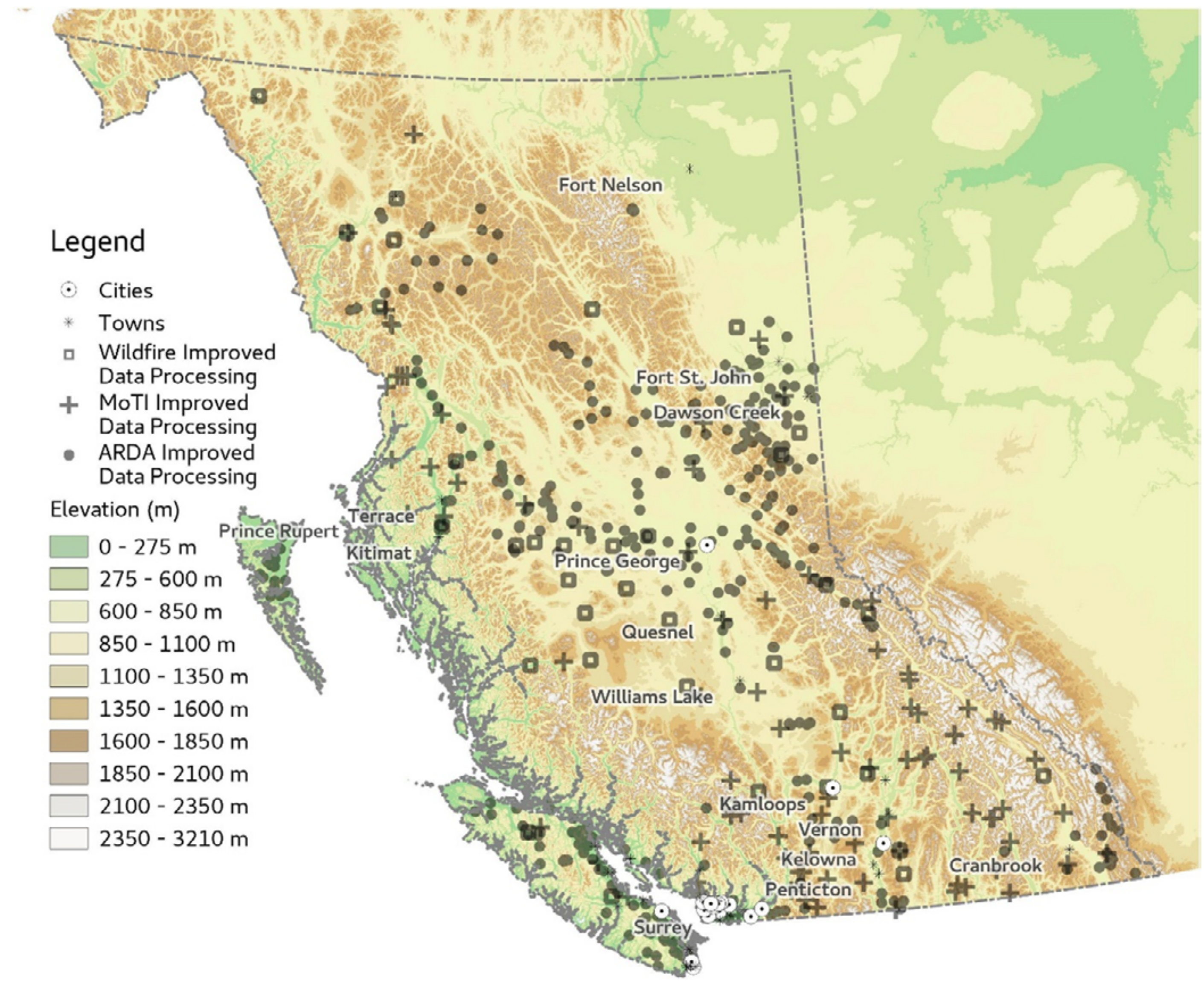


Figure 1: Station locations for which precipitation data processing was improved for the next generation of PRISM maps. This includes MoTI, FLNRORD Wildfire, and ARDA observing networks.

climate maps for the new 1991–2020 climate normal period as well as updates for the existing 1981–2010 climate normal period maps. To achieve this improvement, several subprojects were accomplished in this fiscal year.

PCIC's Climate Analysis and Monitoring (CAM) theme worked to improve the amount of data available for climate mapping by rescuing data that was not processed in earlier PRISM climate maps owing to irregular observation times or periods (Figure 1). A large trove of data from a project funded under the Canadian federal Agricultural and Rural Development Act (ARDA) was processed to produce monthly observations of precipitation totals, resulting in the addition of more than 42,000 monthly observations from more than 2800 additional observation sites. Data from cumulative precipitation gauges in the Ministry of Transportation and Infrastructure (MoTI) observation network were processed into monthly totals, resulting in data becoming available from yet more observation sites. CAM also identified those FLNRORD Wildfire Management Branch stations that have precipitation data for all seasons available. In addition, synergistic efforts with a project aimed at developing PRISM maps for Northwest Territories (NWT) and Yukon (see the Expanding PCIC's Services to Canada's Western Arctic story on p. 11) yielded a large suite of stations along BC's northern border that will greatly improve the maps there. Finally, PCIC has developed near real-time data feeds from BC Hydro's observation network near the Site C dam. While these records are fairly short, they will be of use for climate mapping if there are gaps in the existing data that make detailed mapping in the Peace region challenging.

The inclusion of the newly available data in PRISM was tested by comparing PRISM monthly maps for January and July precipitation for years within the period for which new observations were made available. A new suite of monthly maps was created for each month over the 1980–2000 period, with maps for the January and July precipitation used to demonstrate these changes. Results show fairly strong local impacts on the PRISM monthly maps, and for some months, there are a large number of additional observations available in previously data-sparse locales.

THE CONTINUED GROWTH OF THE PACIFIC CLIMATE DATA SET

Multiple BC ministries, RioTinto, BC Hydro and PCIC joined together in an agreement in 2010 under the Climate Related Monitoring Program (CRMP) to have PCIC bring together, store, maintain and provide data from these groups, for the entire province. The Pacific Climate Data Set (PCDS) is the result. Following eight successful years, in 2018 this agreement was renewed until 2026, and the membership was expanded to include Metro Vancouver and the Capital Regional District (CRD) as partners. During the 2019-2020 fiscal year, a new agreement among the CRMP members was developed and brought close to ratification. This agreement further expands the group to include Environment and Climate Change Canada as a formal member. Environment and Climate Change Canada was an original supporter of CRMP data sharing and their advancement to signatory of the agreement promises ongoing support for data availability for BC that directly benefits PCIC's users. Additionally, the new agreement includes the provision of hydrometric data for sharing amongst the CRMP members.

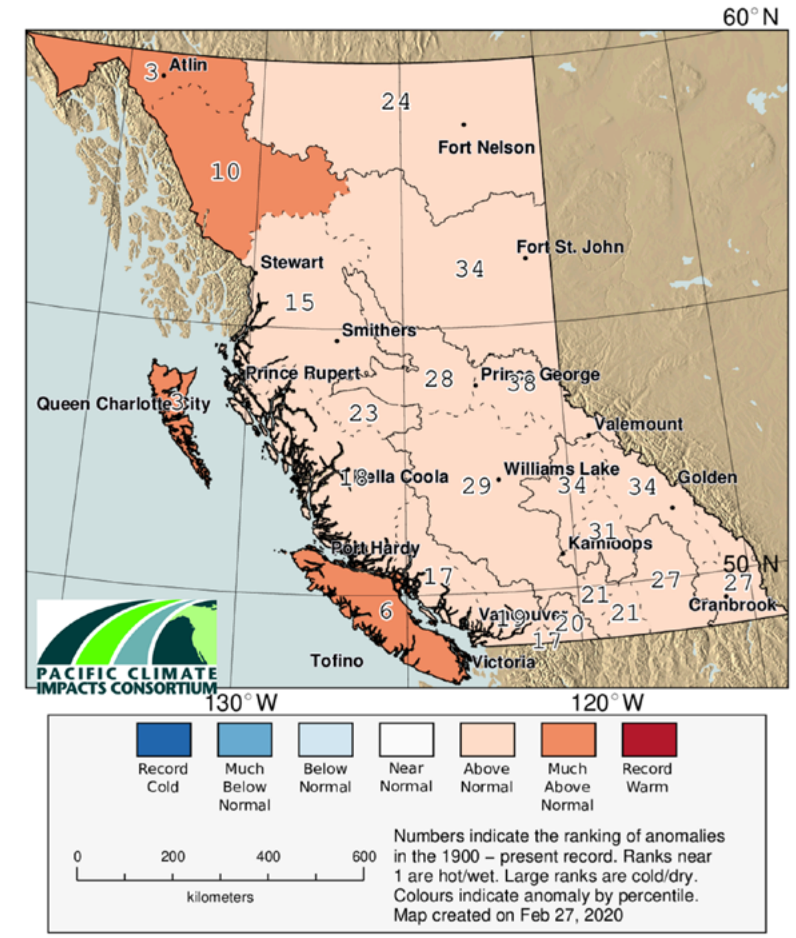


Figure 2: Annual average of daily minimum temperature anomalies for 2019 ranked within the 1900 through 2019 long-term records. Daily minimum temperature continues to run warm over BC.

The CAM theme has continued to collaborate with the CRMP to add to the PCDS and support its growth. The PCDS now contains more than 700 million observations. More than 37 million observations were added during this past fiscal year. A near real-time data stream from the CRD has delivered data began delivering data to the PCDS on January 1st, 2020. Archival data from the CRD are being assembled and will likely be added over fiscal year 2020-2021. Some near real-time data from Metro Vancouver are now also being delivered through their air quality networks, and the archives for those stations and observations from the Metro Vancouver water supply team will be incorporated soon. The theme continues to use these observations to develop PRISM climate maps and to calculate the monthly, seasonal and annual weather anomalies that are reported in PCIC newsletters and in the annual State of the Pacific Ocean report published by the Department of Fisheries and Oceans Canada to provide terrestrial context (Figure 2).

EXPANDING PCIC'S SERVICES TO CANADA'S WESTERN ARCTIC

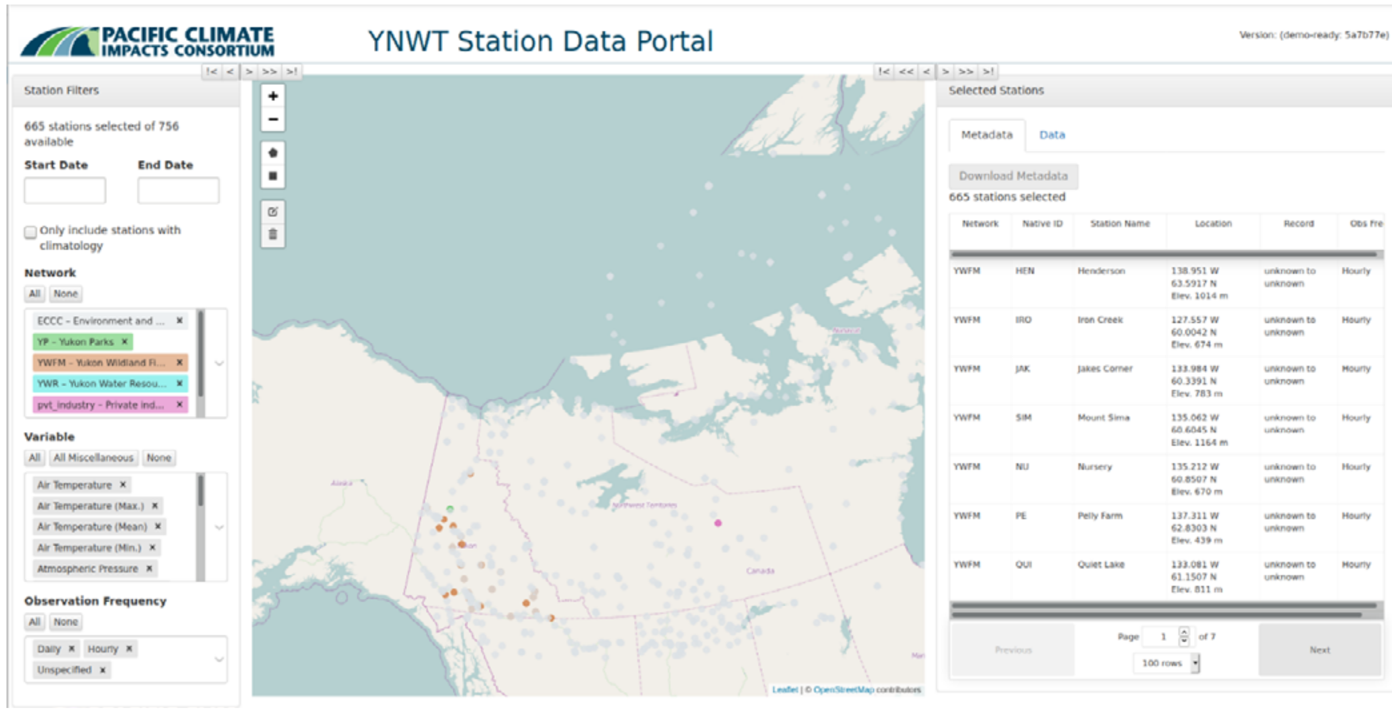


Figure 3: This figure shows a screenshot of the current data portal for the Northwest Territories and Yukon, which is under development.

The CAM theme has been working to enable the creation of PRISM maps over Canada's north and completed another major step toward this goal over the past year. This work focussed on the development of the digital elevation model (DEM) for the topography of the north, furthering the development of a station data portal for the Northwest Territories and Yukon, the development of quality control protocols for observational data, and maintaining communication and consultation with the project contacts in Northwest Territories.

