CORPORATE REPORT: **2023-2024**

PACIFIC CLIMATE IMPACTS CONSORTIUM

Land Acknowledgment

PCIC is situated on the unceded territories of the W̱SÁNEĆ Peoples and of the ləkʷ̓əŋən Peoples of the Esquimalt and Songhees Nations. The First Nations of these unceded territories have long been stewards of this land, and their relationships to the land continue to this day. PCIC serves all people of colonially-named British Columbia and is committed to working with the Indigenous Peoples of this region to understand how the climate is changing, the impacts of those changes, and how to suitably adapt.

CONTENTS: PCIC ANNUAL REPORT 2023-2024

Message from Leadership

Since last fall, it has been my great pleasure to join, lead and collaborate with PCIC's talented team as we uphold a tradition of research excellence and address the growing demand for the targeted climate services PCIC offers. The foundation of PCIC's success and its remarkable growth into a leading applied climate service centre, established under the capable leadership of Francis Zwiers, has made my transition as smooth as I could have hoped. His continued contributions as Scientist Emeritus are invaluable.

Day by day, PCIC continues to deepen its expertise and broaden its impact in key areas— curation and analysis of observational data, statistical downscaling of climate models, hydrological modeling, and the study of climate extremes—always with a focus on transforming research into practical tools and resources for practitioners. We also recognize the importance of growing in areas that will better serve our users, such as enhancing communications and engagement with a diverse range of organizations and communities, and collaborating more closely with users to co-design climate information and tools.

Looking ahead, I am excited to lead the effort in clearly articulating our vision for the future of regional climate services as we develop our new 5-year strategic plan. This will involve consulting with our enthusiastic and skilled team, engaging with our broad network of users—many of whom have been with us since PCIC's inception—and identifying areas where our current capacity can be expanded to meet both immediate and long-term goals.

As this annual update demonstrates, PCIC's staff, leadership, and advisors continue to make significant strides in understanding the changing climate of our region and the country, while maintaining a strong, ongoing dialogue with our users and partners. I am delighted to share these announcements and highlight the work showcased in this report, which reflects how PCIC continues to grow in its research outputs and tools and data it provides, supporting our users as they confront the challenges of climate change.

-Xuebin Zhang

PCIC STAFF AND AFFILIATES

PCIC Staff and Affiliates

Mohamed Ali Ben Alaya, Charles Curry, Abigaïl Dah, Rod Glover, James Hiebert, Isabelle Lao, Tong Li, Shelley Ma, Trevor Murdock (on secondment), Nina Nichols, Stacey O'Sullivan, Dhouha Ouali, Narges Sayah, Markus Schnorbus, Arelia (Werner) Schoeneberg, Michael Shumlich, Stephen Sobie, Kari Tyler, Pei-Ling Wang, Xuebin Zhang and Francis Zwiers.

Not pictured: Izzy Farmer, Tom Kunkel, Kristyn Lang, Samah Larabi, Teresa Rush, John Sampson, Quintin Sparks, Ameneh Mollasharifi Targhi, Kathy Veldhoen, Jingwen Wu, Eric Yvorchuk and Lee Zeman.

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Xuebin Zhang, Director, President & CEO, Pacific Climate Impacts Consortium, University of Victoria

Francis Zwiers, Outgoing Director, Pacific Climate Impacts Consortium

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

Stephanie Tam, Water Management Engineer, Resource Management Unit, British Columbia Ministry of Agriculture and Food

Xuebin Zhang, Director, President & CEO, Pacific Climate Impacts Consortium, University of Victoria

REGIONAL CLIMATE SERVICES

Providing Regional Climate Assessments

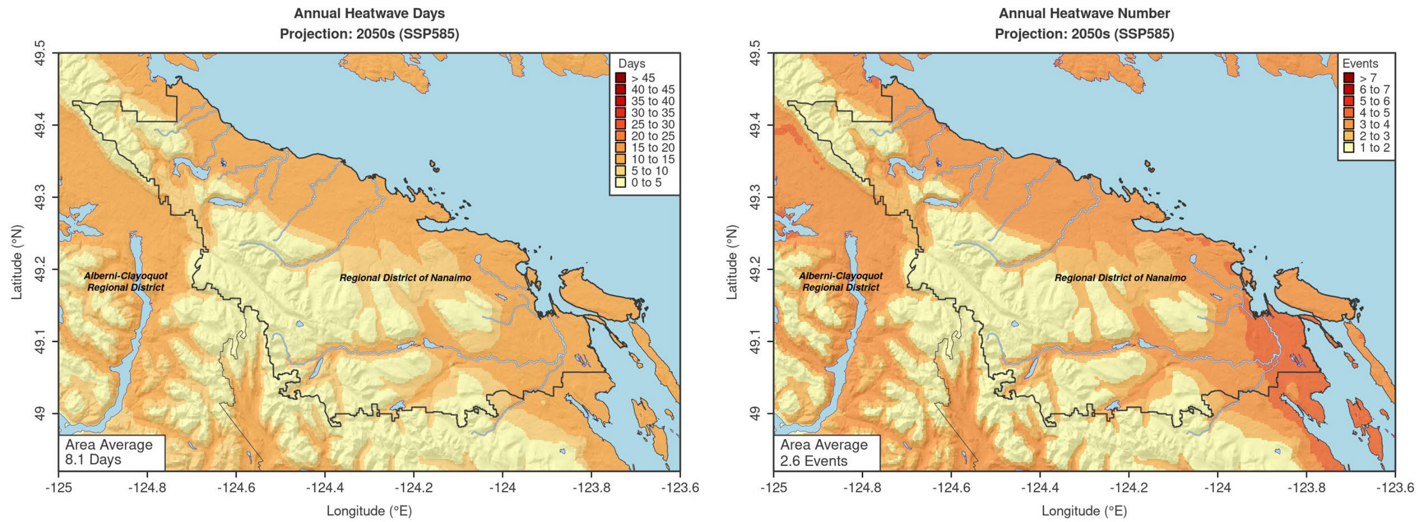


Figure 1 : This figure shows the projected annual count of heatwave days (left) and number of annual heatwaves (right) in the 2050s for the Regional District of Nanaimo. Note that: (i) for both measures, counts in the Past are very low (about 1 per year) and uniform throughout the region; and (ii) average values for low-elevation areas are larger than the regional averages shown on the maps.

Partners: **Regional District of Nanaimo, City of Vancouver and Capital Regional District**

This year PCIC conducted climate assessments for the City of Vancouver, the Regional District of Nanaimo and the Capital Regional District. These assessments provided a wealth of relevant climate information to support ongoing planning efforts in each region. The City of Vancouver's Highlights report presented key results in a concise manner, tailored to their ongoing climate adaptation planning process. The other two reports were more comprehensive, featuring themed chapters that detailed changes in multiple climate change indicators. Each of these reports concluded with a chapter co-produced with the respective partner, focusing on identifying potential future climate impacts by sector.

New to these assessments, compared to those PCIC previously produced, was additional material designed to help contextualise and interpret the findings and guidance on the use of the data and its limitations. Each partner received a comprehensive data package containing information on dozens of climate variables and indices derived from downscaled, high-resolution scenarios. The reports were co-designed through extensive engagement with each partner, ensuring that the reports were tailored to their specific needs.

Climate projections for these locations exhibit strong similarities, with all regions facing warming during every season, a reduction in summer precipitation, and an increase in precipitation during cooler seasons. The projected warmer summer temperatures will bring a longer growing season, hotter summer days and warmer nights, and more heatwaves (Figure 1). Fewer frosty days and less extreme cold temperatures will occur in winter.

Projections also suggest that precipitation will increase in fall, winter and spring, with a higher proportion falling as rain instead of snow. Notably, the amount of rain falling in extreme events, such as over one day or consecutive days, is projected to increase more than average rainfall. Recognizing that effective adaptation planning requires more than just broad, large-scale changes, the results were broken down into tables and maps to show the projected changes in geographic detail.

During the creation of these reports, PCIC consulted with local government staff for input on report content and held workshops to better understand how climate change is already impacting their operations. PCIC also led training workshops for both regional districts, providing practical, worked examples tailored to the local government context. Additionally, PCIC researchers presented to a technical committee on the use of the projections for water management in one of the districts, highlighting how these reports could inform future infrastructure planning in these municipalities.

Expanding Engagement with Indigenous Communities

Partner: **Climate Action Secretariat, British Columbia Ministry of Environment & Climate Change Strategy**

PCIC is committed to working with and learning from BC's Indigenous communities, to co-develop climate information products suited to their needs. Addressing climate change is inextricably linked to addressing colonial impacts and to reconciliation with Indigenous peoples and PCIC is dedicated to providing its services in this effort.

Since 2022, under a shared contribution agreement with the British Columbia Ministry of Environment and Climate Change Strategy, PCIC has been able to build capacity to deliver services to Indigenous audiences and enhance and expand its services to meet growing demand. With this support, PCIC has been able to resource a staff position to provide climate services for Indigenous communities and the organizations that work with them, and facilitate the two-way exchange of climate insights.

This year, we continued to build and enhance our capacity by making new introductions with Indigenous communities and providing climate information and support. We attended and contributed to workshops, meetings and forums with Indigenous participants, many by invitation. Through this work we build our internal capacity to weave together Indigenous knowledge and perspectives with climate science knowledge and expertise so that we can better support climate adaptation in Indigenous communities in BC.

Assessing Climate-related Risk in BC

Partner: **British Columbia Ministry of Emergency Management and Climate Readiness**

To help the BC Government identify and address climate-related hazards, PCIC is working with EMCR and other knowledge partners in the BC Risk Assessment process. This assessment, mandated every five years, had its last report (to which PCIC contributed) released in 2019. PCIC researchers are now contributing to the development of the next report, due in 2025. Their involvement includes chairing an advisory committee focused on the influence of climate change on key hazards and, in some cases, conducting new research using PCIC's datasets and analysis to fill information gaps for the assessment of climate risks.

For example, PCIC provided an analysis of the changing frequency of three-day heatwave events—similar to those used for the BC Heat Alert and Response System—based on statistically downscaled CMIP6 projections. The PCIC-led committee also produced a comprehensive written overview of climate-related hazards in BC, detailing how climate change is expected to affect the magnitude and frequency of these hazards in the coming decades. This information is being integrated into the overall provincial risk assessment. Further details on past and future changes in hazards and their potential impacts will be made available upon the release of the EMCR report.