Extensive work was completed on the development of the DEM and analyzing the sufficiency of the observational network, both spatially and in terms of elevational distribution. Maps were created that show the station distribution for observations and that describe the station density as broken down by ecoprovinces—areas with similar climates and surface features—in the territories. These efforts show which regions should be targeted for additional data gathering efforts by demonstrating the likelihood of spatial gaps in the observational coverage in each region. To demonstrate the coverage of observations by elevation in each ecoprovince, the hypsometry, or land elevation, of the terrain was compared with the density function relating number of stations to elevation. This analysis revealed misalignment in observation coverage in areas where large topographic relief—a large difference in elevation—is present. With these high-needs ecoprovinces highlighted, PCIC was able to identify specific stations that are known to have data, but from which data are not yet held by the NWT project manager nor PCIC.

PCIC has also made great advances in the development of the station data portal (Figure 3) for Northwest Territories and Yukon. Creating this portal was an opportunity for the computational support team to modernize the web portal technology to a newer standard than that used to develop the earlier PCDS data portal for BC. Work was done on the database back-end and the user interface was completely redeveloped to yield a much more modern appearance, and a more responsive and intuitive user interface. PCIC is engaging with Northwest Territories to ensure continued advancement towards the development of a station data portal and PRISM maps for the region.

HYDROLOGIC IMPACTS THEME: ACCOMPLISHMENTS AND IMPACTS

CONTINUED PARTNERSHIP WITH BC HYDRO

The relationship between PCIC and its long-term partner BC Hydro is a special one that extends back to the 2005 meeting at which the PCIC concept was first articulated. Grounded in their shared interest in ensuring the climate resiliency of the province's energy supply and transmission and distribution networks, this partnership has resulted in climate projections across BC and the US Columbia River basin, and hydrologic projections for most of the watersheds that BC Hydro manages.

BC Hydro has reaffirmed its commitment to working with PCIC with a four-year agreement that will extend to March 2023. This renewal of the long-term agreement between PCIC and BC Hydro will include support for BC Hydro's use of climate science in its planning. It will also include work by PCIC to push at the boundaries of knowledge within climate science and hydrology, and to develop and adopt ever more capable, cutting-edge models to meet BC Hydro's needs.

BC Hydro Highlight: Work on the Raven Hydrologic Modelling Framework

An example of this is research that PCIC's Hydrologic Impacts theme is pursuing with a new hydrologic modelling framework, called Raven. Raven's flexible structure accommodates a wide variety of process representations, from simple empirical models to complicated dynamical models. These can be explored with customizable output to diagnose and update individual components. The modular nature of the Raven framework allows for comparatively easy adoption of new model components, which may be needed for the modelling of specific areas and for keeping the model up-to-date as the field advances. For example, if an improved representation of some physical process, such as transpiration, is developed, it is easy to update Raven to include the new representation in the model.

Raven is also computationally efficient, allowing for robust simulations and substantially greater amounts of spatial detail.

As part of PCIC's exploration of Raven, the Hydrologic Impacts Theme has tested the ability of Raven to incorporate glacier dynamics processes. This will allow the explicit modelling the effect of glacier area changes when simulating basins in regions where glaciers may be retreating or advancing. This dynamic

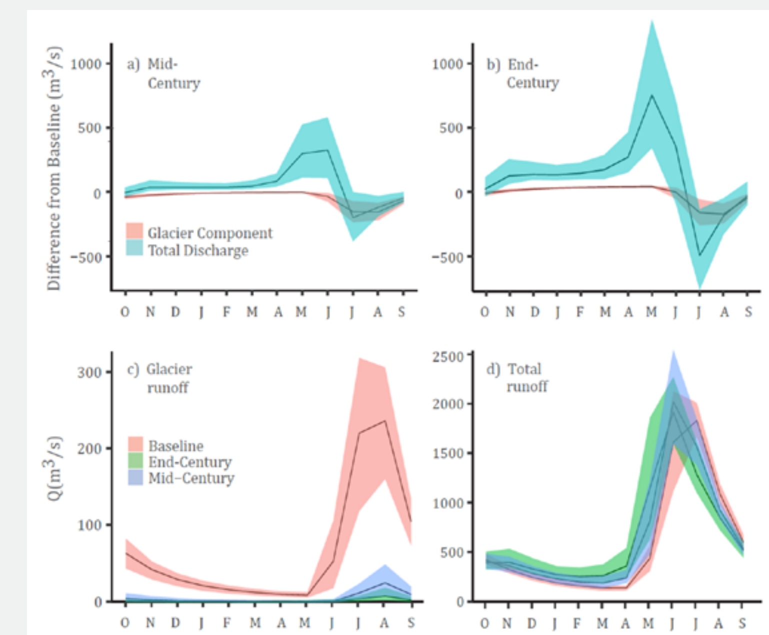


Figure 4: This figure shows projected changes in inflow at the Mica Dam in the Columbia River Basin assuming greenhouse gas emissions follow the RCP 8.5 high-emissions scenario. The top panels show the difference in inflow between the baseline period (1981-2008) and mid-century (2041-2070, Panel a) and the end of the century (end-century, 2071-2098, Panel b), separated into the glacier component of the inflow (salmon) and the total inflow (teal). Positive values indicate an increase from baseline. The bottom panels show the magnitude of average monthly glacier contribution to inflow (Panel c) and the magnitude of average monthly total inflow (Panel d), for the baseline period (salmon), end of century (green) and middle of the century (blue). In all panels, the range of results comes from the combined variability of the six forcing global climate models and six model parameterizations. Analogous plots for a lower emissions scenario (RCP 4.5) show similar trends, but with a generally smaller magnitude of change.

representation of glaciers in Raven has been tested in two stages. Stage one involved simply supplying glacier area changes to Raven using output from an external model (one-way coupling). This modelling system was applied to the Mica basin in the upper Columbia. Figure 4 shows projections of total summer discharge and the glacier component of that summer discharge for the middle and end of this century at the Mica Dam in the Columbia River Basin, in southeastern BC. Straightforward tracking of changes in the glacier component is one of the advantages of coupling Raven to a glacier dynamics model. In these projections, the glacier contribution is projected to decline significantly in the future. For the end of the century, the August and September glacier loss, as measured by runoff, roughly matches that of the total loss of glacier mass.

In stage two, Raven has been coupled to a high-resolution glacier model, named simply the Regional Glacier Model (RGM), at a one-to-one scale (two-way coupling), meaning that each grid cell in the Raven model has a direct counterpart in the glacier model. This makes it clear how to transfer information from one model to the other when information about a grid cell must be transferred between them. Although more complex to implement, from a water budget perspective two-way coupling is more internally consistent than one-way coupling. This fully coupled Raven-RGM system is being applied to the Cheakamus basin in southwestern BC.

If comprehensive testing shows Raven to be suitable for the needs of PCIC's Hydrologic Impacts theme, then the theme will pick up Raven as a new tool to better serve PCIC's users.

SUPPORTING SALMON CONSERVATION

In September of 2019, to aid in wild salmon conservation and the restoration of salmon habitats, Fisheries and Oceans Canada announced 14 projects under the British Columbia Salmon Restoration and Innovation Fund (BCSRIF), jointly supported by the Government of Canada and the Province of BC. PCIC was selected for one of these projects and given a five-year grant to conduct research on the freshwater habitat of salmon in the province, how these habitats may change in the future, due to climate change, and the risks that such changes may pose to salmon. In addition, PCIC is developing risk assessment tools that will support regional management and planning that takes BC's changing climate into consideration. This five-year project focuses on several coastal watersheds, some of which are monitored for salmon life history events, water temperature and streamflow (Figure 5). Two postdoctoral researchers have begun setting up and calibrating two hydrological models, the Variable Infiltration Capacity model with glaciers (VIC-GL) and RAVEN, as part of this project. VIC-GL will simulate the hydrology over coastal BC for use in broad-scale regional analysis, while RAVEN will be used to conduct more detailed modelling of smaller watersheds specifically selected because they are host to some well-studied salmon populations. A third postdoctoral researcher, who will focus on the vulnerability and risk assessment, starts at PCIC in September of 2020. A number of software tools will be developed, or integrated into existing ones, to provide access to salmon vulnerability maps, salmon life-history and climate applications to watershed and fisheries managers throughout the region. Taken together, these efforts will support fisheries management decision-making processes as managers focus on the restoration, protection and maintenance of healthy and diverse salmon populations and habitats in the province, in the changing climate.

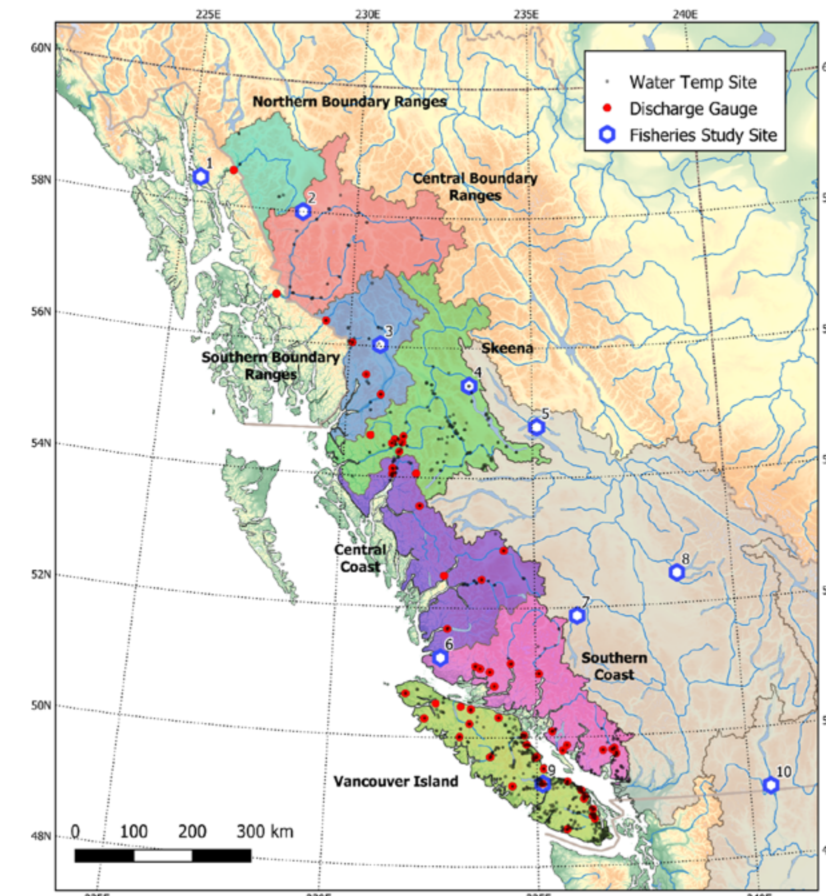


Figure 5: This figure shows a map of the region under analysis for the BC Salmon Restoration and Innovation Fund project for which PCIC is conducting research on the freshwater habitat of salmon. Black dots indicate water temperature sites, red circles indicate streamflow gauges and blue hexagons indicate fisheries study sites.

SUPPORTING WATER-MANAGEMENT DECISION MAKING

The use of climate information to inform planning requires an understanding of some of the high-level "big-picture" concepts regarding climate change, and what the limitations and strengths of different projections and data sets are, to know what they can and cannot tell you. PCIC partnered with the BC Ministry of Environment and Climate Change Strategy (ENV) and the Ministry of Forestry, Lands, Natural Resource Operations and Rural Development (FLNRORD) to support decision making within these communities. The goals of this project were to help water allocation staff understand the strengths and limitations of existing state-of-the art hydrologic projections as a tool for decision-making surrounding water-allocation in the province, and provide materials that would support training on climate change and water management within ENV/FLNRORD.

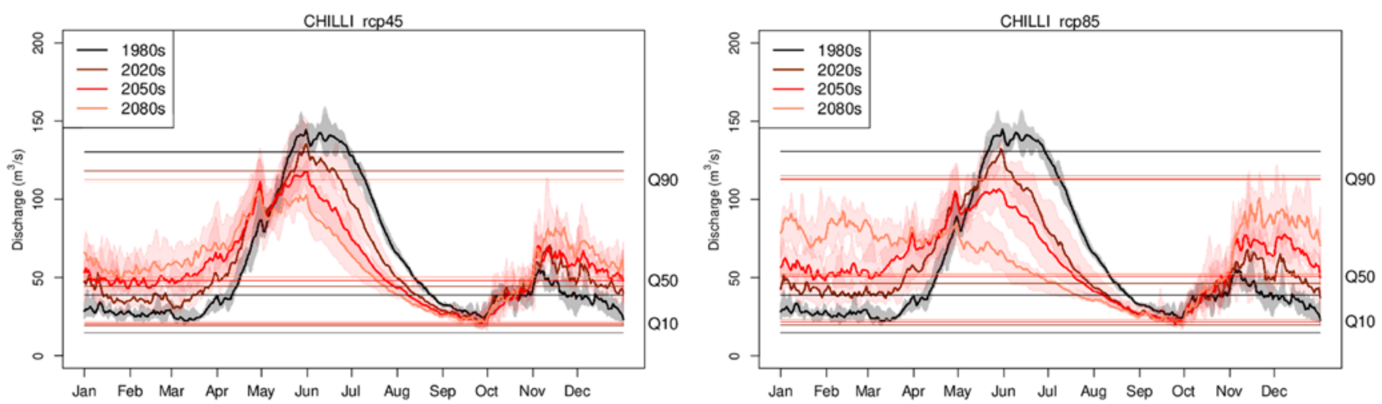


Figure 6: These composite hydrographs , showing the rates of flow of the Chilliwack River at Vedder Crossing for the historical period (1971-2000, black lines) and three future periods (2021-2040, burgundy line, 2041-2070, red line, and 2071-2099, salmon line) based on the output of six global climate models (GCMs) per ensemble. The left panel shows the rates of flow assuming the RCP 4.5 emissions scenario and the right panel shows the rates of flow for RCP 8.5. Median of climatological mean daily discharge amongst driving GCMs in m3 s-1 is shown with the solid line, while shading shows the range of climatological values from different GCMs. Low flow, median flow and high flow in m3 s-1 median and minimum and maximum range are indicated by the horizontal solid line and shading, respectively for the same periods: the 1980s, 2020s, 2050s and 2080s.

PCIC developed a set of hydrologic projections for three selected streams in B.C. using outputs from its most recent hydrologic modelling. This used output from VIC-GL, driven using downscaled climate model output from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) assuming a medium and a high emissions scenario, dubbed Representative Concentration Pathways (RCPs) 4.5 and RCP8.5, respectively. The results, which were presented in the form of a report focused on future changes in low, mean and high flows and on the limitations of these hydrologic projections for these three metrics. This work was a chance for PCIC staff to "dig-into" these latest results, to get a better understanding of where, and for which variables, projections agree in the direction of change, and how to articulate the reasons why. It was a good learning platform. PCIC and ENV/FLNRORD came to a common understanding of what users need to know before they apply the hydrologic modelling results in their work.

The materials for interpretation were written to communicate that, although there is a range in future projections, the story is similar from one scenario to the next, and makes sense physically as a response to increased temperature. For example, in the Chilliwack River at Vedder Crossing (see Figure 6), low and median flows are projected to increase, while high flows are projected to decrease across the models and RCPs used. This makes sense in a watershed that is farther south, at a relatively low elevation and has temperatures close to 0° Celsius in winter. Not much temperature change is required to prevent snow pack from forming and change the regime of the watershed. These composite hydrographs were developed to visualize the response of streamflow to climate change, including the range of uncertainty across six GCMs around the median and the change in low, median and high flow.

The document, figures and tables produced for this report went on to serve as the basis for two webinars on PCIC's hydrologic modelling results and gridded and station data portals.

MODELLING FRASER RIVER STREAMFLOW TEMPERATURES

British Columbia's rivers are among the most important in the world for wild salmon. Changes to the rivers that wind their way through the province can impact salmon populations and have other ecosystem impacts. British Columbia's longest river, the Fraser, flows from the Rocky Mountains across the province to the Pacific Ocean and is spawning grounds for all five species of Pacific Salmon. Changes to the temperature of the Fraser River can significantly affect the pre-spawning mortality rate of these salmon. In 2017, work at PCIC began on integrating a River Basin Model (RBM) into the VIC-GL model. The RBM model takes the meteorological data that are inputs to VIC-GL and the streamflow results as input to calculate stream temperature along stream network. This model has been coupled to PCIC's refactored VIC-GL. Once coupled, it was tested against observed water temperatures in the Fraser River basin. The end goal was to create a reanalysis of water temperature for the Fraser River basin covering the period of 1945 to the present day. It was driven with the Pacific NorthWestern North America meteorological dataset (PNWNAmet, developed at PCIC), and two reanalyses products. A significant outcome of this work was identifying the strong relationship between the trend in water temperature and solar radiation. This work is the basis for PCIC's expertise in water temperature modelling for the coastal watersheds featured in the BCSRIF project in this section of the Corporate Report.

MODELLING THE WATER TEMPERATURE OF THE NECHAKO RIVER

The Nechako River in Northern BC is one of the main tributaries of the Fraser River, supports multiple fish species including white sturgeon and Chinook salmon, and is a migration corridor for sockeye salmon. Over the 2019-2020 fiscal year, PCIC began a research project to understand the effect that climate change may have on the water temperature of the Nechako River (see Figure 7). The focus of this work is on water released at the Skins Lake Spillway, at the beginning of the Nechako River. Water is released via the Skins Lake Spillway during the salmon migration period to moderate the temperature of the Nechako so that salmon migrating up the river are not exposed to excessively warm water. The objectives of this research are to learn more about the impacts of warm water on the salmon and sturgeon that live in the Nechako, and to project future streamflow and water temperature changes in the Nechako River and Nechako Reservoir.

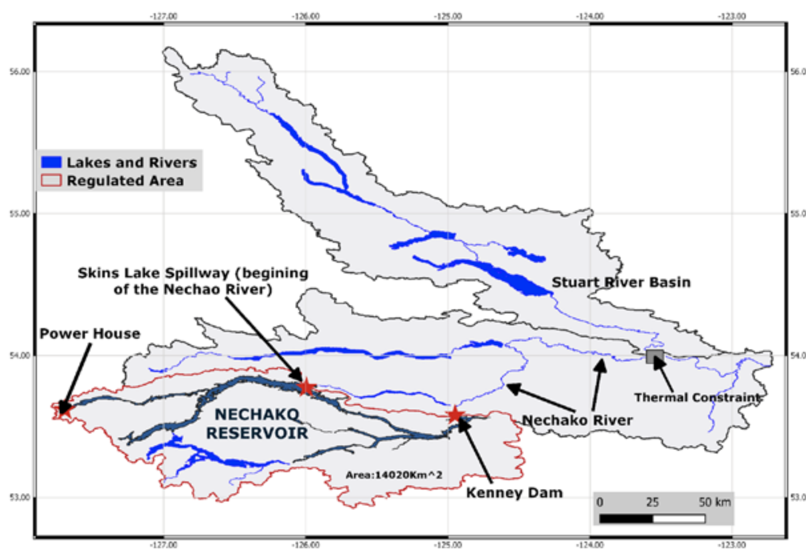


Figure 7: This is a map of the study area for the Nechako River project. Red stars indicate locations of interest, blue shading indicates lakes and rivers, and the red outline indicates the regulated area.

As the climate changes, it may impact fish habitats in several ways, such as by changing the temperature of the water and through changes in the amount of water flowing through the Nechako system due to changes in precipitation and evaporation. Because of this, there is a need to anticipate and better understand the potential impacts of climate change on the temperature and water flow regimes of the Nechako Reservoir. To meet this need, researchers at PCIC have coupled VIC-GL with a hydrodynamic model of the Nechako Reservoir (here, a two-dimensional model that simulates fluid flow in a body of water) and a water temperature model, to simulate water volume, flow and temperature in the Nechako system. This will allow the researchers to represent and simulate the Nechako Reservoir and produce future scenarios of water temperature released at the Skins Lake Spillway, as well as downstream flows and temperatures that can affect salmon. The information that will be obtained from this work will be used to support planning, to help determine how a suitable migration environment can be maintained in the river in the future.

Work on this project is supported by an NSERC Collaborative Research and Development grant. This grant involves researchers from: L'Institut national de la recherche scientifique in Quebec, the École de technologie supérieure in Montreal, the University of British Columbia, Rio Tinto and PCIC.

REGIONAL CLIMATE IMPACTS THEME: ACCOMPLISHMENTS AND IMPACTS

CO-PRODUCING A REGIONAL ASSESSMENT FOR NORTHEASTERN BC

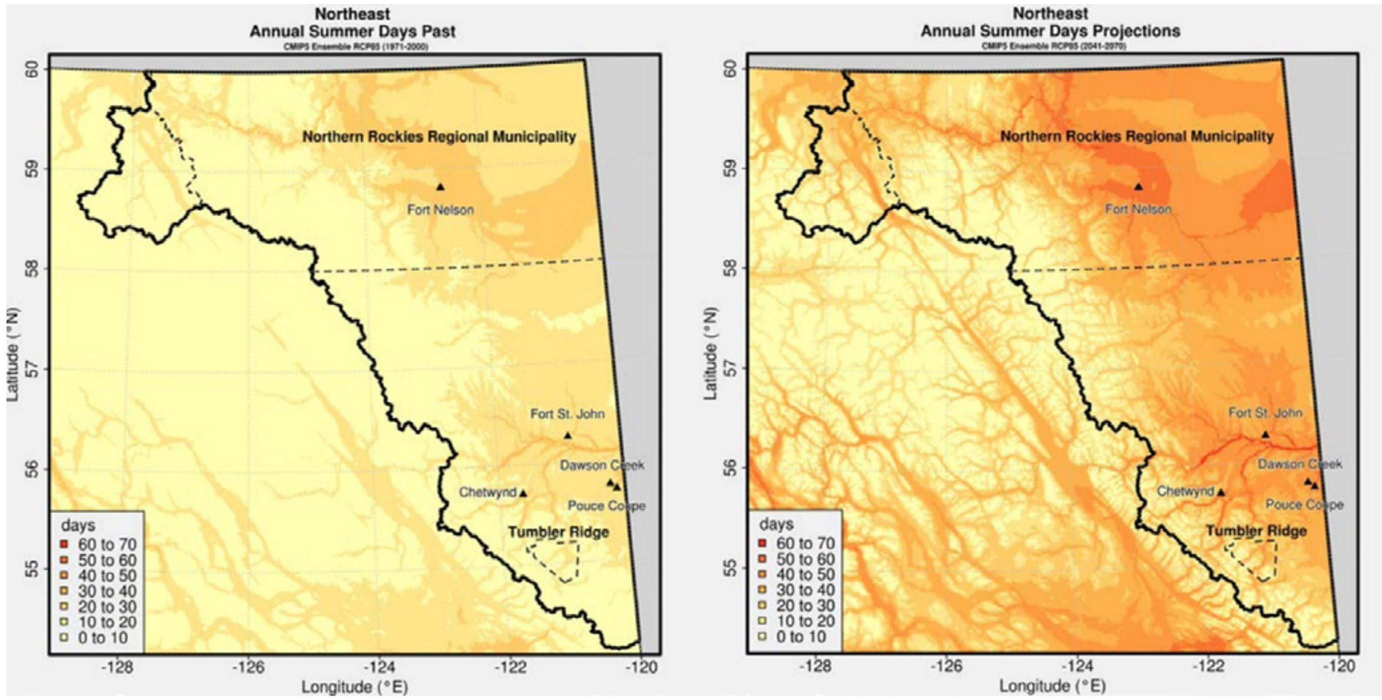


Figure 8: These maps show the number of days with maximum temperatures over 25°C in Northeastern BC in the past (1971-2000), from historical climate model simulations, and in the projections for the 2050s (2041-2070), following the RCP 8.5 high-emissions scenario.

PCIC partnered with the Northeast Climate Risk Network to co-produce a assessment report on projected changes to the climate of Northeastern BC, Funded by the Fraser Basin Council. Northeastern BC is home to about 70,000 residents and the area is subject to environmental risks such as flooding, wildfire and hail that pose risks to the community. To determine the overall shape that projected impacts may take in the region, the report focuses on a high-emissions scenario. The report covers hydrological impacts and regional climate impacts for broad general use, with PCIC providing guidance, projections and review. The co-production method used to create the report focuses on the needs and experience of regional stakeholders, who ask the questions that drive the analysis. It also ensures that the resulting work incorporates regional knowledge and is tailor-made to the needs of its users.

The projections used in the report suggest that the region's climate will warm across all seasons and experience greater precipitation year-round on average. By the 2080s, projections using an RCP8.5 high-emissions scenario suggest that the region may have a climate that is quite different than today's, particularly in terms of temperature. They show a large increase in the number of days with temperatures over 25°C (Figure 8) and 30°C and January temperatures that would feel like March does in the current climate. In addition, the projections show more intense precipitation during extreme precipitation events and a reduction in summer streamflow. These changes could create challenges for crops, water quality and supply, ecosystems and infrastructure.

The co-produced report is part of a series of reports that will be used by municipalities in BC to inform risk management and decision-making practices in preparation for future climate change. In addition to the report, PCIC contributed to a regional workshop and a free public talk in Chetwynd that discussed the projected changes that the region may see in coming decades.

SUPPORTING AGRICULTURAL ADAPTATION IN BC

With the completion of the seventh, eighth and ninth regional adaptation plans this past year as part of the BC Agriculture and Food Climate Action Initiative, a full suite of regional assessments is available for most of the major agricultural regions of BC (Figure 9). The new reports focus on the Kootenay and Boundary, Bulkley-Nechako, Fraser-Fort George and Vancouver Island regions, respectively. PCIC contributed to the development of these assessments by providing regional climate data, analysis, figures and guidance on their interpretation. The resulting reports will be used by agricultural producers and industry partners, to support planning and adaptation that accounts for projected future climate change.

Figure 9: This map shows the agricultural regions for which regional assessments have been completed for the BC Agriculture and Food Climate Action Initiative. (Image credit: BC Agriculture and Food Climate Action Initiative.)