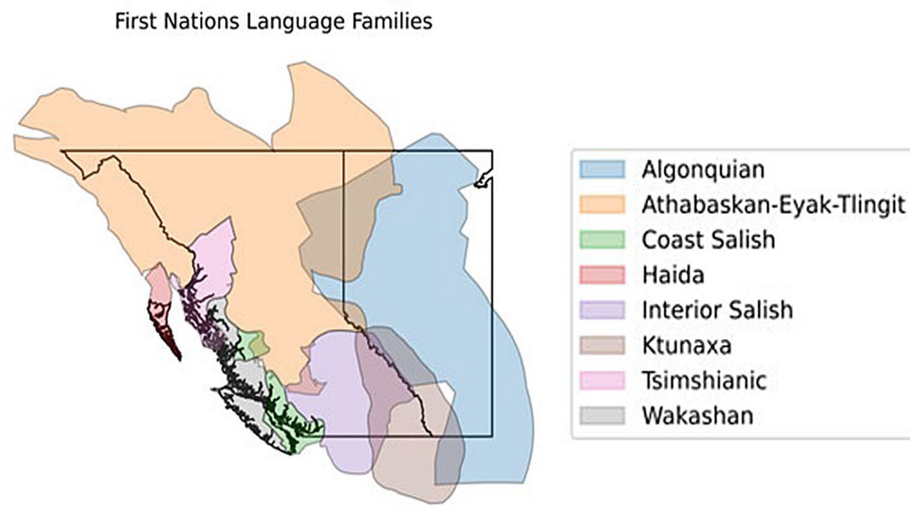


Figure 2 : This figure is a representation of the First Nation language regions that were integrated into the Plan2Adapt tool. A more detailed, sub-regional breakdown has also been integrated into the tool.

As part of this work, PCIC is examining how and where it can incorporate features into its tools to better support climate risk assessment in Indigenous communities. A recent example is the addition of First Nations Language Territories to the regional specification tab of our Plan2Adapt tool. This feature (Figure 2) allows planners in these communities to view climate information in a way that is directly relevant to their regions. This work is consistent with the Province's stated intent to recognize and implement Indigenous jurisdiction as part of BC's decision-making process.

Enhancing Climate Services in British Columbia and Beyond

Partner: **Canadian Centre for Climate Services, Environment and Climate Change Canada / Centre canadien des services climatiques, Environnement et Changement climatique Canada**

As partners with the Canadian Centre for Climate Services (CCCS), PCIC and other regional climate service providers work together to enhance the coordination of climate services delivery across Canada. This past year, PCIC's team continued to conduct training and engagement with diverse user groups, including building design professionals, local governments, First Nations communities, emergency management professionals, and more. PCIC also continued to support the development of training materials and sector-specific modules on ClimateData.ca. Together, we are committed to delivering regional climate services tailored to user needs.

This year, PCIC participated in five bodies convened by CCCS, four as a continuation of last year's work and one new working group. PCIC continued to offer its knowledge and experience to aid in the ongoing development of ClimateData.ca, participating in the Project Management Committee (which ensures coordination between the participants in the collaboration), the Product and Data Working Group (which reviews changes to existing online components and provides guidance on new products in development), the Technical Architecture Working Group (which covers aspects such as software and web design), and the Regional Coordinating Committee (which coordinates Canada's regional climate service providers). This year PCIC was pleased to join the Communications Working Group, a new community of practice that is dedicated to supporting communications and outreach work for climate service providers across Canada. Finally, we also participated in the Training Sub-Group, which shares best practices and coordinates the development of training materials, and the Support Desk Working Group, which advises the CCCS on its responses to user queries.

Supporting and Enhancing ClimateData.ca

Partner: **Computer Research Institute of Montréal / Le Centre de Recherche Informatique de Montréal**

PCIC is dedicated to helping Canadians incorporate climate change considerations into their decision-making and is a proud partner in the ongoing development of the ClimateData.ca online platform, which provides open and free access to expert-reviewed climate information. PCIC shares its scientific expertise via the provision of high-quality data products and by reviewing and developing other platform content. This year, PCIC scientists generated an additional ensemble of CMIP6-downscaled GCM simulations for implementation on ClimateData.ca. This new ensemble is driven by greenhouse gas and aerosol emissions under the Shared Socioeconomic Pathway 3-7.0 scenario, complementing the SSP2-4.5 and SSP5-8.5 scenarios previously downscaled at PCIC.

Over the past year, PCIC also provided advice and detailed reviews of several data products now available on ClimateData.ca. These include Building Climate Zones, Humidex variables, and the Fire Weather Projections app (developed by CCCS) and the Climate Analogues panel app (developed by Ouranos). A new version of ClimateData.ca (v2.0) has been in development over the past year and PCIC has provided guidance and advice on many improvements, including map design, user customization options, and additional data download and analysis options. In collaboration with CCCS, PCIC helped distill information from our Design Value Explorer tool into a series of "one-pagers" aimed at infrastructure engineers and planners. These documents, available for download via a map interface on ClimateData.ca, combine location-specific climatic data from the National Building Code of Canada with PCIC's projected future design values in a simple, easy-to-read format.

Finally, as part of ClimateData.ca's Content and Engagement Working Group, PCIC's team supported engagement efforts for a new Marine Sector module, which aims to inform coastal adaptation across Canada, and contributed to the development of training materials for existing sector modules.

NEW METHODOLOGIES AND CLIMATE KNOWLEDGE INTEGRATION

Refining PCIC's Downscaling Methods

Partner: **Environment and Climate Change Canada / Environnement et Changement climatique Canada**

Many climatic phenomena of practical interest are influenced by the simultaneous behaviour of more than one climate variable. For example, both drought and wildfire tend to result from the combination of exceedingly dry and hot conditions in a given region over an extended time. Another example is that rainy days tend to be associated with colder temperatures in coastal regions. While this interdependence is embedded in climate model simulations, it may not be preserved when model variables are downscaled separately, leading to a sub-optimal description of compound events.

To address this issue, PCIC scientists have been evaluating a multivariate downscaling method that preserves the dependence structure between different variables, known as the N-Dimensional Multivariate Bias Correction (MBCn) approach. In this project, we investigated the performance of MBCn for a larger set of variables than the three we typically downscale— i.e. daily maximum temperature, daily minimum temperature, and daily precipitation amount—over British Columbia's Fraser River Basin. The additional variables—relative humidity, shortwave and longwave radiation, and wind speed and direction—are important not only for the study of compound events, but also for applications

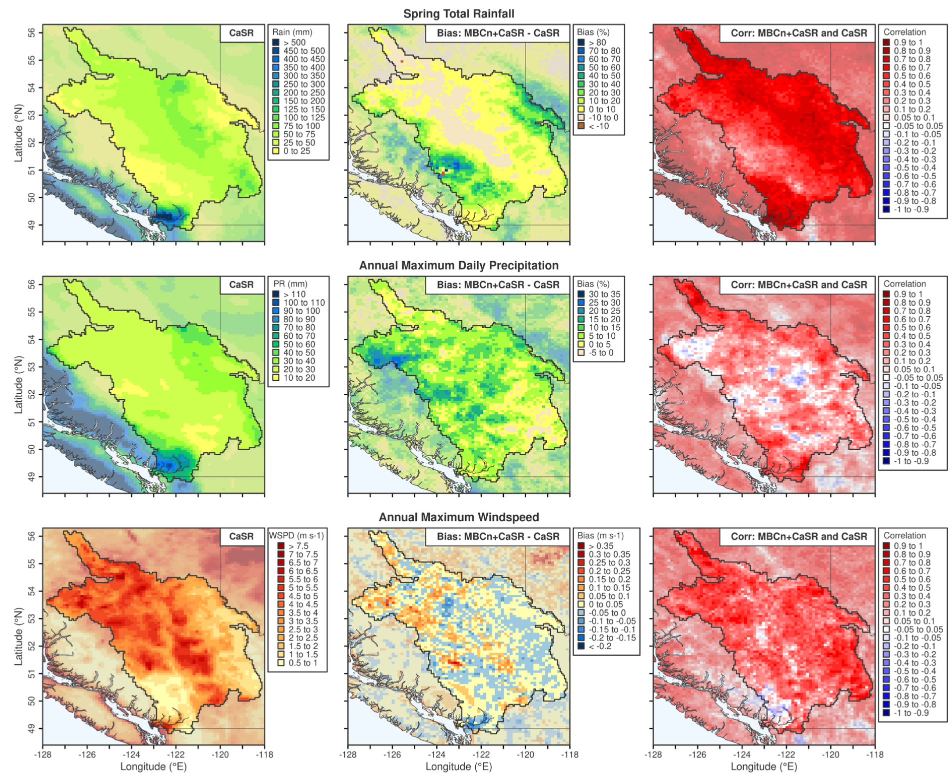


Figure 3: Comparisons of the CaSR target data (leftmost column) with variables downscaled using the MBCn method, over the Fraser River Basin (black-outlined area). The middle column shows differences between the MBCn-downscaled data and CaSR, while the right-hand column shows the temporal correlation between the two over the 1980-2018 period. Top row: Spring total rainfall; middle row: annual maximum daily precipitation; bottom row: annual maximum wind speed.

such as hydrologic modelling. The daily evolution of minimum and maximum temperatures affects a watershed's snowmelt dynamics which, along with the timing and amount of precipitation, governs river flows and the potential for flooding or hydrologic drought. Net radiation balances and wind speed, in turn, influence surface temperature, evaporation, transpiration, and soil moisture levels.

PCIC's team assessed the ability of MBCn to represent the set of nine climate variables by applying the method to coarse-resolution (~250 km) simulations from the Canadian Earth System Model Version 5 (CanESM5). For the downscaling target, they used high-resolution (~10 km) daily climate information from the Canadian Surface Reanalysis Version 2.1 (CaSR). The CaSR dataset is a reconstruction of historical climate using observations fed into a global weather forecast model run in a hindcast mode. In the first phase of this work where CaSR was averaged to coarser resolution to mimic GCM input, PCIC's team found that MBCn produced daily, monthly, and annual mean outputs that agreed well with the CaSR target data, while largely preserving the correlations between most variables (Figure 3). Some limitations were noted for certain variables in mountainous regions and in representing annual extremes, which will help to refine the method in future. By comparing these results to those found using a univariate method, the team also demonstrated that MBCn better preserved the dependencies amongst multiple climate variables. The MBCn-downscaled CanESM5 simulations will be used for hydrologic modelling in a future project.

This work also allowed PCIC scientists to refine the calculation of several multivariate indices of interest for applications, such as Humidex, Fire Weather Index, and potential evapotranspiration. Overall, these results are promising for the application of MBCn-downscaled GCM outputs in hydrologic modelling over the Fraser River Basin and similar watersheds.