The reports were created in partnership with local agricultural organizations, local governments and the provincial government to ensure that they were developed around the needs of regional stakeholders. The assessments discuss climate projections, impacts and potential strategies and actions to reduce the magnitude of the impacts that agriculture in the region may face from a changing climate. While they were developed using the RCP 8.5 high-emissions scenario focused on the 2050s, if global emissions follow a lower trajectory, these conditions may be experienced later on in the century, by the 2060s or 2070s. In broad strokes, the projected future climate for all three regions is one with warming during all seasons (Figure 10). Indices associated

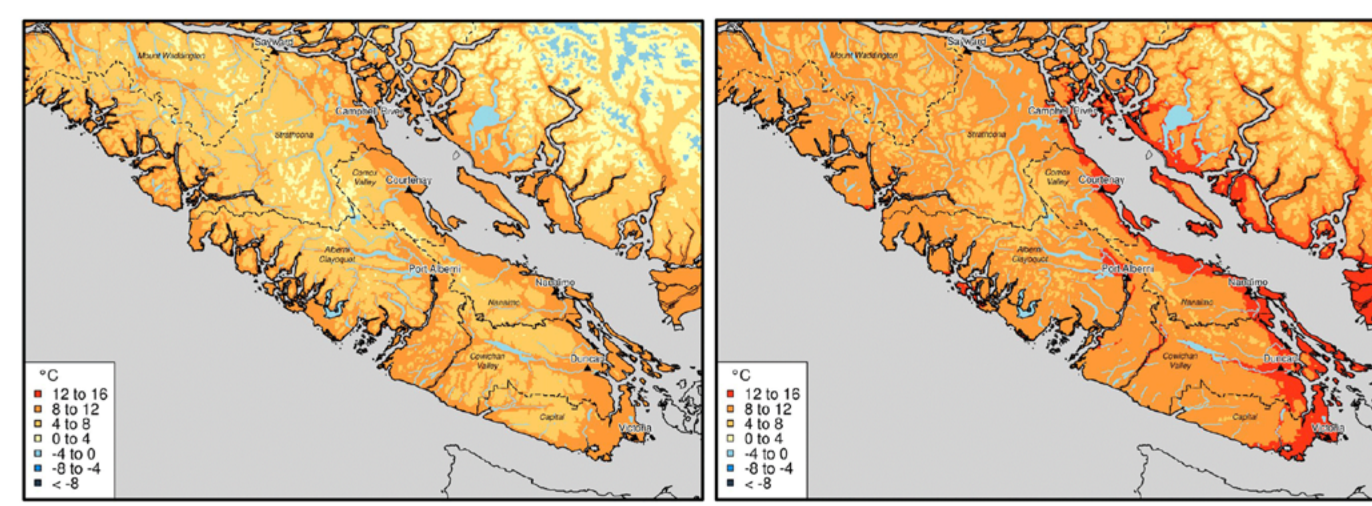


Figure 10: This figure shows the average annual temperature of Vancouver Island in the past (1971-2000) from historical climate model simulations, and in the future projections for the 2050s (2041-2070) following the RCP 8.5 high-emissions scenario.

with warmth are projected to increase and indices associated with cold conditions are expected to decrease, with increases to hot extremes and heavy precipitation events. Hot and dry summers are projected for the Kootenay and Boundary regions and Vancouver Island. The reports detail a number of potential impacts for agriculture. These include summer water demand issues, increased weather variability and increased wildfire risk in all three of the regions. In the Kootenay and Boundary region, other impacts include increased flood risk, while in Bulkley-Nechako and Fraser-Fort George, other impacts include changes to pest and beneficial insect populations; both flooding and changes to insect populations are highlighted as potential impacts for Vancouver Island. The reports also discuss potential adaptation strategies, including enhancing water storage and increasing wildfire preparedness, to increasing climate knowledge and the availability of agricultural decision-making support tools.

NEW CLIMATE REPORTS FOR THE BC HEALTH SECTOR

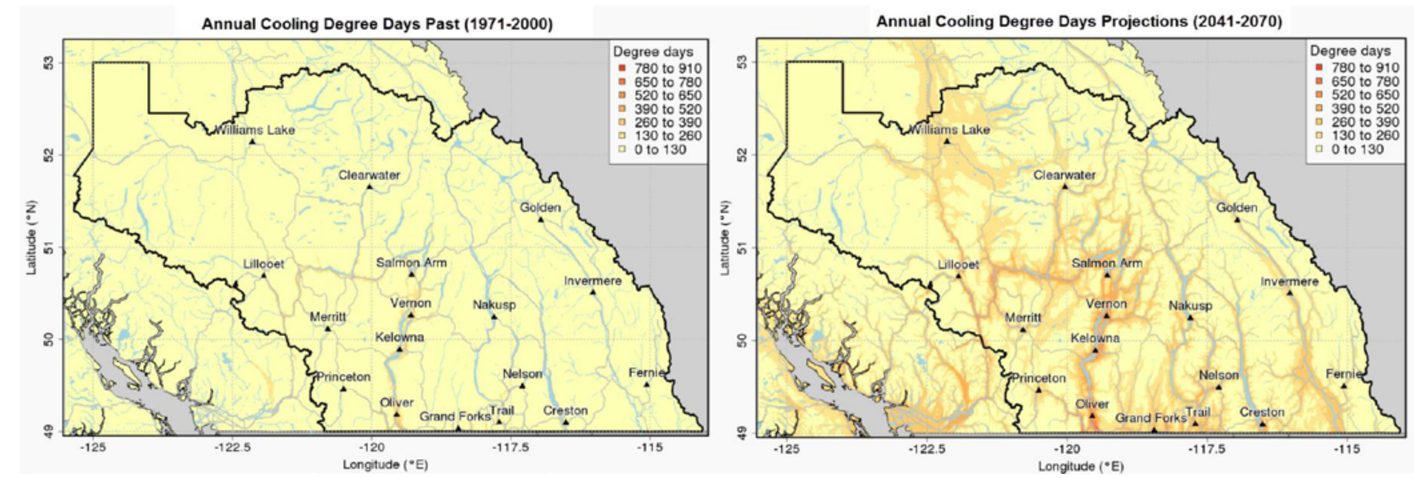


Figure 11: These maps show the number of annual Cooling Degree Days, an index that is used as a measure of the energy required for cooling, in the Interior Health region in the past (1971-2000), from historical climate model simulations (left panel), and in the projections for the 2050s (2041-2070), following the RCP 8.5 high-emissions scenario (right panel).

PCIC has been engaged in multiple projects to help to increase the climate resiliency of BC's health sector. In the two most recent of these, PCIC partnered with Vancouver Coastal Health (VCH) and Interior Health (IH) to produce reports that discuss projected changes in climate for these regions and potential resilience-building strategies. VCH delivers healthcare services to nearly a quarter of BC's population, through a number of facilities, including 13 hospitals, three treatment centres and 15 community health centres in Metro Vancouver and the Coast Garibaldi area on BC's coast. Interior Health serves about a fifth of the province's population through 46 hospitals and health centres. Both reports use climate model projections that assume the RCP 8.5 high-emissions scenario to determine the shape that future climate impacts may take in each region for the 2050s and 2080s.

In the first project, VCH partnered with PCIC to assess climate risk for the region it serves, the resilience of its major infrastructure projects, and present these in a co-produced report. The results of this work were compiled by Pinna Sustainability into a report, titled Moving Towards Climate Resilient Health Facilities for Vancouver Coastal Health. This report discusses projected changes in the region's climate, potential impacts and a set of resilience-building strategies. The projections in the report show that there may be a dramatic increase in the number of days above 25°C and 30°C. Projections also show that the all of the facilities examined will see an increase in nights with minimum temperatures above 20°C. Based on precipitation projections, VCH experts expressed concern that storm intensity and overland flood risks may increase, and that there may be increased stress on water availability for drinking, reprocessing equipment, washing, dialysis and bathing. Based on the climate projections, there may be an overall shift in energy requirements for the warming climate, with heating needs decreasing and cooling needs increasing.

The second project, in which IH partnered with PCIC, followed from the earlier work with VCH. However, while the area that VCH serves is about 59,000 square kilometres, the area that IH serves is much larger, about 215,000 square kilometres. Because IH serves a smaller population spread out over a much larger area, the approach taken in this region used specific locations as case studies. The study considers potential future climate impacts for the region, specific impacts for IH in terms of health, infrastructure and healthcare delivery, and focuses on seven high-risk facilities in the region. Among the primary findings are that summers are projected to lengthen and become drier, heat waves are projected to become more frequent and more intense and more snow is projected to fall in the winter. As with the VCH region, the IH report shows an increase in days over 25°C and 30°C, and a corresponding increase in cooling needs (Figure 11). The shifting climate may bring an increased risk of heat stress, wildfires, extreme precipitation and flooding. Many of the climate impacts may have multiple impacts to the community, health delivery and IH facilities, which the report outlines. For instance, a reduction in air quality due to increased wildfires can increase respiratory illness in the community, reduce the air supply to exchange the air in operating rooms and also strain building ventilation systems.

Through considering these projected impacts, VCH and IH can better prepare for the challenges to healthcare provision that the changing climate may bring.

FUTURE-SHIFTED WEATHER FILES AND HOUSING

Buildings are long-lasting structures. They are built to function for decades and, through routine maintenance, renewals, adaptations and upgrades, they can last for much longer. Buildings constructed in the current climate will thus be exposed to the climatic conditions of the future. This has a number of implications, among them, changes in the need for seasonal heating and cooling requirements. Energy modelling is conducted as part of the design process for new buildings and is used to study how a building's design will affect the comfort of the people inside. A key feature of energy modelling is determining cooling and heating demand, which is affected by the weather outside. To do this, engineers use weather files, which contain data for each hour of the year for a given location. The data that is typically used is based on historical data. To account for the changing climate, PCIC has partnered with the University of British Columbia (UBC) and the BC Ministry of Housing to update these weather files and provide guidance to engineers who are incorporating future climate considerations into their building design work.

The first project in this work was convened by UBC and focused on researching the impacts of overheating on four building archetypes representative of those found in residential neighbourhoods. RDH Building Design worked with PCIC on this report, as an applied research partner. This project was a proof of concept, and involved calculating future-adjusted weather files using existing methods already employed in the United Kingdom to "future-shift" available daily data. This work was built upon during BC Housing's Mobilizing Building Adaptation and Resilience (MBAR) project, which included two engineering consulting companies, Integral Engineering and Focus Engineering, as applied research partners. The resulting MBAR project produced the BC Energy Step Code Design Guide and Supplement on Overheating and Air Quality. This is the first guidance document for the buildings sector that advises on the use of future weather files in energy modelling and the consideration of future climate in design, particularly for overheating. It raises these issues and provides some solutions for building designers to consider. This work also supported the development of the Designing Climate Resilient Family Buildings report for UBC Sustainability and Engineering. Through this work, the partners became aware that there would still be some need for training and support. To this end, the Climate Action Secretariat (CAS) of the BC Ministry of Environment and Climate Change Strategy has supported further training and engagement. They have also supported continued refinements in methodology, ongoing calculations, and the development of an online web portal. The support of CAS has also allowed for some expanded interpretation, including the development of summary tables at each station that is used for weather files data and the refinement of calculations and available data.

SUPPORTING CLIMATEDATA.CA

Decision-makers, engineers and planners require detailed climate data that they can include in their development and planning processes. PCIC is a partner in the development of ClimateData.ca, which supports these users by bringing together Canada's regional climate services to create a coherent national data source. ClimateData.ca provides climate data, including temperature, precipitation and various climate indices for all of Canada, as well as location-based summaries of projected changes in climate. The site has an intuitive interface through which users can access and download local and regional data. The available data are organized by location, variable and sector. ClimateData.ca also includes case studies and training materials to help users incorporate climate projections into their planning processes.

The partnership that is developing ClimateData.ca consists of the Computer Research Institute of Montréal, Ouranos, the Pacific Climate Impacts Consortium, the Prairie Climate Centre, Habitat Seven and the Canadian Centre for Climate Services, who financially supported the project. PCIC contributed downscaled future climate projections data. PCIC also provided and reviewed content and the layout, and assisted with the development of the health sector and agricultural modules, and leads the transport and buildings modules.

COMPUTATIONAL SUPPORT GROUP: ACCOMPLISHMENTS AND IMPACTS

UPDATES TO PCIC'S DATA PORTALS

Water resources are indispensable to the functioning of natural systems and human societies. Anthropogenic climate change is projected to have substantial impacts on the hydrology of British Columbia, affecting these vital water resources. Working with PCIC's Hydrologic Impacts (HI) theme, the Computational Support Group has developed two new data portal pages that provide convenient access to output from the hydrologic model VIC-GL, that is used by PCIC's HI theme. The output includes historical simulations and future projections, through an easy to use map-based point-and-click interface.

The first of these is the Gridded Hydrologic Model Output Data Portal page, which serves up gridded, 1/16th of a degree (in BC, about 35 km2) projections of 13 hydrologic variables such as runoff, evaporation, snow cover and glacier melt, for the Peace, Fraser and Columbia watersheds. To create this output, VIC-GL was driven with 12 statistically-downscaled global climate model (GCM) projections from CMIP5. These were made using two future emissions scenarios: RCP 4.5, a scenario with modest emissions reductions, and RCP 8.5, a high-emissions scenario. The 12 projections were chosen because they span a wide range in future climate extremes. The downscaling technique, Bias Correction/Constructed Analogues with Quantile mapping reordering, version 2 (BCCAQv2), was developed at PCIC and was used for its ability to preserve changes in magnitude, spatial characteristics and the day-to-day sequencing of variables.

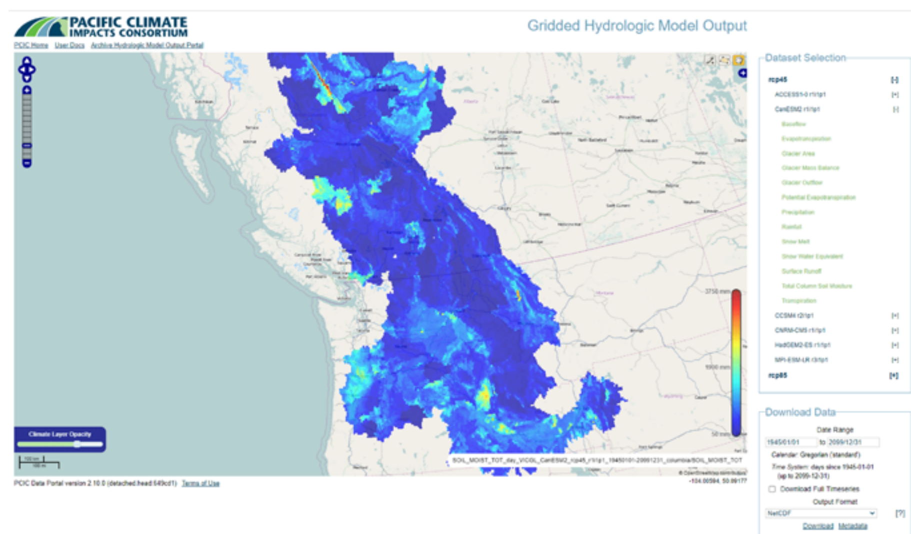


Figure 12: This figure shows the graphical user interface for the Gridded Hydrological Model Output Data Portal page.

The second of these is the Station Hydrologic Model Output Data Portal page, which provides simulated streamflow data, generated by the VIC-GL model, for 190 locations corresponding to a combination of Water Survey of Canada and US Geological Survey hydrometric gauges, and dam sites in the Peace, Fraser and Columbia watersheds. A historical run, driven by PCIC's gridded meteorological data for northwest North America (PNWNAmet), is available from 1945 to 2012 and 12 future hydrologic scenarios are available, with future emissions again being given by RCP 4.5 and RCP 8.5.

UPDATING PLAN2ADAPT AND THE PCIC CLIMATE EXPLORER

Different people working to study climate change and account for it in their planning require climate data and information with differing levels of technical details. In order to help address these needs, PCIC offers a variety of tools, observational data and model output. Two of PCIC's tools underwent significant development over the 2019-2020 fiscal year: Plan2Adapt and the PCIC Climate Explorer (PCEX).

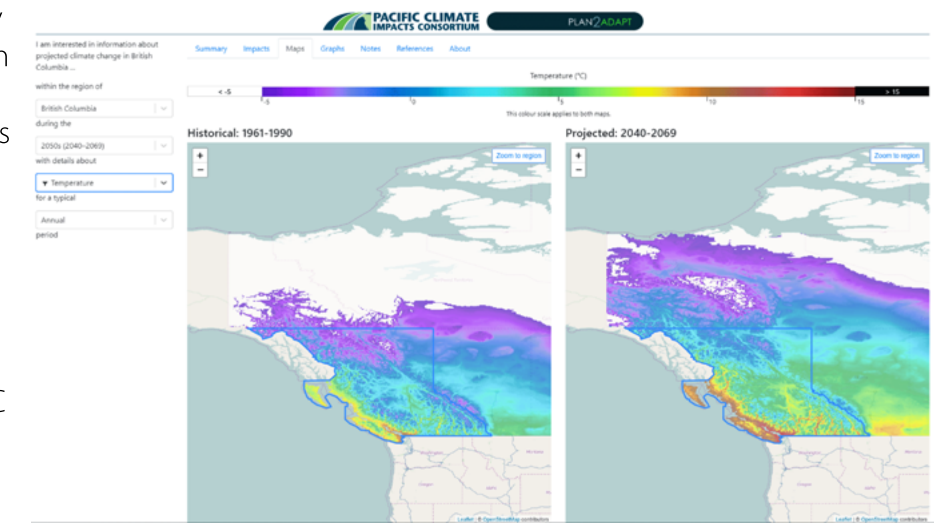


Figure 13: This figure shows the graphical user interface of the redesigned Plan2Adapt tool.

PCIC's Plan2Adapt tool supports planning by providing a high-level overview of projected regional changes in British Columbia. It generates maps, graphs, and data describing projected future climate conditions for regions throughout British Columbia, as well as listing some plausible potential impacts by sector. Over the 2019-2020 fiscal year, the computer code for Plan2Adapt was entirely rewritten, to incorporate newer model projections, modernize the code of the "impacts rules engine" that determines potential climate impacts, and to improve its user interface. The new tool incorporates projections made using RCP 8.5, the high future-emissions scenario used in CMIP5. RCP 8.5 was selected because it is the scenario that our users refer to most often. The rule engine determines whether a certain climate impact applies to the user's selected region given the region's data, drawn from PCIC's downscaled climate model output, and the rule definition. This is then displayed on the Impacts page where users can see the sectors that may be impacted and what that projected impacts may be. The rewritten impacts rules engine will allow for a rapid deployment, without any further coding, of any future revisions to the impacts rules. It will also allow for the rules to be extended in their application to broader physical domains. The new Plan2Adapt sources its information from the PCIC Climate Explorer tool (PCEX, described below). Because it draws its information from PCEX, which is updated as new data becomes available, Plan2Adapt will also be able to draw from new sources of input data, such as CMIP6, when they become available. This means that its overviews will be able to reflect the most recent projections available.

Released at the end of the 2018-2019 fiscal year and updated over 2019-2020, PCEX is a tool for locating, visualizing and downloading data describing projected future climate conditions for regions of interest within the Pacific and Yukon Region. PCEX uses statistically-downscaled global climate model output from CMIP5, and the CLIMDEX indices of climate extremes. PCEX provides visualizations in the form of maps and graphs and allows users to select their data, including temperature, precipitation and climate indices, by climate model, emissions scenario, time period and region of interest.

This year a number of new application programming interfaces (APIs) were added to PCEX, allowing for programs to directly and easily interface with PCEX to request data. These include a pilot project for an API that provides streamflow climatologies. Other APIs serve up information about the physical hydrology of watersheds, support the functions of Plan2Adapt and provide access to ensemble averages for a wide range of variables. The development of the PCEX tool and interfacing APIs has been supported by the BC Ministry of Transportation and Infrastructure.

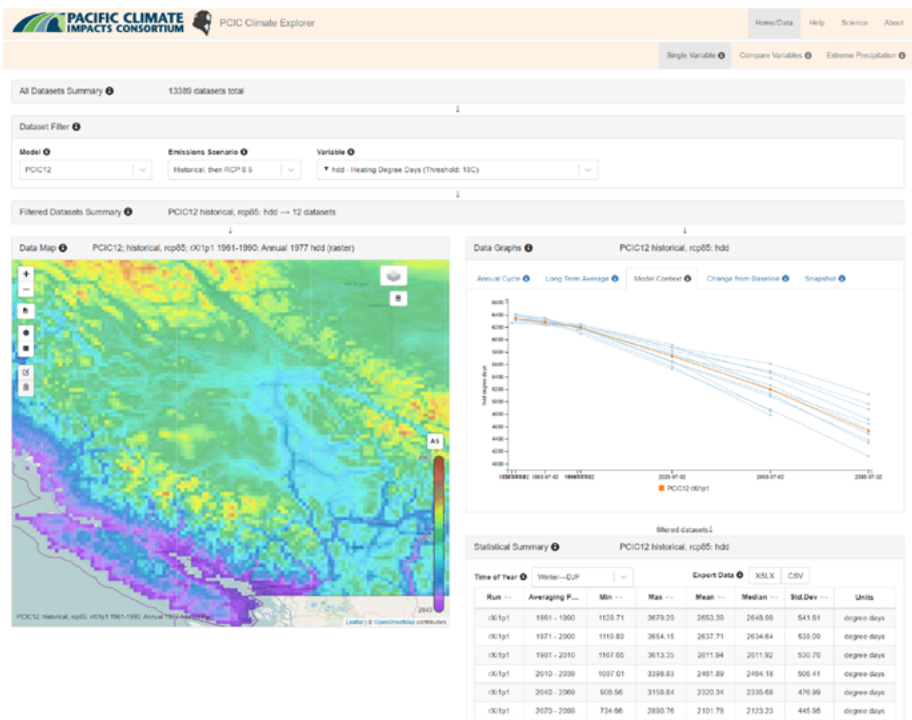


Figure 14: This figure shows the user interface for the PCIC Climate Explorer tool.

MAKING CLIMATE DATA ANALYTICS MORE EFFICIENT

Each time that a new phase of the Coupled Model Intercomparison Project becomes available, researchers from institutions all over the world download petabytes of data and perform various operations on it for analysis or use it to run other models, such as hydrologic models. This uses immense resources and results in much duplicated work. Much of this could be avoided if the analysis could be performed on the data where it resides, rather than moving the data to the location where the analysis is performed. Partnering with the University of Toronto and the Computer Research Institute of Montréal, with the support of the Canadian Cyber Infrastructure fund of the Canadian Foundation for Innovation, PCIC is participating in a three-year project to realize this goal. PCIC's Computational Support Group is contributing to the development of a series of Data Analytics for Canadian Climate Services (DACCS) nodes, which will be storage systems with nearby computational resources where people can send their analysis requests. PCIC's team has also developed web processing software tools to utilize the data on a DACCS node that do commonly done climate analytics and incorporate the back ends of PCIC's tools. Ouranos has similarly been developing web processing software for the hydrologic model Raven. The development of this web processing software will mean that people will be able to pick out data, and specify analyses and operations to be performed on data without having to move the data from the node on which it is stored. For example, one of these tools, known as Thunderbird, will allow users to run the same operations that are used to process data for PCIC's Climate Explorer to create climatologies from high temporal-resolution data and climate model output. Each of the web processing services are encapsulated pieces of software, named after birds: Raven uses the modelling engine from the Raven hydrological modelling framework, Sand Piper is the Plan2Adapt impacts engine, Osprey performs river routing used for the Variable Infiltration Capacity hydrologic model and, as mentioned, Thunderbird is the back end from PCIC's Climate Explorer. PCIC is proud to support the development of this ground-breaking project that stands to improve the efficiency and availability of climate data analytics in Canada.

PARTNERSHIPS AND THEME INTEGRATION

PARTNERSHIPS AND THEME INTEGRATION

The three themes that comprise PCIC's research program, along with PCIC's Computational Support Group are deeply integrated, with work from each group being supported by, and in turn supporting, work from others. For example, the Climate Analysis and Monitoring theme supports the Hydrologic Impacts theme by supplying data and aiding in glacier modelling, and supports the Regional Climate Impacts theme through supplying historical data. The Computational Support Group supports each of the themes and provides strong operational support for the Climate Related Monitoring Program, allowing for a near real-time stream of data from across the province. The other themes supply data, model output and analysis to the Computational Support Group, to be delivered to PCIC's users through PCIC's data portals and analysis tools. Several of the projects that PCIC works on span across themes, for instance the project for the National Resource Council of Canada (NRC) discussed in this section, which draws together researchers from all across PCIC. PCIC itself is embedded and integrated into a larger network of partners, across the public and private sectors, and including other climate service providers and research groups, working together to increase climate resiliency at the provincial, national and international levels. PCIC leverages this partnership network to serve its regional stakeholders and gives back through research, data and training the next generation of scientists.

PARTNERSHIP WITH THE CANADIAN CENTRE FOR CLIMATE SERVICES

Responding to the needs of Canadians for regional climate services requires strong coordination among Canada's regional service providers. To this end, PCIC is participating in an effort to support climate services across Canada through coordination and collaboration that is being led by the Canadian Centre for Climate Services (CCCS). PCIC supports the coordination of regional climate services as a member of the Regional Coordinating Committee convened by CCCS to provide coordinated national guidance on the development of climate services and tools.

Over the 2019-2020 fiscal year, PCIC collaborated with Ouranos, CCCS and the Prairie Climate Centre on the development of introductory training materials to familiarize decision makers with the core concepts needed for the use of climate change information in decision making. To test the content as it was being refined, PCIC led several webinars with users in BC and nationally. The complete version of these training materials, along with some of the recorded training videos developed by the partners involved, have been posted in the training section of climatedata.ca.

In addition, with support from CCCS for user engagement and training, PCIC engaged with and delivered training widely to stakeholders in BC over the past year. The user engagement and training specialist delivered twenty-eight presentations at workshops, conferences and online over the course of the fiscal year. Eight of those presentations have been to Indigenous communities and audiences, including five in-person presentations in First Nations communities and three at fora or workshops for Indigenous communities and community members.

PCIC continues to engage actively with our user base to coordinate and share lessons learned from that experience through the collaborative platforms and working groups with CCCS. PCIC staff continue to participate in various CCCS-supported working groups and to respond to inquiries directed from the CCCS Support Desk.

PCIC provided advice and review in the course design of the BRACE (NRCAN) funded project delivered by Royal Roads University (Inspiring Climate Action) engaging BC mid-career professionals. PCIC also provided support and capacity building to engage public sector partners in understanding climate impacts to aid informed discussion about the development of BC's Adaptation strategy.

SUPPORTING THE CONSIDERATION OF CLIMATE CHANGE IN ENGINEERING

Because infrastructure is particularly long-lived, infrastructure that is designed today will experience the climate conditions of the future. They may be subject to changing temperature, precipitation and wind, and the demands for heating and cooling inside buildings may change as winters and summers become warmer. Thus, to make climate-resilient infrastructure, it is important that engineers and planners have access to the best available information about potential future conditions. The next section details PCIC's efforts to support the engineering community by increasing the availability of such information.

UPDATED GUIDANCE ON CLIMATIC DESIGN VALUES FOR INFRASTRUCTURE DESIGN

The changing global climate has the potential to affect buildings and infrastructure by changing the conditions that they are exposed to. Such environmental shifts will potentially include changes in temperature, the type and amount of precipitation that falls in a given season, and to the magnitude and frequency of hazards such as high snow-accumulation, extreme wind speeds, and flooding. In order to prepare for these changes, the National Research Council of Canada (NRC) has been supporting a collaborative project between PCIC and Environment and Climate Change Canada (ECCC). Working together, ECCC and PCIC are developing updated guidance to the engineering community that accounts for the changing climate.