Developing a Canada-wide Rainfall Intensity, Duration and Frequency Data Product

Partner: **Environment and Climate Change Canada / Environnement et Changement climatique Canada**

Intensity-duration-frequency (IDF) information for extreme rainfall events occurring over the relatively short durations of a day or less is a critical and much-used resource for infrastructure planners and civil engineers, allowing them to design structures to accommodate extreme "1-in-N-year" events, for example. These are events of

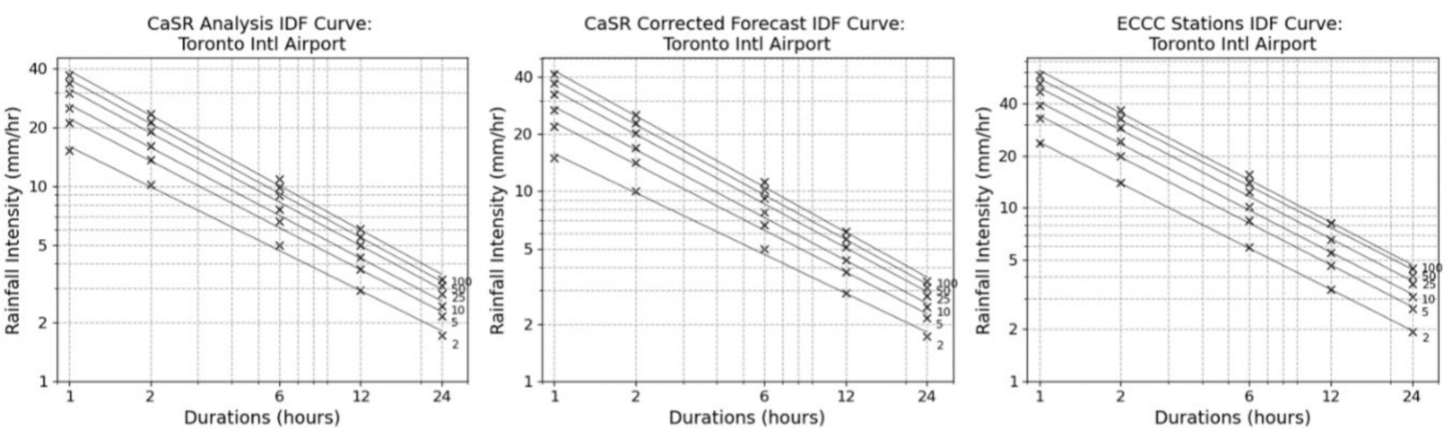


Figure 4 : Rainfall IDF curves at Toronto's Pearson International Airport produced using CaSR-Analysis (left), the bias-corrected CaSR-Forecast (center), and ECCC's IDF station data (right). Each line describes the relationship between rainfall intensity and accumulation interval (1 to 24 hours) for a given return period between 2 and 100 years. The analysis was performed over the CaSR period (1980-2018).

a rarity such that they only occur, on average, once in every N years. Environment and Climate Change Canada maintains a historical database of annual extreme rainfall amounts recorded at a range of sub-daily intervals at over 600 stations in Canada. However, while the database includes most Canadian towns and cities, it does not cover the vast majority of the country. The recent development of another ECCC product, the Canadian Surface Reanalysis Version 2.1 (CaSR), which covers all of Canada at a resolution of 10 km x 10 km, provides an opportunity to bridge this data gap. In this project, PCIC researchers conducted a comprehensive analysis of the two hourly gridded precipitation variables contained in CaSR: one a precipitation forecast (CaSR-F), and the other a version of the forecast corrected against an independent, station-based gridded product (CaSR-A). The goal of the project was to assess the suitability of these data for deriving spatially complete IDF information across the entire CaSR grid. The evaluation of CaSR-F was of particular interest, since this variable is closely related to the precipitation forecasts produced by ECCC's operational weather forecast system. For forecasts of heavy rainfall, this makes it possible to express the prediction as a 1-in-N-year event even if the forecast amount is biased.

After first converting the precipitation variables to rainfall by using CaSR's surface air temperatures, the research team compared the inferred annual maximum rainfall from CaSR-A with both the ECCC IDF dataset and another station-based daily rainfall product at nearly 450 locations across Canada. By and large, the team found that the CaSR-A extreme rainfall amounts agreed well with the station-based values, except at the shortest 1- and 2-hour durations, where CaSR-A often underestimated the rainfall amounts. This was, in fact, an expected outcome attributable to the difference in spatial scale between the 10 km reanalysis and point-scale station observations. A similar evaluation of the CaSR-F derived rainfall revealed much larger rainfall extremes than in CaSR-A product over all durations, and nationwide except along the BC coast. This indicated that, particularly for the purpose of issuing warnings of extreme rainfall amounts, the forecast rainfall requires some form of bias correction.

PCIC's team devised a bias correction scheme to bring the CaSR-F annual rainfall extremes into close agreement with the CaSR-A amounts (Figure 4). They then performed an IDF analysis on these corrected CaSR-F data to enable the efficient—potentially "real-time"—calculation of a return period for any forecasted heavy rainfall event. The implications of this are two-fold: first, IDF curves can be produced anywhere in Canada on the CaSR grid, at a 10 km x 10 km resolution, which is especially useful since station-based IDF data are only available at a small number of locations in Canada; and second, extreme rainfall warnings can be expressed in terms of a 1-in-N year event, and with a bias-corrected forecast amount, to inform emergency management.

Contributing to the 2025 Canada's Changing Climate Report

Partner: **Environment and Climate Change Canada / Environnement et Changement climatique Canada**

As one of Canada's leading regional climate service providers, PCIC is contributing its expertise to the upcoming national climate assessment report, *Canada's Changing Climate Report 2025* (CCCR 2025). This assessment will provide a comprehensive update on how and why Canada's climate is changing, and how it is projected to change in the future.

PCIC scientists have contributed to the assessment both in terms of report development and by performing targeted research and analysis to fill various gaps. PCIC staff serve as coordinating lead author, lead authors, contributing authors and reviewers on several chapters. PCIC Director, Dr. Xuebin Zhang, is also a member of the advisory panel for the report, bringing decades of climate research experience and continuity from his involvement in the previous CCCR report issued in 2019.

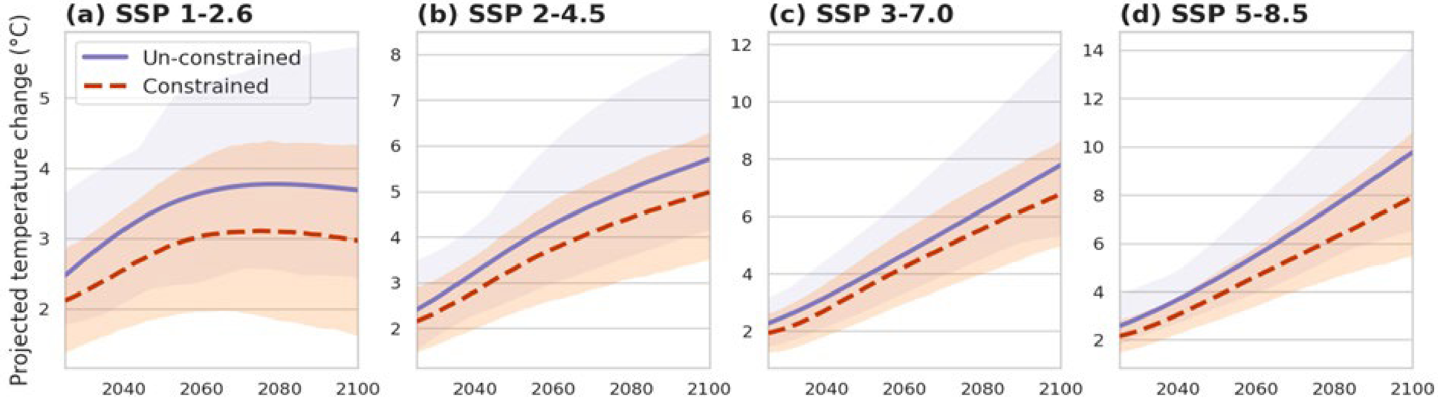


Figure 5 : An example of PCIC's data analysis performed for Canada's Changing Climate Report. The figure shows projected warming from 2023-2100 relative to preindustrial over Canada under the four illustrative SSP scenarios. Solid lines show the best estimates of projected future warming from climate models and dashed lines show the corresponding constrained projections. Light purple shades show the 5th-95th percentile uncertainty range in climate model projections while orange shades show the corresponding uncertainty range for observation-constrained projections.

Targeted research conducted at PCIC to support the assessment includes an analysis of snowfall extremes in our statistically downscaled CMIP6 simulations as well as the generation of future climate projections with reduced uncertainty. One way of doing the latter is to present climate projections at fixed levels of global warming. Since the timing of those warming levels differs across climate models and is thus uncertain, this approach is more relevant to mitigation questions, such as estimating impacts according to climate policy targets. For adaptation planning, which is typically tied to future timelines, PCIC has used a different technique. In this method, a statistical relationship between an observable metric, such as the global warming trend, and the warming projected by an ensemble of climate models is combined with observations to constrain projections of future behaviour. Our approach results in a 40% reduction in the uncertainty of temperatures projections for Canada by the end of the 21st century under a high-emissions scenario (Figure 5). These results are important for effectively communicating anticipated changes in Canada's climate over the coming decades.

HYDROLOGIC MODELLING

BC Hydro's Continuing Support of Hydrologic Modelling across BC

Partner: **BC Hydro**

PCIC's longstanding partnership with BC Hydro, established at PCIC's inception, has been highly productive, generating significant research on the climate and hydrology of the province. This includes hydrologic modelling at various scales across the province and hydrologic projections for all watersheds managed by BC Hydro. PCIC remains committed to supporting BC Hydro by providing results from existing climate science and continuing to develop insights that address BC Hydro's needs as they work to deliver power to 95% of the province. The partnership is now enabling updated hydrologic modelling for British Columbia, incorporating the latest climate model projections from CMIP6 and a new modular hydrologic modelling framework. This collaboration also strengthens PCIC's core expertise in hydrologic modelling, allowing the organization to extend projections to various communities and serving as the foundation of PCIC's hydrologic modelling capabilities.

For the updated modelling, PCIC researchers used the Variable Infiltration Capacity hydrologic model with glaciers (VIC-GL) to generate CMIP6-based hydrologic projections for the Peace River basin above Peace River, Alberta. This work leveraged the multivariate, statistically-downscaled projections discussed earlier in this report (*Refining PCIC's Downscaling Methods* p. 8).

With BC Hydro's support, PCIC's hydrology team is transitioning from VIC-GL to the more versatile Raven hydrologic modelling platform. Raven's modular design is expected to shorten the cycle of model development, deployment and projections, allowing PCIC researchers to focus more on data delivery, analysis, and interpretation. Given the long-term goal to apply Raven for projections across BC and Yukon, the team has begun by modelling small coastal sites that BC Hydro has identified as high priority. Throughout this process, PCIC researchers have implemented several key model upgrades (including soil infiltration and runoff, canopy evaporation, soil percolation, and vegetation transpiration processes), explored options to optimize model deployment, evaluated various physics components, and improved techniques for including glacier dynamics in simulations. This work has been important not only in addressing BC Hydro's specific adaptation needs, but also in rapidly building PCIC expertise with the Raven framework, benefitting a wide range of stakeholders.