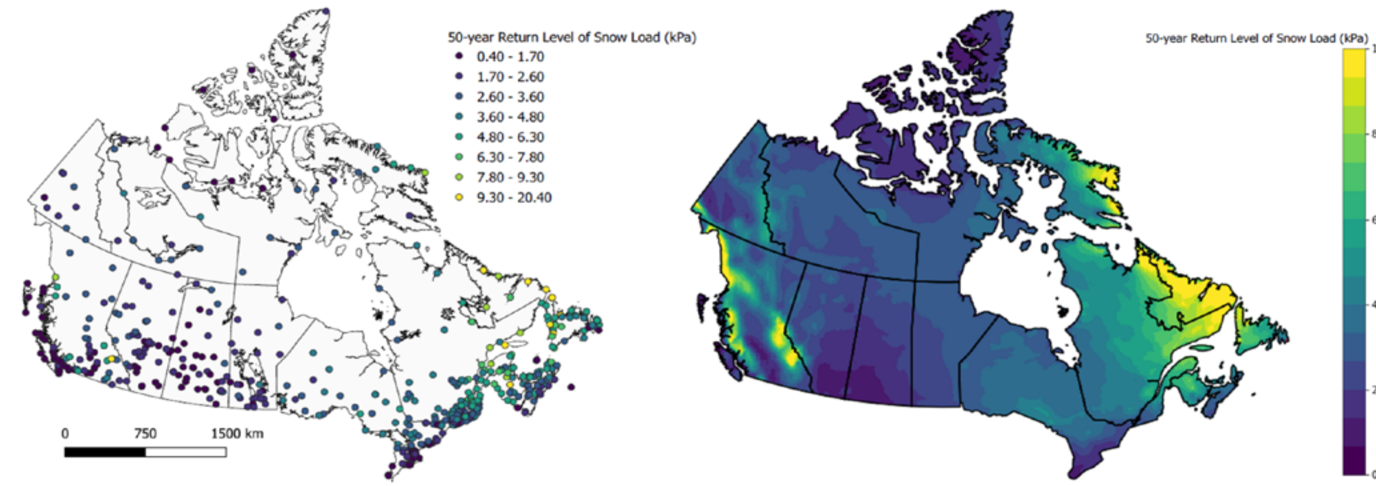


Figure 15: This figure shows the 50-year return level of snow load. The left panel shows a map of the 50-year return levels derived from quality-controlled observations of snow depth at Meteorological Service of Canada stations. The right panel shows a recently-generated map of the 50-year return level of snow load created from a novel reconstruction technique that uses the snow load estimates at the observing stations shown on the left, along with regional climate model-simulated snow loads, as inputs.

One aspect of this work is the development of updated climate design data for the recent historical period. These include updated snow load and rain-on-snow load data for 500 locations across Canada, climatological temperature indicators, such as maximum and minimum temperatures and heating degree days—used as a measure of energy demand for heating—and measures of humidity, hourly temperature, and daily and sub-daily rainfall extremes. An example of this is shown in Figure 15, which displays the estimated 1-in-50 year extreme snow load at each station location.

In many instances, PCIC is able to leverage knowledge gained from prior work in the development of these datasets, such as with PCIC's experience with snow data in BC and expertise in the area of climate extremes. For example, PCIC is contributing an updated analysis of rainfall intensity-duration-frequency curves based on the most recent state of the art research in this area, and incorporating results from regional climate simulations to develop an innovative mapping tool. PCIC has also contributed to the development of a report that provides guidance to structural engineers on how climate design values may change in the future, and is developing maps of design-values along with an online tool for engineers to explore design values across Canada.

INFRASTRUCTURE RESOURCE CLIMATE MAPPING

Engineers need climate variables while developing projects in BC and they are required to incorporate climate change into their projects by provincial mandate. To aid in this, MoTI has partnered with PCIC to more seamlessly include climate change information into their infrastructure planning. In order to support MoTI as they incorporate projections of future climate change into their internal tools, PCIC's Computational Support Group (CSG) opened up and documented the Application Programming Interfaces (APIs) that PCIC uses, so that MoTI's internal tools can request maps and data directly into their proprietary mapping system. These provide data for all of BC, for baseline variables such as temperature and precipitation and a pilot project for the Peace Watershed to provide streamflow data (Figure 16). The eventual goal is to provide access to streamflow projections for any of the watersheds that PCIC has modelled. The successful incorporation of PCIC climate data into MoTI's tools shows that people can access PCIC's data for use in their own tools.

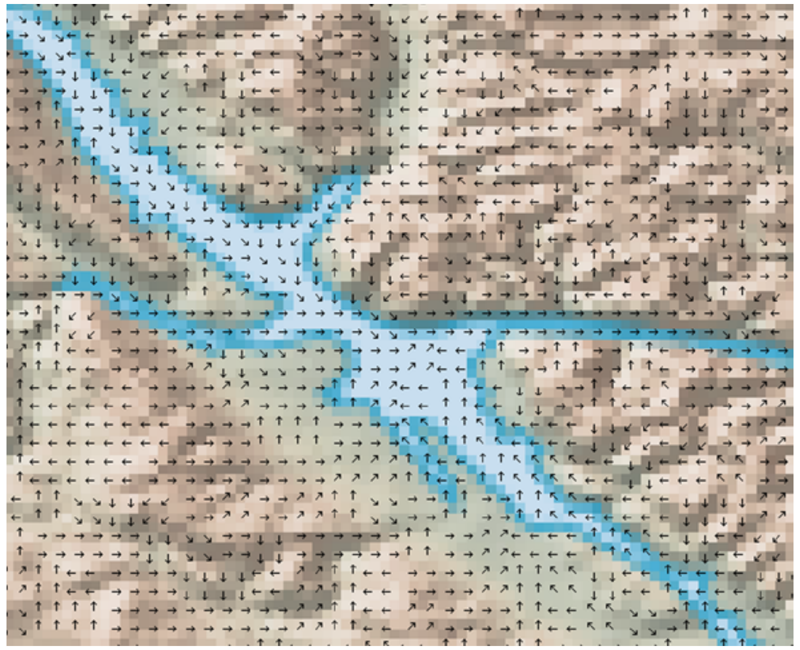


Figure 16: This figure shows the flow vectors that indicate the direction of water flow through the Peace Watershed.

SUPPORTING SITE-SPECIFIC ASSESSMENTS

In its ongoing engagement with the engineering community, PCIC has partnered with engineering firms to aid in the use of climate data for site-specific assessments. Three projects illustrating this over the 2019-2020 fiscal year are discussed here. The first project was an assessment for the Toquaht First Nation in partnership with Kerr Wood Leidal. The second was a Public Infrastructure and Engineering Vulnerability Committee (PIEVC) assessment for the Penticton Airport in partnership with Prism Engineering and Transport Canada. The third project was an assessment for the City of Calgary in partnership with GHD Group. This work is part of PCIC's ongoing commitment to support the use of climate data in engineering projects. PCIC looks forward to continuing this work in the future and supporting climate-resilient design.

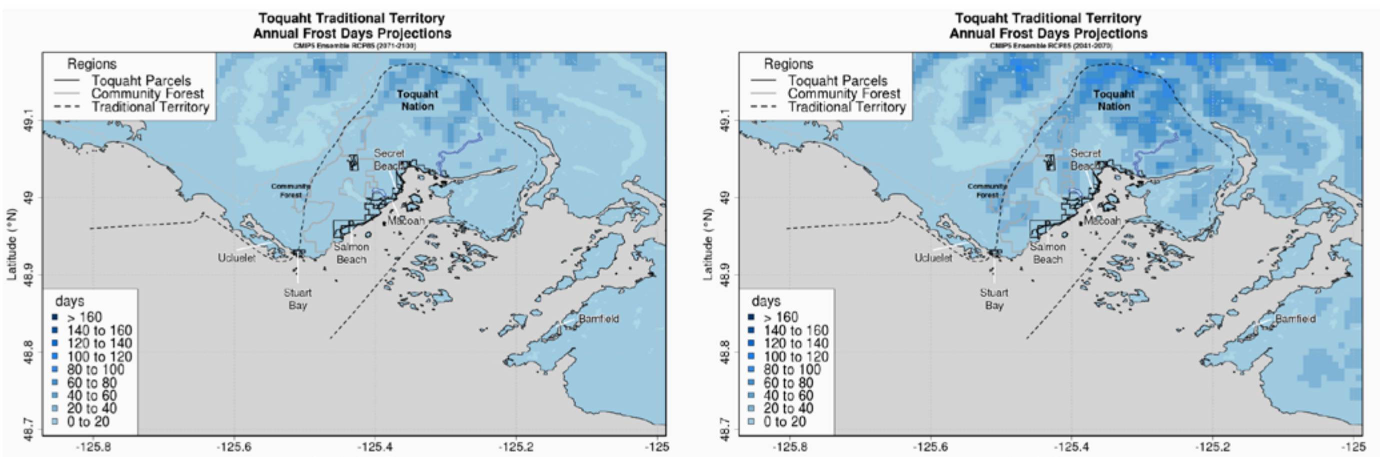


Figure 17: This figure shows the number of nights for which the temperature falls below zero in the Toquaht Nation and surrounding region, for the 2050s (left panel) and 2080s) right panel, in future projections following a high-emissions scenario. The average change for each period is given below the respective panel.

For the first project, PCIC was contacted by Kerr Wood Leidal to assist with assessments to determine how the changing climate may affect the Toquaht Territory. This work is PCIC's first collaboration with an engineering consulting firm directly for an indigenous community in BC. PCIC researchers travelled to the community to listen and engage, taking the time to understand the community context and determine how PCIC's climate information resources could best serve their interests. For this assessment, PCIC provided future projections, high-resolution maps, tables, and plots, and participated in dialogues, sharing our researchers' knowledge about their use and interpretation. Some of the findings from the assessment include warmer summer temperatures in the region, which may have impacts on heat stress, cultural practices and recreation, and fish health. They also showed warmer winters, with fewer nights below zero (see Figure 17) which may mean less snow in the mountains and less spring melt, which could in turn reduce water quality and may also affect fish health. Changes to precipitation include increased winter and overall annual precipitation, with decreased summer precipitation that could result in greater erosion, bridge and culvert damage, droughts, and increased landslide risk. Warming may also affect fog, which has ecological significance for the region.

For the second project, PCIC was brought on board by the Prism Engineering firm to support a PIEVC assessment for the Penticton Airport with Transport Canada. During the evolution of this contract, PCIC provided guidance on climate tools and data. PCIC also provided maps, tables and plots of various climate variables for the assessment as well as some interpretation regarding the likelihood of various weather and climate events of concern based on the projections. PCIC researchers also attended several preparatory meetings and the session where risk scores were developed, providing further guidance. The resulting report, which presented the analysis of the existing infrastructure in light of site-specific climate parameters, found 136 climate-infrastructure interactions, of which 67% were low-risk, 26% were medium risk, requiring action or further engineering analysis and 7% were deemed high-risk, requiring action. One result was that the drainage infrastructure would need to be evaluated due to projected precipitation changes and the mechanical systems would require further analysis to prevent failing in case of repeated heat waves occurring outside of the range for which they were designed. These findings highlight the need for assessments that take into account changing climate conditions.

GHD contacted PCIC to aid in the third project, an assessment for the City of Calgary. Begun in the 2019-2020 fiscal year, this assessment is ongoing as of autumn 2020. For this work PCIC has provided guidance on the methodology used and on the interpretation of the results that have been generated thus far.

AFFILIATE RESEARCHERS: ACCOMPLISHMENTS AND IMPACTS

GWF: THE GLOBAL WATER FUTURES PROJECT

PCIC is proud to be a part of the pan-Canadian Global Water Futures project, led by the University of Saskatchewan, which seeks to create and deliver risk-management solutions to address the impact of climate change on water resources and water disasters in Canada and other cold regions of the world. To support this, PCIC researchers are currently studying changes in precipitation and drought, and working on challenges in hydrologic modelling.

GWF: ESTIMATION METHODS FOR LONG RETURN-PERIOD PRECIPITATION EXTREMES

The estimation of extreme precipitation events is important for the planning and design of engineering projects and for water resource management. This year PCIC researchers examined a commonly used method for the estimation of extreme precipitation events and showed that caution is required when making ambitious estimates of the magnitude of very rare extreme precipitation events.

Existing records may not be long enough to gather sufficient data on very rare extreme events. For instance, a precipitation event that happens, on average, only once in 100 years—referred to as an event with a 100-year return period—might not be captured in a record that is only 50 years long. A widely used practice among engineers and other practitioners involves the use of statistical extreme value theory. By this method, the Generalized Extreme Value (GEV) distribution is fitted to samples of annual maximum precipitation in order to estimate 50- or 100-year return levels. For some purposes, however, engineers and practitioners might need to design based on longer return periods, going up to 1000 or 2000 years. Making such ambitious estimates raises the question of whether this method can reliably supply such information. The estimation of long-period return values relies on the assumption that the series of annual maxima exhibit regular behavior as defined by the max-stability property of the GEV distribution. Max-stability means that, if one were to construct a sample by randomly drawing a number of values from a given GEV distribution, the maximum of the resulting sample also would have a GEV distribution with the same shape as the initial distribution. The important practical point is that data to which the GEV distribution is fitted may not be max-stable, thus raising questions about the usefulness of the approach for long-period return level estimation. A challenge, however, is that a typical 50-year observed data record is not long enough to study such a question.

To get around this limitation, PCIC researchers used a large ensemble of historical simulations from the Canadian Regional Climate Model (CanRCM4) over North America to assess whether model simulated extreme daily and sub-daily precipitation amounts can be well described by a max-stable distribution. Their research shows that the annual maxima of short duration precipitation extremes tend not to be max-stable in the simulated climate. Figure 18 shows the return-level estimates obtained using their method. Their work also shows that long-period return-level estimates based on GEV distributions fitted to annual maxima may be seriously biased due to this apparent lack of max-stability.