Finally, PCIC continues to support BC Hydro's use of climate projections. This year, PCIC provided methodological advice and review for drought analysis work, advice on the use of climate scenarios and model ensemble selection, delivered climate change briefings to BC Hydro's executive team, and collaborated on a proposal to address key uncertainties about the effects of hydropower facilities on fish habitat and fish populations.

Expanded Streamflow Analysis for BC River Basins

Partner: **British Columbia Ministry of Transportation and Infrastructure**

The serious impacts of weather and climate extremes on transportation infrastructure were brought into stark focus by the rainfall-driven flooding and landslides of November 2021 that cut southwestern British Columbia off from the rest of Canada by land. The potential risks to BC's transportation networks from climate extremes and climate change were previously recognized: the British Columbia Ministry of Transportation and Infrastructure (MoTI) released directives and guidance for incorporating climate adaptation into engineering designs in a 2019 Technical Circular. The Circular stipulated that transportation engineering projects should incorporate information about changes in weather and climate extremes in the future.

PCIC has partnered with BC MoTI to support the implementation of guidance on climate change impacts on transportation infrastructure. This year, PCIC researchers quantified design flood values (for 2-, 20-, 50-, 100- and 200-year events) for historical and future periods over a region including the Peace, Fraser and Upper Columbia basins, and made these values accessible as a gridded product via our Climate Explorer tool. PCIC's research team also completed a pilot study to explore and develop metrics to describe extreme low river flow in the Nicola Basin. This work is intended to allow engineers to incorporate climate change considerations into their infrastructure design process.

The design flood values were developed using VIC-GL, driven by the CanESM2 50-member large ensemble (CanESM2-LE), which allows for the robust counting of rare events, from which changing return periods can be

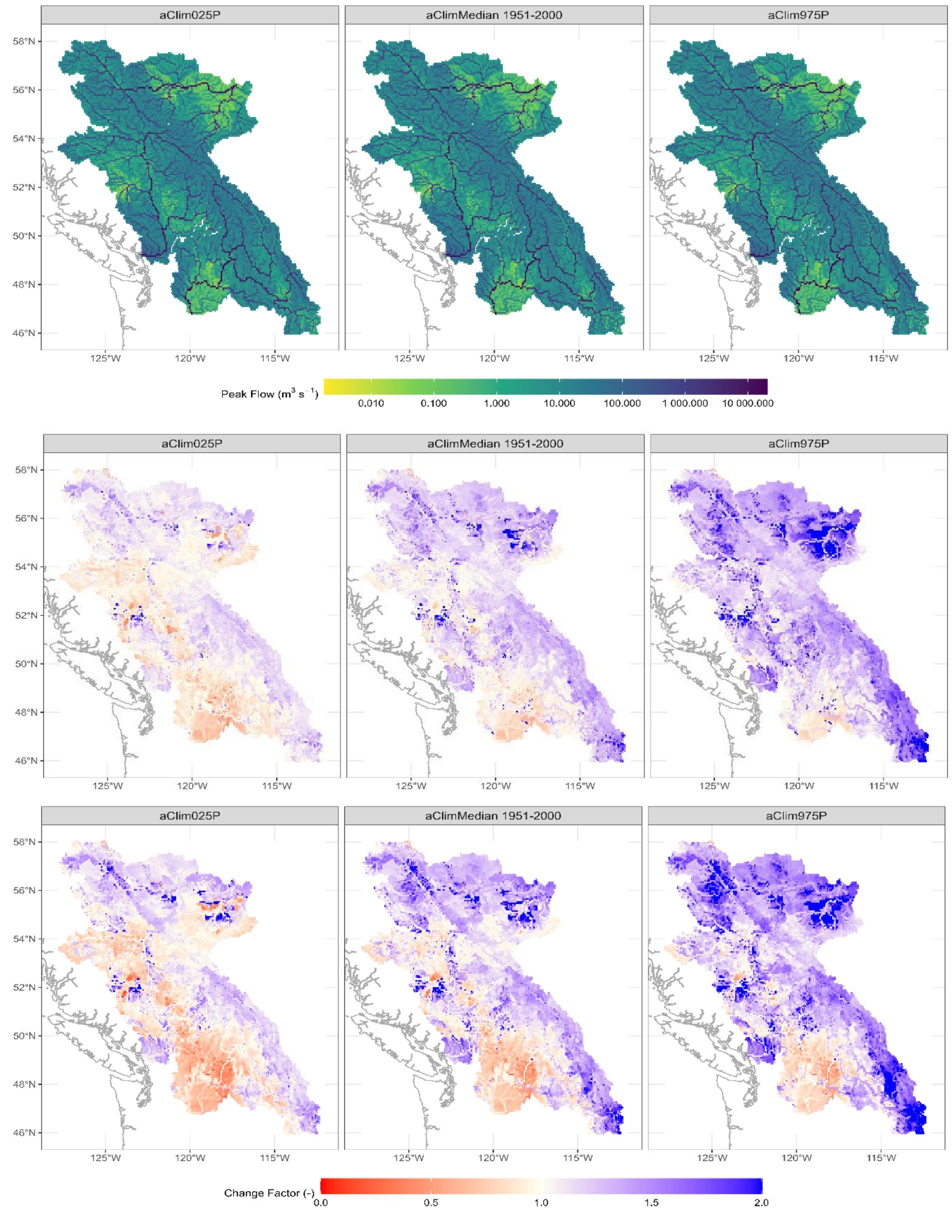
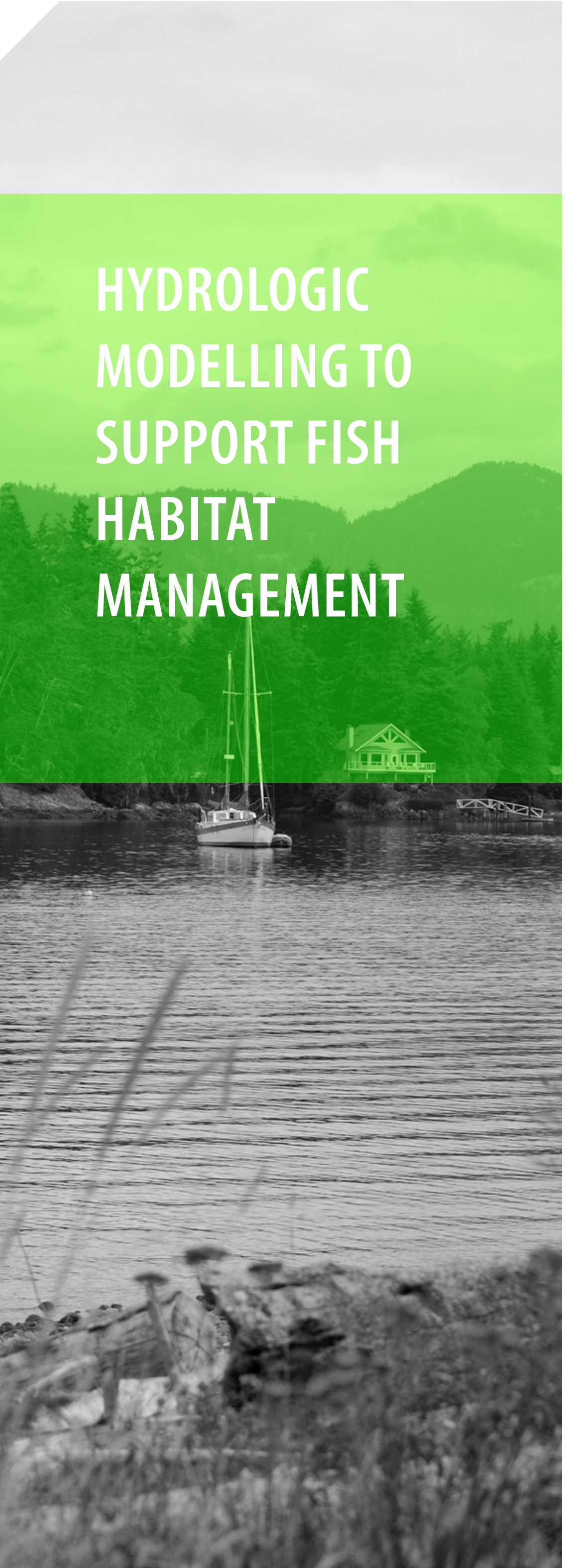


Figure 6: This figure shows the absolute value of annual peak flow during the 1951-2000 period (top row) and change factors in annual peak flow magnitude for 100-yr return period events for 2041-2070 (middle row) and 2071-2100 (bottom row) versus the baseline period (1951-2000). The maps cover the Peace, Fraser and Upper Columbia basins.

estimated. Design flood values for each high-resolution grid cell (an area of approximately 30 km^2) are based on streamflow that enters from the area upstream of the selected cell. This means the size of areas ranges from one grid cell to the full 665,000 km^2 of the catchment. These flood design values were provided for discrete 30-year windows from 2015 to 2085 (for example, from 2041-2020 and from 2071-2100; Figure 6). This builds on previous work supported by MoTI, beginning with a pilot project where the Pacific Climate Impacts Consortium estimated historical and future design flow values for the upper Fraser watershed. These estimates were provided through a prototype online design-flow tool, which was added to the PCIC Climate Explorer.

Since conditions of hydrologic drought are also of interest, PCIC's hydrologists also conducted a low-flow frequency analysis of the Nicola Basin in south-central BC. This pilot study estimated low-flow metrics based on annual minima of seven-day average flow for return periods of 2-, 5-, 10-, 20-, 50-, and 100-years. This work also took advantage of the large ensemble to produce robust estimates of rare extreme low-flow events, with information provided for the same 30-year windows as for high-flow events. The resulting metrics have the same familiar return-period interpretation as those for the extreme high flows and can be easily implemented within existing workflows designed for peak flow analysis. The results of this analysis show that extreme low flow varies between sites and between quantiles. Much of the latter variation may be due to the hybrid nature of low flows in snow-dominated basins, being a mix of summer and winter low-flow events.



Developing Projections and an Online Tool for Salmon Habitat Assessment

Partners: **British Columbia Salmon Restoration and Innovation Fund, Fisheries and Oceans Canada, Pacific Region / Fonds de restauration et d'innovation pour le saumon de la Colombie-Britannique, Pêches et Océans Canada, region du pacifique**

Researchers from PCIC, in collaboration with scientists from the Department of Fisheries and Oceans Canada (DFO), recently completed a project to better understand how climate change may affect terrestrial freshwater environments where salmon populations are found. They focused on streamflow and water temperature to quantify historical and projected future freshwater hazards over a large spatial domain from daily to seasonal time scales. PCIC's team also developed an online portal to deliver this knowledge to a broad range of users.

Changes to British Columbia's climate are expected to impact certain key hydrological factors important for salmon growth, survival, and habitat interconnectivity. To provide planners and managers with information that can be used to support actions to protect wild salmon and their habitats, PCIC and DFO scientists calculated hazard indicators using streamflow and water temperature projections from an ensemble of climate model experiments over the period of 1970-2100. Their experimental design explicitly assessed the uncertainty in future greenhouse gas emissions, differences between climate models and internal climate variability. The hazard indicators permit two types of assessment: a detailed fine-scale assessment specifically tied to Sockeye and Chinook salmon population monitoring sites in eight watersheds, and a broader-scale regional assessment at a coarser resolution over a 400,000 km^2 area of coastal-draining watersheds.

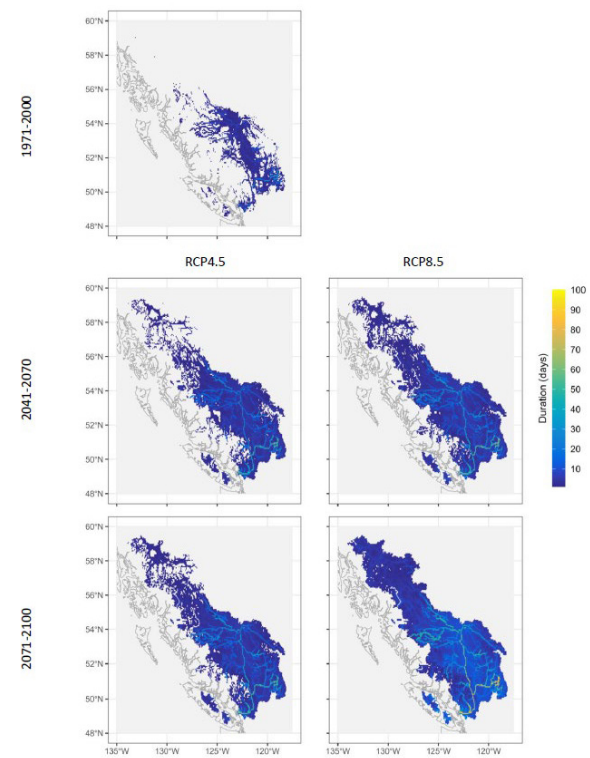


Figure 7: This figure shows the annual mean consecutive number of days that daily stream temperature exceeds 19 °C in the study region for the baseline 1971-2000 period (top), and ensemble mean projected change for mid- and end-century (middle and bottom, respectively) for moderate (RCP 4.5, left) and high (RCP 8.5, right) emissions scenarios.

PCIC's team developed the online Salmon Climate Impacts Portal (SCIP) to make this information available to a range of users interested in fisheries management. The SCIP enables users to locate, visualize, summarise, and download summary data describing projected changes to broad-scale hazard indicators in the freshwater environment within the BC Coastal domain. These regional population- and watershed-based hazard summaries can be used to support climate change ecological vulnerability assessments. Although not incorporated into the SCIP, fine-scale hazard indicators are also available from PCIC, and provide a valuable resource for vulnerability assessment of the relevant salmon stocks.

Improved Modelling of BC's Coastal Salmon Habitat

Partners: **British Columbia Salmon Restoration and Innovation Fund, Fisheries and Oceans Canada, Pacific Region / Fonds de restauration et d'innovation pour le saumon de la Colombie-Britannique, Pêches et Océans Canada , Pacific Region / Pêche et Océans Canada, region du pacifique**

The watersheds of British Columbia that drain into the Pacific Ocean are complex in their topography and provide a vital habitat for a vast number of species, including different salmon species. To meet the planning needs of salmon habitat managers in BC, PCIC researchers are currently working on four interconnected projects. These are: expanding VIC-GL hydrologic projections to ungauged basins, improving lake temperature modelling, implementing oxygen saturation into their modelling, and creating an ensemble of streamflow and water quality projections downscaled to a very high-resolution stream and lake network. Each project involves a complex set of challenges that have required the development of targeted research.

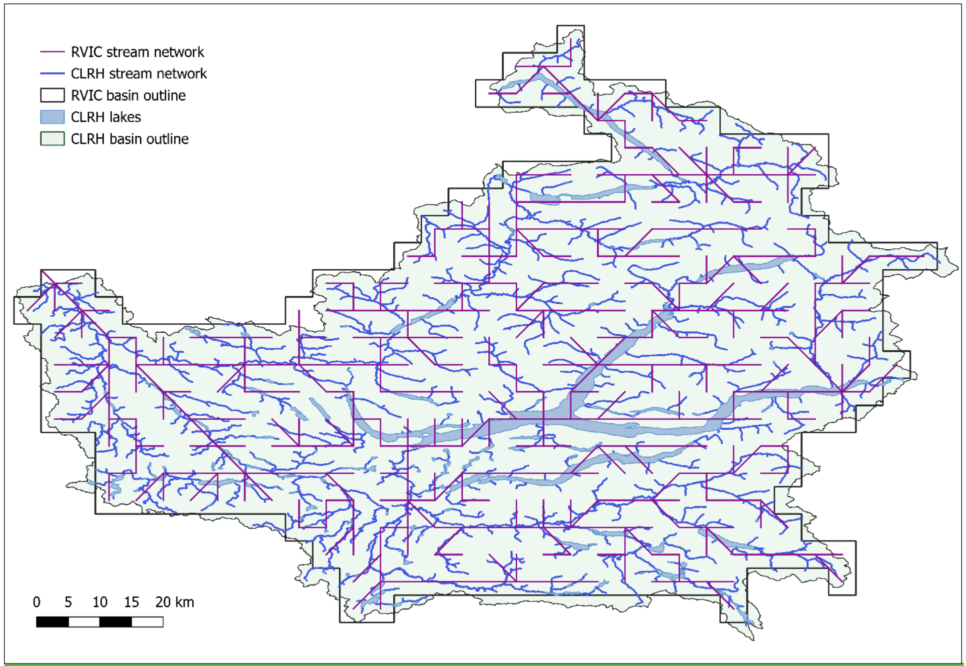


Figure 8: This figure shows a map of the Quesnel River basin (upstream of Likely, BC) comparing the VIC-GL-RVIC and RAVEN-CLRH basin outlines and streamflow networks.

Deploying the VIC-GL model in ungauged basins requires some means of calibrating the model in the absence of streamflow data. As there is no one method that consistently outperforms the others, PCIC's hydrologists tested two different regionalization methods, both of which use data from gauged basins to estimate model parameters in ungauged basins: (1) a physical similarity clustering method that uses catchment attributes, and (2) a deep learning approach. The researchers found that the deep learning model performed best for this application. This method has been used to expand VIC-GL projections for ungauged basins and, ultimately, to expand the offerings of PCIC's streamflow and water temperature projections for salmon habitat managers.

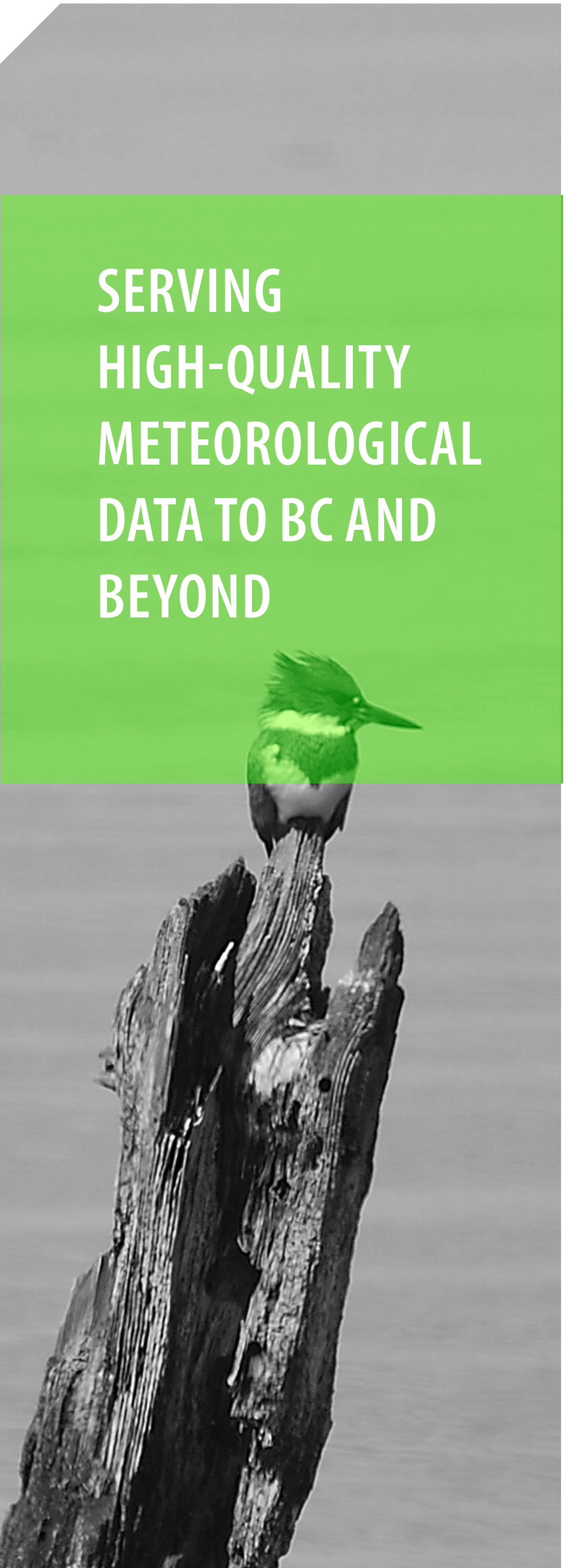
To project future water temperatures in BC's hydrological networks, realistic lake temperature modeling is essential. PCIC hydrologists are currently developing a new lake temperature model to be implemented within the Raven hydrologic modelling framework. This is a two-layer lake model that will provide a reasonable representation of temperature stratification of the water column. The top layer exchanges heat with the atmosphere, while heat transfer between the top and bottom layers occurs via conduction. PCIC researchers are also modifying Raven to estimate the saturation concentration of dissolved oxygen in its hydrologic simulations, which is the maximum amount of dissolved oxygen that water can hold, based on factors such as temperature and atmospheric pressure.

The ensemble of high-resolution streamflow and water quality projections will be based on Raven's vector-based routing. In this framework, each river network is broken into lines with a given direction and magnitude of flow (Figure 8), with the amount of water flowing into each section calculated for each small river segment. These downscaled projections of streamflow, water temperature and saturation dissolved oxygen will cover a large spatial domain, encompassing most of BC's Pacific drainage. They will be developed and shared at the scale of reaches (river segments that are about 100 metres long) and lakes, all available through a web-based data portal. The data resulting from this work will directly support climate change vulnerability assessments at site- and population-specific levels. Whereas previous products had constraints on spatial resolution, these improvements will provide information on reaches and specific channel sections, allowing local, site-specific assessments.