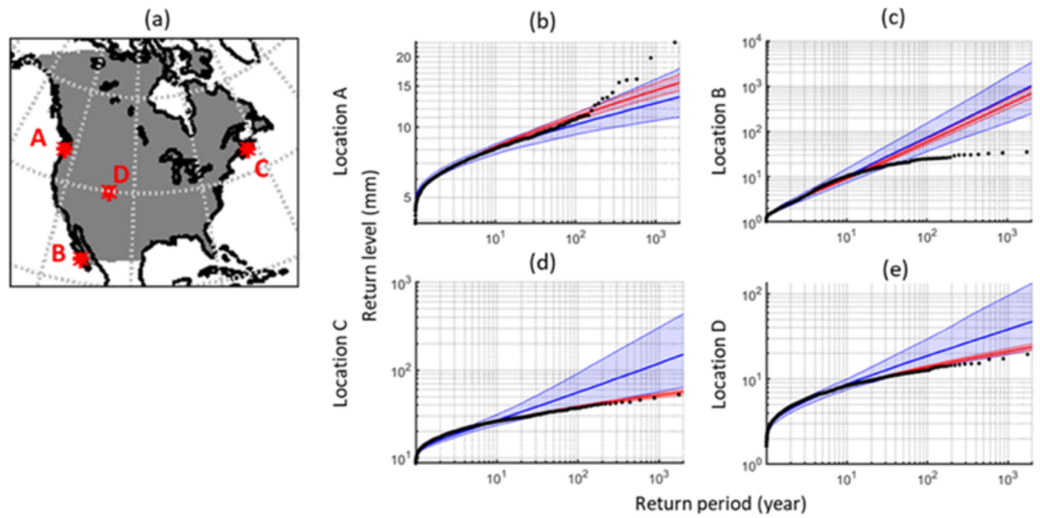


Figure 18: This figure shows return level estimates based on fitting the generalized extreme value (GEV) distribution to annual maxima at four different locations (a), as labeled in panels (b), (c), (d) and (e). Blue lines indicate estimates using one CanRCM4 simulation over 1951-2000 (50 annual maxima) and red lines indicate estimates from an ensemble of 35 simulations for the same period (1750 annual maxima). Black dots indicate empirical return level estimates obtained directly from the 1750 annual maxima without fitting a GEV distribution. Shading indicates 80% confidence intervals.

Because of this, the researchers are working on an alternative approach, mainly based on an application of a conditional extremes model, with the aim of using it to estimate the extremes of precipitation by bringing additional physically-based information into the model. By jointly modelling the extremes of precipitable water and precipitation efficiency—loosely, the ratio of the rain that reaches the surface compared to the amount of water available to condense into precipitation—the researchers can obtain a model for extreme precipitation that better describes the behavior of extremes and is able to reduce biases in estimates of very long-period return levels.

GWF: EXTREME DROUGHT EVENT MODELLING

Drought can have wide-ranging effects, ranging from increased wildfire risk to impacts on water quality, ecosystems, human health and agricultural yields. Globally, it can also be a source of political conflict. In British Columbia it is a recurring feature of the climate that may be exacerbated by anthropogenic climate change. Understanding the spatial behavior of extreme drought events is an important research topic within climate science. Ongoing research at PCIC, jointly supported by the Global Water Futures project and the Canadian Statistical Sciences Institute, aims to construct a spatial extreme value model for a drought index called the Standardised Precipitation-Evapotranspiration Index (SPEI). The main idea of this research is to bring the concept of conditional spatial extremes, which is an ongoing research topic in statistics, to SPEI data, to understand its underlying spatial behavior. Using the proposed method, conditional spatial extremes behavior can be expressed with a few nonlinear equation curves according to spatial distance. In Figure 19, a conventional method for doing this is compared to the new method being developed at PCIC. The proposed new method, in blue lines, provides simple spatial behaviour, using less than 15 parameters, whereas the conventional method estimates the parameters separately and, in this example, requires the estimation of 236 parameters. Because the proposed method represents each parameter as a function of spatial distance, it can be used to predict conditional SPEI values for unobserved locations at different points in space. In addition, the new method enables model downscaling and avoids overfitting problems. This research will eventually provide helpful information for those who need extreme drought information, such as farmers and crop insurance companies.

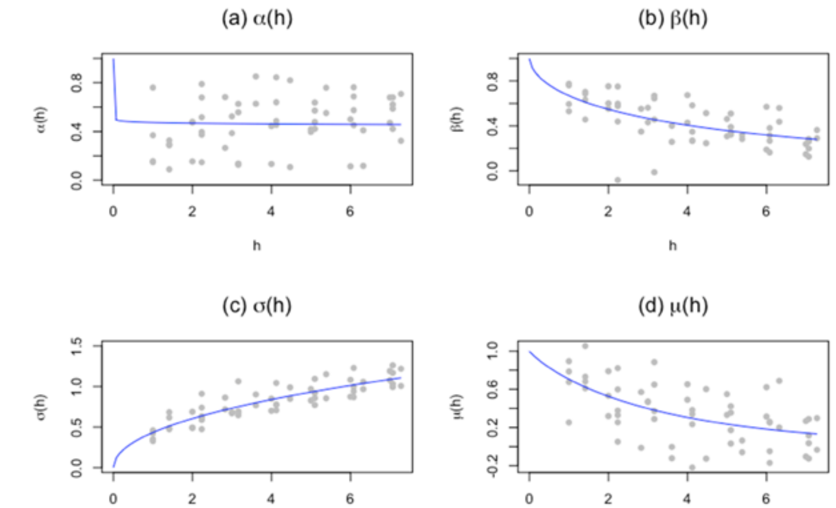


Figure 19: This figure shows a comparison between two methods of estimating spatial extreme behaviour. The symbols α (alpha), β (beta), σ (sigma) and μ (mu), in panels a, b, c and d, respectively, are parameters, functions of spatial distance, h, that are used to describe conditional spatial extreme behavior. The conventional method of estimation is shown in grey dots, and the proposed new method is shown in blue lines.

GWF: UNDERSTANDING HOW EXTREME PRECIPITATION SCALES WITH TEMPERATURE

As anthropogenic influences continue to shape the global climate, an important question to ask is how precipitation—and, in particular, extreme precipitation—will change with increasing temperatures. Quantifying how the intensities of extreme precipitation will change with warming is a key concern when assessing the impacts of climate change. While basic thermodynamic considerations show that the amount of water vapour in a parcel of air that is available to feed a precipitation event should increase by about 7% for every °C of warming, atmospheric dynamics and the availability of water also play important roles, especially at smaller spatial scales, and complicate the analysis of precipitation extremes. Recent research at PCIC, conducted under the Global Water Futures program, is examining the scaling relationship between precipitation extremes and temperature, and applying detection and attribution methods to changes in precipitation extremes.

The first step in this work was a study to improve the understanding of extreme precipitation scaling relationships—that is, how much does extreme precipitation change for every °C of warming—and clarify the relationship between shorter term intra-annual temperature scaling for sub-daily or daily precipitation extremes (called, "binning scaling") and longer term inter-annual temperature scaling (called, "trend scaling"). This work used a large ensemble simulation of the Canadian Regional Climate Model (CanRCM4). Results show that the magnitude and spatial pattern of binning and trend scaling rates are quantitatively different regardless of precipitation duration or choice of temperature variable. This suggests that binning scaling with temperature is not a reliable predictor for future changes in precipitation extremes. This is an important result, because binning scaling has been widely used. Evaluating it as a predictor is an important step in the research community's continuing search for a method to quantify how extreme precipitation will change in the warming climate.

The second step in this research at PCIC was the analysis of observed changes in extreme precipitation represented by the annual maxima of one day (Rx1day) and five-day (Rx5day) precipitation accumulations using high-quality station data up to 2018. Two different methods of analysis were used to evaluate a possible shift in the behavior of Rx1day and Rx5day at global, continental and regional scales. The results suggest that extreme precipitation has increased at about two-thirds of stations and the percentage of stations with statistically significantly increasing trends is significantly larger than what could be expected by chance alone. This is true for the world as a whole, at the scale of continents, for Asia, Europe, and North America, and at the sub-continental scale, for: Central North-America, Eastern North-America, North-Central-America, Northern Europe, the far east of Russia, Eastern Central Asia, and East Asia. The research finds that the global median sensitivity, the percent change in extreme precipitation per °C increase in global mean surface temperature, is 6.6% (5.1 to 8.2%, 5–95% confidence interval) for Rx1day and is slightly smaller at 5.7% (5.0 to 8.0%) for Rx5day.

The third step in this research is a detection and attribution analysis of extreme precipitation (Rx1day and Rx5day) changes using a different attribution method, more recent observations, and different model simulations than previous studies of the causes of the observed changes in precipitation extremes. A new framework for the detection and attribution analysis, which is based in extreme value theory, is being used. The results from this work enhance confidence that the effect of anthropogenic forcings has been detected on the intensification of extreme precipitation over the Earth's land regions as a whole, over three continents: North America, and western and eastern Eurasia, and several sub-regions, with consistent results found between different model output and different methods used.

GWF: IMPROVING HYDROLOGIC MODEL PARAMETERIZATION

Improving the ability of hydrologic models to efficiently simulate the impacts of climate change on hydrologic processes is a matter of constant refinement. Hydrologic models have sets of parameters, often a single value, representing physical processes or important features of the landscape, such as the threshold water level past which water flows near the surface, or the temperature at which snowmelt initiates. Some of these must be tuned for a given region. Improving these parameters and the calibration methods used to set these parameters for watersheds is one way of reducing the computational resources required to set up a hydrologic model over a large domain. One topic of research at PCIC is therefore to develop methods and workflows for process-based parameter estimation for large-scale hydrologic and land-surface models. A part of this involves conducting a sensitivity analysis of VIC-GL over PCIC's study domains. Generally, model sensitivity analysis is conducted on small watersheds and restricted to streamflow. The objective of this research is to extend the sensitivity analysis of VIC-GL to internal model state variables such as evaporation, snow cover, snow water equivalent and glacier mass balance, in order to identify sensitive model parameters that need to be addressed in a process-based calibration.

To conduct VIC-GL sensitivity analysis, a sequential screening method is used, in which only "informative" parameters—a subset of parameters that most impact model output—are selected for calibration. This method is computationally inexpensive. PCIC uses a process-based calibration approach for the VIC-GL model over several large-domain basins. This approach calibrates the model against evapotranspiration, snow cover and glacier mass balance (where applicable) in addition to streamflow and requires approximately 2000 model evaluations. With this approach, only common VIC calibrated parameters are estimated. Ongoing research aims at evaluating the efficiency of this approach to achieve robust and realistic model calibration by conducting synthetic tests.

MODELLING COMPOUND EXTREME EVENTS

A number of the climate extreme events that most greatly impact human societies are compound extreme events. That is, the occurrence of extremes of two (or more) climate variables in the same place at the same time. Some examples include, drought and heat extremes, coastal flooding due to extremes of both high water levels and precipitation, and extremes of both wind and precipitation during storms. Considering the impacts and risks presented by extremes in only one variable can lead to an underestimate of the impacts and risks when extremes of more than one variable occur at the same time. The flood risk on a coast during a storm surge event can be made worse if heavy rain is also occurring, and the risks to agriculture from a heat wave can be made worse if a drought is also occurring. Due to the complex interactions in the physical elements underpinning these events, it isn't enough to simply consider each variable separately to determine their compound probability, because they can be related. For example, storms can bring both heavy rain and strong winds, and droughts can reduce the ability of land to cool by evaporation and transpiration, intensifying heat waves, while heat waves exacerbate drought.

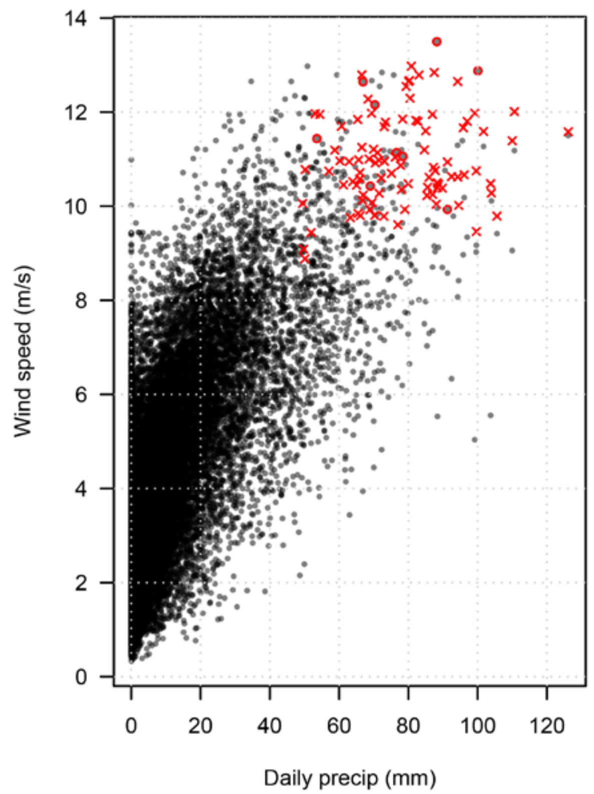


Figure 20: This figure shows simultaneous daily data for precipitation and wind speed (black dots) for 100 simulation years. Annual maxima for these simulation years are shown in red (denoted by red circles if annual maximum daily precipitation and wind speed happened simultaneously, and by red exes otherwise).

Over the 2019-2020 fiscal year, research was performed at PCIC that focussed on modelling compound extreme events, specifically, the combination of extreme wind and extreme precipitation, which frequently occur together in the Pacific Northwest during atmospheric river events. Concurrent extremes of wind and rain are of interest in part because they can have an impact on building structures. In particular, buildings must be designed such that strong winds do not drive rain water behind the surface materials of a building and this requires information about the probability of concurrent extremes of precipitation and wind speed. The researchers developed a statistical framework that estimated the distribution of wind speed when precipitation is at a seasonal maximum. The framework used combines two different statistical modelling methods and the researchers considered how these methods can be used together to estimate the distributions of compound extreme events. Figure 20 illustrates one of their findings: that wind speed extremes tend to be larger when precipitation is larger. (A related finding from the paper shows that this connection is also present when precipitation is extreme.) The researchers also tested their framework over three locations in North America using a large ensemble of regional climate model output. Their work also examines some of the strengths and weaknesses of the two estimation methods used and outlines steps for future research. This work was supported by the Canadian Statistical Sciences Institute and US National Science Foundation-funded Statistical and Applied Mathematical Sciences Institute, and will help to facilitate the future modelling of concurrent wind and precipitation extremes.