After confirming that Raven performs as well as VIC-GL within the Fraser watershed while providing streamflow at a higher resolution, PCIC is now deploying it across the entire domain, an area of 399,400 km^2 of coastal draining watersheds in BC.

While the primary application of this work is the conservation of wild salmon populations, the results will be of use to anyone interested in fisheries management in the freshwater environment in BC.

SERVING HIGH-QUALITY METEOROLOGICAL DATA TO BC AND BEYOND



Updating PCIC's High-Resolution Climatologies

Partners: **Bonneville Power Administration, National Oceanic and Atmospheric Administration Northwest River Forecast Center (NWRFC), Oregon State University (OSU) PRISM Group, Agricultural Climate Information Service of Alberta**

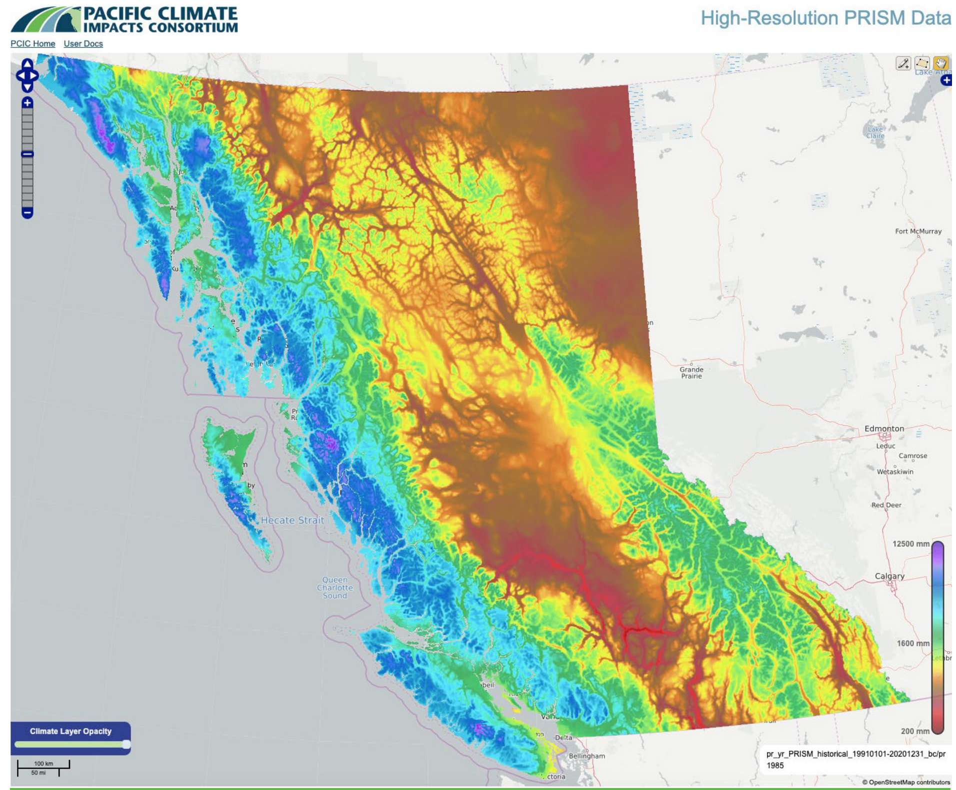


Figure 9: This figure shows an example of a high-resolution PRISM climatology map for precipitation over the 1991-2020 period. The figure highlights the very wide diversity of climates in BC, with estimated annual precipitation amounts ranging from about 200 mm to more than 12,500 mm each year, on average.

This year, PCIC completed the development of a new series of high-resolution (approximately 1 km x 1 km) monthly temperature and precipitation climatologies for British Columbia updated for the 1991-2020 climate normals period (Figure 9). These new maps were created using the Parameter-elevation Regressions on Independent Slopes Model (PRISM), which integrates point data, a digital elevation model, and various factors such as proximity to coastlines, temperature inversions, terrain complexity, and expert knowledge to produce high-resolution, gridded climate estimates. PCIC scientists used this model on data from four sources: the Pacific Climate Data Set (PCDS), the OSU PRISM group, the Agricultural Climate Information Service of Alberta and the NOAA 20th century reanalysis (v3), resulting in maps that represent BC's climate at a very high level of detail even at its borders. Compared to the previous 1981-2010 climatological maps, the new climatologies show that BC has warmed by roughly 0.2 °C between the two periods, consistent with warming observed in Canada and globally.

In developing these maps, PCIC scientists performed extensive quality control on the temperature and precipitation station data, made detailed comparisons with the 1981-2010 climate normal maps to understand changes in small scale features, and ensured seamless integration with the corresponding climate normal maps for the coterminous United States produced by the OSU PRISM group at BC's southern border.

PCIC is grateful for the support of our colleagues at the Bonneville Power Administration, the Northwest River Forecast Center and the OSU PRISM group in this work. The data from this project will greatly enhance the modelling and understanding of present and future climate change in BC. Moreover, our partners will use these maps as a key component in their modelling of the hydrology of the Columbia River Basin, which extends from BC and Alberta southward to Wyoming, Nevada and Utah.

High-resolution Climatologies for Canada

Partners: **British Columbia Ministry of Forests, Environment and Climate Change Canada / Environnement et Changement climatique Canada**

PCIC has been leveraging its experience with BC PRISM climatologies to create an ambitious, Canada-wide "mosaic" of climatological maps. This comprises a weaving together of separate, existing data products to create a set of contiguous, high-resolution monthly climatologies for use in multiple applications across our themes.

Over the past several decades, a number of research groups have produced gridded, station-based datasets covering parts or all of North America, with resolutions comparable to our BC PRISM data (approximately 1 km x 1 km). This opens up the possibility of constructing a mosaic of existing maps to cover the wider area, provided that an effective method can be developed to merge the maps. An initial phase of this project, supported by the British Columbia Ministry of Forests, resulted in a continuous map stretching from Alaska, through BC, to the coterminous U.S., all using existing

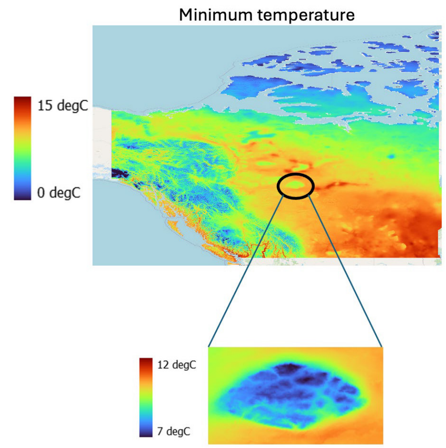


Figure 10: This figure shows a high-resolution mosaic map of minimum temperature for western Canada, representing a typical July during the 1981-2010 period. The inset at the bottom shows a detail of the minimum temperature map in northern Alberta.

PRISM climatologies spanning the 1981-2010 period. In this phase, significant technical challenges in extending the mosaic to incorporate additional datasets were identified. Now in the second phase, supported by ECCC, we are extending the mosaic eastward within Canada, with the goal of spanning the entire country.

Because data products from separate areas often show discrepancies in overlapping regions, PCIC's team developed new methods to merge the individual maps at their boundaries while maintaining consistency with our understanding of the regional-scale climate. One method used was to separate each monthly map into a coarse-grained background field and a fine-scale anomaly field. The fine-scale anomalies often reflect how the local climates vary with topography, while differences in coarse-grained maps in the same region may reflect biases in the underlying products. By merging the coarse- and fine-scale fields separately and combining the resulting maps, we were able to create reasonably smooth climatological maps covering the areas spanned by multiple products.

The resulting high-resolution climatologies of daily maximum temperature, daily minimum temperature (Figure 10) and daily precipitation for the 1981-2010 period will be valuable to a wide range of stakeholders, researchers, and others studying historical climate across Canada. Moreover, we plan to integrate these maps into our on-demand "climate imprint" downscaling tool, which is under development and currently targets BC only (see the *Providing*

Local Scale Climate Scenarios for Adaptation story on p. 22). This tool refines our ~10 km resolution statistically-downscaled climate change scenarios to the finer resolution of the background climatology, which, for BC's PRISM maps, is around 1 km. By developing a national mosaic of climatologies of similar resolution, we will enable external users across Canada to perform customized downscaling of various climate variables and extreme climate indices, providing fine-scale information directly relevant to planning and adaptation efforts.

PCIC's Station Data Portals: Continued Expansion and Development

Partners: **British Columbia Climate Related Monitoring Program: British Columbia Ministry of Environment and Climate Change Strategy, British Columbia Ministry of Agriculture and Food, British Columbia Ministry of Forests, British Columbia Ministry of Transportation and Infrastructure, BC Hydro, Rio Tinto, Environment and Climate Change Canada, Metro Vancouver, The Capital Regional District, The Pacific Climate Impacts Consortium**

University of Northern British Columbia

Government of the Northwest Territories, and numerous agencies that provide observations for inclusion in the Western Arctic data portal

British Columbia Ministry of Emergency Management and Climate Readiness

PCIC operates, develops, and maintains two meteorological data portals that provide users with near-real-time access to weather observations collected in British Columbia and Canada's Western Arctic. The BC station data portal,

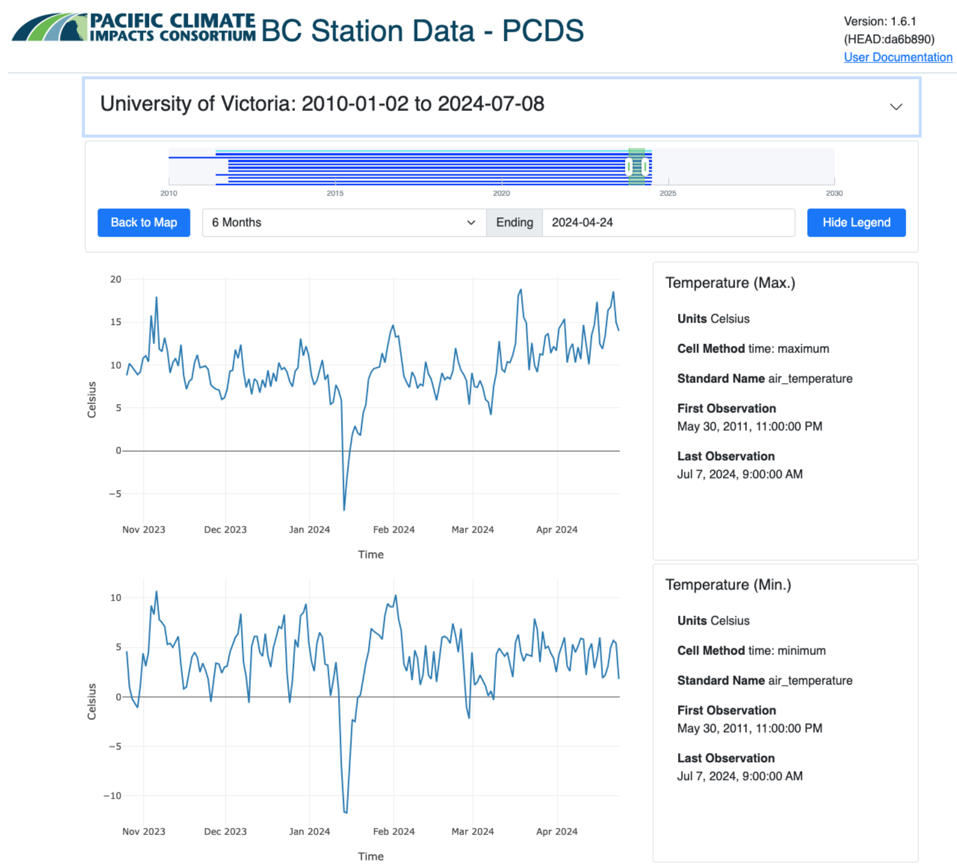


Figure 11: This figure shows an example from the time series viewer, for temperatures recorded at the nearest station to PCIC between the 25th of October 2023 and the 23rd of April 2024. The cold snap in January is clearly visible, with a maximum temperature of -7 °C and a minimum temperature of -11.7 °C recorded on January 14th. The full preview page for this station shows 11 time series charts like these (one for each of the 11 variables recorded at that station). The horizonal bar across the top shows the periods of availability for the different variables (each represented by a different blue line), and the green shading indicates the part of the record that is being displayed to the viewer, which can be adjusted.

now in its 13th year, provides access to nearly 1 billion observations from roughly 7000 locations across the province, with some records dating back to 1871. The portal's holdings are continuously updated through automated data feeds and periodic additions from observing networks that do not provide automated data feeds. The Western Arctic data portal, which has been operating for over one year now, offers a similar functionality with 798 stations spanning from ~55°N to 82°N latitude.

This year, both portals have been significantly improved with the introduction of a time series data viewer (Figure 11). Users can now view time series of each variable from a given station for any 6-month period, allowing for an intuitive understanding of the data, variability, characteristics of the different variables, and any gaps in observations.

Both portals have expanded this year. The BC Station Data Portal, which provides access to the Pacific Climate Data Set (PCDS), has added 61 million observations. It now includes near-real-time data from BC Hydro, one of PCIC's longest-standing partners, at a 15-minute temporal resolution. Meanwhile, the Western Arctic Weather Data Portal has grown by 16 million observations.

As PCIC's meteorological databases continue to expand and interest grows in performing quality assurance on the raw data it ingests, there is a need for database structures that reliably track data evolution. With this in mind, PCIC is developing a version control system for the PCDS, which will provide users with information about changes made to the observations and metadata (e.g., station location and elevation). These changes, often implemented as quality control measures to correct errors and improve data homogeneity, can create discrepancies between PCIC's data and the original archives. The version control system will allow PCIC to make such corrections while retaining the original data and will give users transparency about what changes were made and why.

SOFTWARE, COMPUTER INFRASTRUCTURE AND ONLINE TOOL DEVELOPMENT

Providing Local-Scale Climate Scenarios for Adaptation

Partners: **Environment and Climate Change Canada / Climate Change Canada / Centre canadien des services climatiques, and DACCS partners: Canada Foundation for Innovation/ Fondation canadienne pour l'innovation, British Columbia Knowledge Development Fund, University of Toronto, Ouranos, Computer Research Institute of Montréal, McGill University / Le Centre de Recherche Informatique de Montréal, Concordia University**

To meet the need for regional- and local-level climate information throughout BC's complex landscape, PCIC has developed an on-demand climate downscaling tool through the Data Analytics for Canadian Climate Services (DACCS) project. While we currently provide high-resolution (~1 km) monthly and annual climatologies for gridded observations, and also mesoscale (~10 km) gridded observations and future scenarios at a daily resolution, the new tool will allow users to generate their own km-scale future projections for small areas of BC.

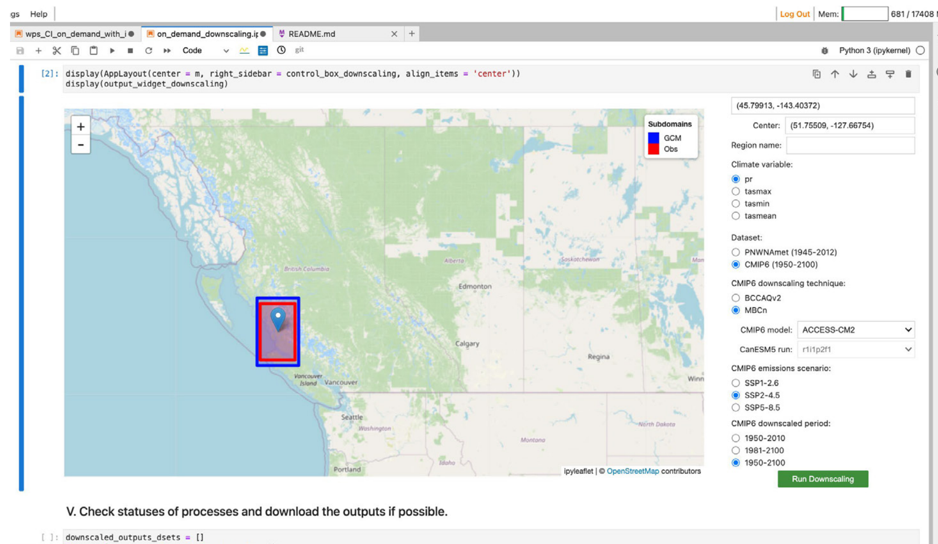


Figure 12: This figure shows a screenshot from the Jupyter notebook interface used to generate high-resolution, daily observational and future-projected climate data in an on-demand fashion.

Leveraging DACCS, which brings computational resources close to data storage for efficient climate data product generation, the tool enables statistically downscaled projections in real time for user-selected regions across BC using a Jupyter Notebook. A Jupyter Notebook is a type of computable document that combines code, figures and explanation, and is a commonly used tool in data analysis. On the back end, this process runs a version of ClimDown, an R-based software package that PCIC developed for "climate imprint" downscaling. When a user runs the notebook (Figure 12), they select a region of interest via a built-in map interface, input dataset (gridded observations or a climate model), downscaling method, future emissions scenario, and a time period. Additional indices of climate extremes can also be created from the daily downscaled data that may be helpful for assessing a variety of climate-related behaviour and hazards. After the computations are complete, the user receives a link to download the high-resolution downscaled climate data for that area.

This new tool, which is currently in beta-testing mode, is a semi-expert level product that requires the users to execute Python code in the notebook, although no coding is necessary. Expert users can also expand on its functionality, as the tool operates within PCIC's cloud, providing access to extensive data stored there. Working with data in PCIC's cloud is computationally cheaper and faster than downloading large tracts of model output and working with it on a user's system. By offering this tool, PCIC enables intermediate-level users to access high-resolution data they need to better understand past and future-projected climate in their specific region of interest.

On-Demand Streamflow Data

Partners: **DACCS partners: Canada Foundation for Innovation/ Fondation canadienne pour l'innovation, British Columbia Knowledge Development Fund, University of Toronto, Ouranos, Computer Research Institute of Montréal / Le Centre de Recherche Informatique de Montréal, McGill University, Concordia University**

This year, PCIC developed a Jupyter Notebook that provides on-demand access to streamflow projection data for any location in British Columbia. This tool was created to meet the need for hydrologic streamflow projections at specific sites where users are performing work or planning future projects. Previously, PCIC only produced streamflow projections for gauged sites, a limited number of locations where hydrologists could calibrate models. This was restrictive, as there are far fewer gauged sites than the number of locations where hydrologic data is needed, such as where pipelines cross over waterways or road and highway crossings. The new service allows users to calculate streamflow at their sites of interest. Moreover, on-demand modelling is computationally cheaper than running a hydrologic model for an entire watershed domain.

This development, like the one described in the last story, builds on PCIC's work under the DACCS project, which places computational resources (called "nodes") near the data, enabling efficient, remote calculations in response to user requests. Here, the Jupyter Notebook uses a web service called Osprey, which runs the streamflow routing component of the Variable Infiltration Capacity model used at PCIC on a DACCS node, then provides the results to the user.

Enhanced Software for Calculating Climate Indices

Partners: **Environment and Climate Change Canada / Environnement et Changement climatique Canada, the World Meteorological Organization, the University of New South Wales**

An internationally agreed-upon suite of climate extreme indices, based on daily precipitation and temperature data and developed by the Expert Team on Climate Change Detection and Indices (ETCCDI), has enabled the comparison of analyses from different parts of the world. These indices facilitate the seamless merging of data to produce a global picture, despite challenges in sharing daily precipitation and temperature observations across countries. A software package developed at PCIC, climdex.pcic, which computes these indices, has been widely used and has made an important contribution to this international standardization.

This year, we introduced two new features to this popular software. One enhancement enables the computation of indices on a seasonal scale, allowing users to analyze changes in extreme indices for different seasons. The other addition allows climdex.pcic to output the exact dates of extreme events, making it possible to analyze changes in the timing of these events.

Maintaining and Upgrading PCIC's Computational Infrastructure

PCIC stores a vast amount of meteorological data and model output of various types, for both British Columbia and Canada. For example, the Pacific Climate Data Set (PCDS) is a unique provincial resource available exclusively through PCIC. Located in in Victoria, BC—a seismologically active region about 100 kilometres east of the Cascadia Subduction Zone—PCIC operates in an area prone to earthquakes, posing a serious threat to life and infrastructure.

As stewards of these valuable data resources, PCIC is also responsible for ensuring their safety and security. To protect its data assets from potential earthquake damage, PCIC moved all servers this year to a seismically protected equipment rack (Figure 13). This process required significant effort, including large-scale hardware upgrades, server improvements and transferring all equipment to the new seismic rack. As an added benefit, these upgrades have improved server communication speed, reducing the time needed for research tasks.


Figure 13: This figure shows the new seismically-protected rack containing PCIC's servers.

In addition to the seismic upgrades, PCIC conducted a comprehensive risk analysis for UVic's Central Audit department. This assessment covered all of PCIC's information technology systems, servers, and disk storage, addressing risks from fire, flooding, and cyber attacks. The findings were used to further strengthen the resilience of PCIC's systems, its information security policies and provide greater peace of mind for PCIC's users.