COMMUNICATIONS AND OUTREACH

SCIENCE BRIEFS AND NEWSLETTERS

PCIC uses multiple channels of communication to share information that is of use to its user base. Among these are the PCIC Science Briefs and newsletters. PCIC Science Briefs are plain-language summaries of recent research, relevant to PCIC's regional stakeholders and presented with context sufficient to understand the findings.

Figure 21: This figure shows a sampling from the newsletters and Science Briefs released over the 2019-2020 fiscal year.

Over the 2019-2020 fiscal year, PCIC released two Science Briefs, focusing on two papers in the peer-reviewed literature. In the first, the authors use daily weather station data from across Canada to compute 35 temperature and precipitation indices over the 1948-2016 period for all of Canada, and over the 1900-2016 period for locations in southern Canada. They found that the changes in the indices that they examined are consistent with warming, with greater warming seen in indices of cold temperatures and that changes in the precipitation indices they examine vary by location. In the second, the authors estimated the contributions of atmospheric circulation and thermodynamic changes to observed precipitation over Eastern North America and Northern Eurasia over 1920-2015. They found that the thermodynamic component, due to anthropogenic emissions, contributes to increases in precipitation in both regions, and that the dynamic component accounts for about 40% of the winter precipitation trend in Northern Europe and contributes a drying influence to Eastern North America.

Over the same fiscal year, the PCIC Update covered a variety of topics. These include some of the important research projects covered in this report, in addition to staff profiles, information on webinars and talks, a PCIC researcher's experience at the Northwest climate conference, stories on media coverage of PCIC's work and a list of publications put out by PCIC researchers.

VIDEO SERIES ON CLIMATE CHANGE AND BC AGRICULTURE

There is a need among PCIC's users to have educational materials and guidance on climate science, adaptation concepts the use of climate projections. To address this need, in the spring of 2019, members of PCIC's Regional Climate Impacts theme participated in the BC Agriculture and Climate Change Education Series hosted by the BC Agricultural Climate Adaptation Research Network (ACARN). The series produced a set of video modules that address key climate change issues for the agriculture sector in BC. The videos guide users through the use of climate projections and introduce adaptation concepts, using case studies as concrete examples. They discuss recent work that has been done and also provide guidance on moving organizations along the path of adaptation. The videos discuss collaborative research for agricultural producer adaptation and bring together industry and university-based researchers to address the challenges that BC's agriculture sector faces. Each module has a presentation from a leading expert in the given field, followed by a question period.

THE PACIFIC CLIMATE SEMINAR SERIES

PCIC hosts the Pacific Climate Seminar Series, which is an opportunity for local and visiting researchers to share their findings and connect with PCIC's users, members of the research community on the UVic campus and the general public. This series leverages the large research network that PCIC is a part of, to bring together researchers and the community, to network and better understand the current research landscape. The Pacific Climate Seminar Series was suspended in February 2020, near the end of the fiscal year, due to the COVID-19 pandemic.

Figure 22: This figure shows Dr. William Hsieh delivering his talk as part of the Pacific Climate Seminar Series on April 10th, 2019.

Over fiscal year 2019-2020, the Pacific Climate Seminar Series hosted the following talks:

Applying Machine Learning Methods to the Environmental Sciences—Opportunities and Pitfalls
Dr. William Hsieh, April 10th, 2019.

Rethinking the Water Cycle in the Anthropocene
Dr. Tara Troy, September 26th, 2019.

Recognizing Interdependence: How Urban Collaborations Enhance Adaptation
Dr. Hannah Teicher, October 23rd, 2019.

Climate Change and Building Science
Robert Lepage, November 20th, 2019.

The Dragons of Inaction – and How to Slay Them
Dr. Robert Gifford, February 26th, 2020.

OPERATIONS AND FINANCE

OPERATIONS AND FINANCE

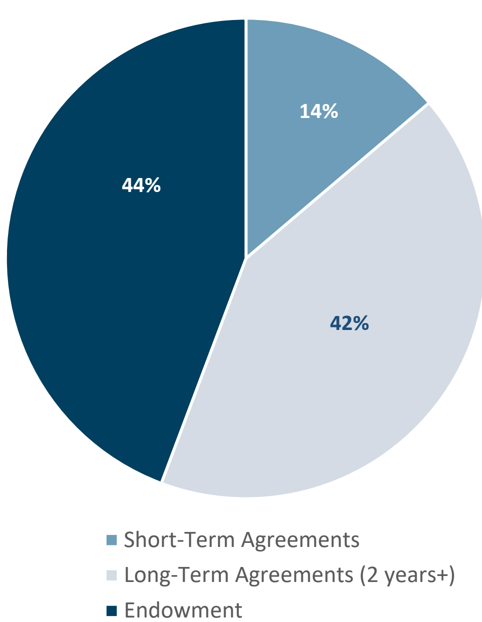
In fiscal year 2019-2020, PCIC continued to enjoy a stable funding and operational environment in support of its programs and service delivery. PCIC managed 30 active agreements related to user-commissioned projects, research grant programs and other projects. Twelve new agreements were signed, including the fourth, 4-year renewal of our research agreement with BC Hydro and a 5-year contribution agreement with Fisheries and Ocean Canada. In addition, UVic renewed its commitment to PCIC for another 5-year funding cycle through an endowment placed at the University of Victoria by the Government of British Columbia in 2008.

Direct leveraging of endowment resources well exceeded the value of the endowment itself and was at its highest yet during the 2019-2020 fiscal year, allowing a total budget that was more than double the amount received from the endowment, with users and stakeholders providing approximately 58% of PCIC's budget. Indirect leveraging in the form of the time and effort of PCIC's partners and external research funding, continued to increase total leveraging of the endowment, resulting in a level of activity and productivity that, conservatively, more than triples the value of the endowment.

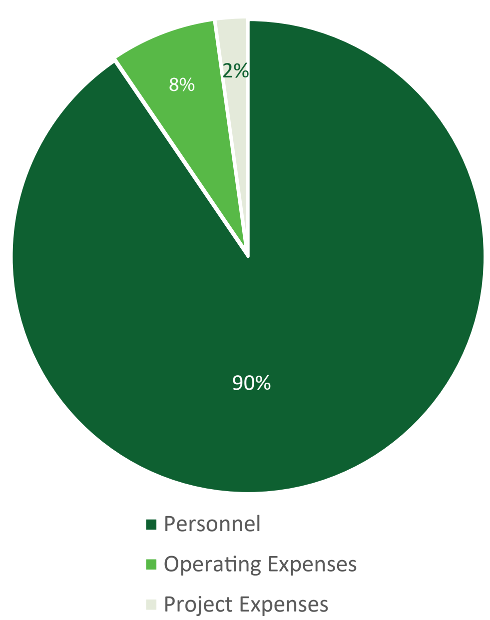
With its most important resource always being its staff, 90% of PCIC's expenditures supported the salaries of its 26 staff members. Operational expenses comprised 8 percent of the budget, including investment in computing resources, and 2% of the budget supported external partnerships. As a not-for-profit corporation, PCIC carefully plans and budgets its expenditures to ensure maximum value from the funding it receives.

At the end of the fiscal year, in response to the global pandemic, PCIC staff transitioned to a remote working environment. Despite the additional challenges associated with the transition, staff adapted quickly and have continued to work productively with our partners, thereby maintaining a stable operational environment. Meeting this challenge could not have been achieved without the dedication, hard work and excellent teamwork of our very talented staff, UVic's excellent supporting infrastructure and the ongoing commitment of our partners, for which we express our sincere appreciation.

2019-2020 REVENUE



2019-2020 EXPENSES



PUBLICATIONS

PCIC PUBLICATIONS

The BC Agriculture & Food Climate Action Initiative, 2019: *Bulkley-Nechako & Fraser-Fort George Adaptation Strategies*. BC Agriculture & Food Climate Action Initiative, 64 pp.

The BC Agriculture & Food Climate Action Initiative, 2019: *Kootenay & Boundary Adaptation Strategies*. BC Agriculture & Food Climate Action Initiative, 64 pp.

The BC Agriculture & Food Climate Action Initiative, 2020: *Vancouver Island Adaptation Strategies*. BC Agriculture & Food Climate Action Initiative, 64 pp.

BC Housing, BC Hydro, the City of Vancouver, the City of New Westminster and the Province of BC, 2019: *BC Energy Step Code Design Guide Supplement 3 on Overheating and Air Quality*. BC Housing, 40 pp.

BC Ministry of Environment and Climate Change Strategy, 2019: N*anaimo Regional General Hospital: Assessing Climate Risks and Opportunities*. BC Ministry of Environment and Climate Change Strategy, 4 pp.

The Fraser Basin Council, 2019: *Climate Projections for the BC Northeast Region*. The Fraser Basin Council, 48 pp.

Interior Health, 2020 : *Advancing our Knowledge: Climate Change Impacts*. Interior Health, 74 pp.

Lower Mainland Facilities Management, Pinna Sustainability and The Pacific Climate Impacts Consortium, 2019: *Moving Towards Climate Resilient Health Facilities for Vancouver Coastal Health*. Lower Mainland Facilities Management, 113 pp.

The Pacific Climate Impacts Consortium, 2020: *PCIC Corporate Report: Retrospective 2014-2019*. The Pacific Climate Impacts Consortium, 63 pp.

The Pacific Climate Impacts Consortium, 2020: *PCIC Science Brief: The Human influence on North American and Eurasian Precipitation*. The Pacific Climate Impacts Consortium, 5 pp.

The Pacific Climate Impacts Consortium, 2019: PCIC *Science Brief: Update on Daily Temperature and Precipitation Changes in Canada*. The Pacific Climate Impacts Consortium, 8 pp.

The Pacific Climate Impacts Consortium, 2020: *PCIC Update: February 2020*. The Pacific Climate Impacts Consortium, 1 pp.

The Pacific Climate Impacts Consortium, 2019: *PCIC Update: June 2019*. 1 pp.

The Pacific Climate Impacts Consortium, 2019: *PCIC Update: October 2019*. 1 pp.

PEER-REVIEWED PUBLICATIONS

Alam, M.S., L. Barbour and M. Huang, 2020: Characterizing uncertainty in the hydraulic parameters of oil sands mine reclamation covers and its influence on water balance predictions. *Hydrology and Earth System Science*, **24**, 735–759, doi:10.5194/hess-24-735-2020

Ben Alaya, M.A., C. Ternynck, S. Dabo-Niang, F. Chebana and T.B.M.J. Ouarda, 2020: Change point detection of flood events using a functional data framework. *Advances in Water Resources*, **137**, 103522, doi:10.1016/j.advwatres.2020.103522.

Ben Alaya, M.A.., **F. Zwiers**, and X. Zhang, 2019: Evaluation and comparison of CanRCM4 and CRCM5 to estimate probable maximum precipitation over North America. *Journal of Hydrometeorology*, **20**, 10, 2069–2089, doi:10.1175/JHM-D-18-0233.1.

Ben Alaya, M.A., **F.W. Zwiers** and X. Zhang, 2019: Probable maximum precipitation in a warming climate over North America in CanRCM4 and CRCM5. *Climatic Change*, **158**, 611–629, doi:10.1007/s10584-019-02591-7.

Chhetri, B.K, Galanis, E., **Sobie, S.**, Brubacher, J., Balshaw, R., Otterstatter, M., Mak, S., Lem, M., Lysyshyn, M., **Murdock, T.**, Fleury, M., Zickfeld, K., Zubel, M., Clarkson, L. and T.K. Takaro, 2019: Projected local rain events due to climate change and the impacts on waterborne diseases in Vancouver, British Columbia, Canada. *Environmental Health*, **18**, 116, doi:10.1186/s12940-019-0550-y.

Li, C., **F. Zwiers**, X. Zhang, G. Chen, J. Lu, G. Li, J. Norris, Y. Tan, Y. Sun and M. Liu, 2019: Larger increases in more extreme local precipitation events as climate warms. Geophysical Research Letters, 46, 12, 6885-6891, doi:10.1029/2019GL082908.

Meshesha, T.W., J. Wang and **N. Demelash Melaku**, 2020: A modified hydrological model for assessing effect of pH on fate and transport of Escherichia coli in the Athabasca River basin. *Journal of Hydrology*, **582**, 124513, doi: 10.1016/j.jhydrol.2019.124513.

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.

Shrestha, R.R., A.J. Cannon, **M. Schnorbus** and H. Alford, 2019: Climatic Controls on Future Hydrologic Changes in a Subarctic River Basin in Canada. *Journal of Hydrometeorology*, **20**, 9, 1757-1778, doi:10.1175/JHM-D-18-0262.1.

Sillmann, J. et al., including **F.W. Zwiers**, 2019: Extreme wet and dry conditions affected differently by greenhouse gases and aerosols. *npj Climate and Atmospheric Science,* **2**, 24, doi: 10.1038/s41612-019-0079-3.

Sun, Q., C. Miao, M. Hanel, A.G.L. Borthwick, Q. Duan, D. Jid and H. Li, 2019: Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environment International*, **128**, 125-136, doi:10.1016/j.envint.2019.04.025.

Tan, Q., **F.W. Zwiers**, S. Yang, **C. Li** and K. Deng, 2020: The role of circulation and its changes in present and future atmospheric rivers over western North America. *Journal of Climate*, **33**, 4, 1261-1281, doi:10.1175/JCLI-D-19-0134.1.

Williamson, S.N., C. Zdanowicz, **F.S. Anslow**, G.K.C. Clarke, L. Copland, R.K. Danby, G.E. Flowers, G. Holdsworth, A.H. Jarosch, and D.S. Hik, 2020: Evidence for Elevation-Dependent Warming in the St. Elias Mountains, Yukon, Canada. *Journal of Climate*, **33**, 8, 3253–3269, doi:10.1175/JCLI-D-19-0405.1.

University House 1, 2489 Sinclair Road,
University of Victoria, Victoria, British Columbia, Canada
Telephone: (250) 721-6236
FAX: (250) 721-7217
PacificClimate.org