Enhancing Features of PCIC's Tools and Incorporating New Climate Projections

Partners: **Environment and Climate Change Canada / Environnement et Changement climatique Canada, British Columbia Ministry of Emergency Management and Climate Readiness**

PCIC users have a need for downscaled climate output from the most recent and advanced climate models available, presented for their regions of interest. This drives the ongoing development of multiple tools and products at PCIC. Over the past fiscal year, PCIC has added output from the sixth and most recent phase of the Coupled Model Intercomparison Project (CMIP6) to its Plan2Adapt tool, PCIC Climate Explorer and the Statistically Downscaled Climate Scenarios portal.

In order to integrate the new climate model output into these tools, PCIC first downscaled the output from 26 climate models participating in CMIP6 and compared these to prior results from CMIP5. They also tested different downscaling techniques, comparing techniques that downscale one variable at a time with multivariate techniques that treat all variables of interest simultaneously. The resulting data for two downscaling methods and three emissions trajectories have been added to PCIC's Data Portal and the multivariate dataset integrated into the PCIC Climate Explorer. For the Plan2Adapt updates, a 12-model subset of output from the CMIP6 data on Climate Explorer was selected to sample the overall range of model projections. In addition, baseline data for the 1981-2010 climatological period were added to the Summary table of the tool.

The incorporation of the most recent climate model output into PCIC's tools and Data Portal is aligned with PCIC's goal to provide users in our region and across Canada with the highest-quality results from the cutting-edge of climate modelling.

Communications

PCIC maintains a robust program of communication and outreach to keep its users abreast of its ongoing projects, new products, online tools, and relevant research. PCIC's researchers also regularly share their findings with the broader scientific community, through peer-reviewed journals, conferences and other activities. This provides a two-way dialogue that enhances the quality of PCIC's research. Over the 2023-2024 fiscal year, PCIC staff presented on a wide array of topics including: the detection of human influence on precipitation, uncertainty reduction for extreme precipitation projections, observationally constrained projections of warming in Canada, high-resolution climate mapping of coastal and mountainous regions, process-based calibration of hydrologic models, and temperature and hydrologic conditions over BC in 2023. PCIC also released two Science Briefs: 'On Cloud-Circulation Coupling and Climate Sensitivity,' and 'Observed Increases in Extreme Fire Weather Driven by Humidity and Temperature.' PCIC's team also presented at multiple workshops and stakeholder meetings, sharing their knowledge with the public, planners, and the broader scientific community. An example of this is "Climate Change Informed Flow and Thermal Indicators for Resilient Stewardship of BC's Watersheds," a presentation delivered at the Canadian Water Resources Association (BC Branch) 2023 conference.

OPERATIONS AND FINANCE

Operations and Finance

In fiscal year 2023-2024, PCIC maintained a stable funding and operational environment in support of its programs and service delivery to its partners, stakeholders and the public.

We provided services via more than 25 user-commissioned projects, externally funded research grant programs and other projects. Short-term and long-term agreements with our partners provided 56% of our revenue, with the balance provided by an endowment that was placed at the University of Victoria by the BC Government in 2008. We continued to maintain and advance relationships with over 50 partners from several federal and provincial government ministries, municipalities and a host of other organizations within and outside of BC and Canada.

As a service organization, all of our activities are dependent on having a talented and dedicated team of professionals. With our most important resource being our staff, 91% of our expenditures supported the salaries and benefits of 23 staff and 2 co-op students. The remaining expenses supported computing resources, staff professional development, conference and meeting travel in support of both professional development and our programs, and general operational expenses. As a not-for-profit corporation, PCIC carefully plans and budgets its expenditures to ensure maximum value from the funding it receives.

Thanks to the PCIC team for their dedication, hard work and teamwork and to the University of Victoria and all our partners for their support. Together, we furthered PCIC's mission to translate, create and deliver authoritative quantitative information about the climate of our region and beyond, and assisted users of that information in understanding the impacts of climate variability and change.

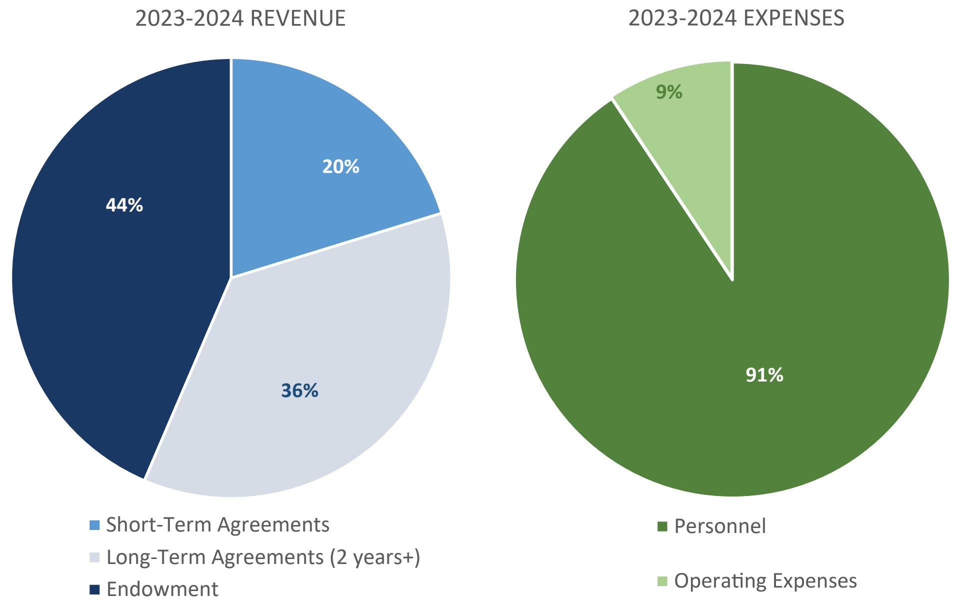


Figure 14: This figure shows a breakdown of PCIC's revenue (left) and expenses (right) for the 2023-2024 fiscal year.

Peer-Reviewed Publications and Book Chapters

1. Chow, K.K.C., H. Sankaré, E.P. Diaconescu, **T.Q. Murdock** and A.J. Cannon, 2024: Bias-adjusted and downscaled humidex projections for heat preparedness and adaptation in Canada. *Geoscience Data Journal*, **00**, 1–19, doi:10.1002/gdj3.241.
2. **Dah, A.**, B. Khouider, and C. Schumacher, 2023: A multicloud model for coastal convection. *Geosciences*, **13**, 264, doi:10.3390/geosciences13090264.
3. Dunn, R. J. H. and 27 co-authors including **X. Zhang**, 2024: Observed global changes in sector-relevant climate extremes indices - an extension to HadEX3. *Earth and Space Science*, **11**, 4, e2023EA003279 doi:10.1029/2023EA003279.
4. Forster, P. M. and 58 co-authors, including **X. Zhang**, 2024: Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence, *Earth System Science Data*, **16**, 2625–2658, doi:10.5194/essd-16-2625-2024.
5. Khorsandi, M., A. St-Hilaire, R. Arsenault, J.-L. Martel, **S. Larabi**, **M. Schnorbus** and **F.W. Zwiers**, 2023: Future flow and water temperature scenarios in an impounded drainage basin: Implications for summer flow and temperature management downstream of the dam. *Climatic Change*, **176**, 164, doi:10.1007/s10584-023-03634-w.
6. **Larabi, S.**, J. Mai, **M. Schnorbus**, B. Tolson and **F. Zwiers**, 2023: Towards reducing the high cost of parameter sensitivity analysis in hydrologic modelling: a regional parameter sensitivity analysis approach. *Hydrology and Earth System Sciences Discussions*, **27**, 17, 3241–3263, doi:10.5194/hess-27-3241-2023.
7. **Larabi, S.**, **M.A. Schnorbus** and **F.W. Zwiers**, 2023: Diagnosing the ability of reservoir operations to meet hydropower production and fisheries needs under climate change in a western cordillera drainage basin. *Climatic Change*, **176**, 161, doi:10.1007/s10584-023-03632-y.
8. Lau, Y.T.A., T. Wang, J. Yan and **X. Zhang**, 2023: Extreme value modeling with error-in-variables in detection and attribution of changes in climate extremes. *Statistics and Computing*, **33**, 125 doi:10.1007/s11222-023-10290-8.
9. Li, C., Q. Sun, J. Wang, Y. Liang, **F.W. Zwiers**, **X. Zhang** and **T. Li**, 2024: Constraining projected changes in rare intense precipitation events across global land regions. *Geophysical Research Letters*, **51**, 3, e2023GL105605, doi:10.1029/2023GL105605.
10. **Li, T.**, **X. Zhang** and Z. Jiang, 2024: What aspect of model performance is the most relevant to skillful future projection on regional scale? *The Journal of Climate*, **37**, 5, 1567-1580, doi:10.1175/JCLI-D-23-0312.1.
11. Ma, S., T. Wang, J. Yan and **X. Zhang**, 2023: Optimal Fingerprinting with Estimating Equations. *Journal of Climate*, **36**, 20, 7109-7122, doi:10.1175/JCLI-D-22-0681.1.

12. Seong, M.G., S.K. Min and **X. Zhang**, 2022: A Bayesian attribution analysis of extreme temperature changes at global and regional scales. *Journal of Climate*, **25**, 24, 8189- 8203, doi:10.1175/JCLI-D-22-0104.1.

13. **Sobie, S.R.**, **D. Ouali**, **C.L. Curry** and **F.W. Zwiers**, 2024: Multivariate Canadian Downscaled Climate Scenarios for CMIP6 (CanDCS-M6). *Geoscience Data Journal*, doi:10.1002/gdj3.257.

14. Souaissi, Z, T.B. Ouarda, A. St-Hilaire and **D. Ouali**, 2023: Regional frequency analysis of stream temperature at ungauged sites using non-linear canonical correlation analysis and generalized additive models. *Environmental Modelling & Software*, **163**, 105682, doi:10.1016/j.envsoft.2023.105682.

15. Sun, Q., **F.W. Zwiers**, **X. Zhang** and Y. Tan, 2023: The effect of greenhouse gas induced warming on the impact of El Niño and La Niña events on daily precipitation extremes in the boreal cold season. *Journal of Climate*, **36**, 18, 6393-6407, doi:10.1175/JCLI-D-22-0713.1.

16. Tam, B., B. Bonsal, **X. Zhang**, Q. Zhang and R. Rong, 2023: Assessing Potential Evapotranspiration Methods in Future Drought Projections across Canada. *Atmosphere-Ocean*, **62**, 3, 193-205, doi:10.1080/07055900.2023.2288632.

17. Zhu, H., Z. Jiang, L. Li, W. Li, S. Jiang, P. Zhou, W. Zhao and T. Li, 2023: Intercomparison of multi-model ensemble-processing strategies within a consistent framework for climate projection in China. Science China Earth Sciences, 66, 2125–2141, doi:10.1007/s11430-022-1154-7.

PCIC Publications and Other Reports

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