PACIFIC CLIMATE IMPACTS CONSORTIUM

PCIC UPDATE November 2021

PROJECT AND RESEARCH UPDATES

Atmospheric River Brings Heavy Rains and Flooding to BC

The heavy rains and flooding that slammed southern British Columbia over November 12th through 15th was the tail end of events that may have started more than 10 days prior. At that time a cyclone southwest of Japan dug into very humid air from the tropical western Pacific, excavating a warm and very moist air mass out of the tropics and loading it into the eastwardly flowing storm track that brings BC its weather. Its course was meandering, but on November 12th, the air mass began to combine with a developing storm. It was then propelled toward the coasts of BC and Washington to deliver what would become a destructive wallop of rain, causing more than 17,000 people in BC to have to evacuate their homes, leaving 200,000 without power and cutting off Vancouver and several other communities from the rest of Canada.

Figure 1: This figure shows some of the damage that flooding caused to British Columbia's highway system. Clockwise from top left, these are: Highway 1, the Malahat, on Vancouver Island outside of Victoria; Highway 1 in Abbotsford; Highway 1 at the Tank Hill Underpass; and Highway 5, the Coquihalla, at Juliet. All photos courtesy of the British Columbia Ministry of Transportation and Infrastructure.

At mid-day on the 13th, the first of the moisture hit, producing heavy rains and saturating soils already near-full from previous rainfall events. There was a brief pause overnight until the morning of the 14th, when a narrow stream of moisture took aim at southern Vancouver Island and The Fraser Valley and began to deliver heavy rains. This continued until a cold front passed through on the afternoon of the 15th, bringing with it a final flourish of extremely heavy rain and strong winds that persisted into the night. At the summit of the Coquihalla highway, 290 millimetres (mm) of rain fell over the course of four days from the 12th through the 15th. Accumulations were 200 mm at summit of the Malahat, 251 mm in the Fraser Valley at Agassiz, and 325 mm in Hope. The four-day precipitation over this period at various locations across the province can be seen in Figure 2.

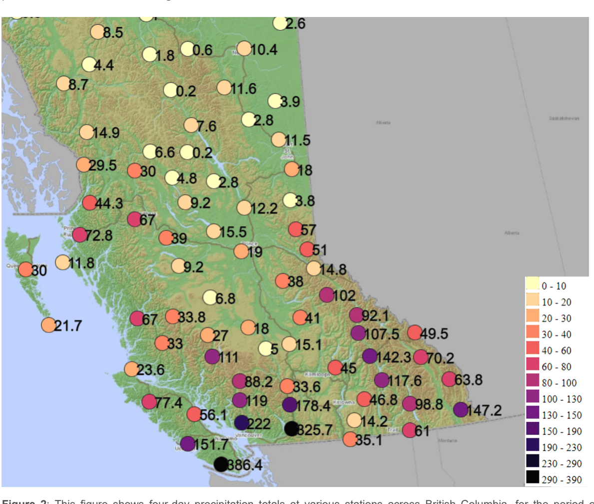

Figure 2: This figure shows four-day precipitation totals at various stations across British Columbia, for the period of November 12th through 15th, 2021. Amounts are listed in millimetres.

More than 90% of the precipitation that falls on western British Columbia is tropical in origin. Much of the precipitation comes from relatively narrow bands of moisture called atmospheric rivers. Occasionally, the moist air is warmer and wetter than typical and becomes better aligned into narrow bands that are blown against the mountains of British Columbia and produce very heavy rainfall (or snowfall if cold air is already in place) along a narrow corridor like what we saw this November.

Our climate is warming and a basic principle of atmospheric physics is that warmer air has a greater capacity to hold moisture; roughly 7% more for every degree of warming. Despite the complexity of forming precipitation, it is reasonable to expect that extreme precipitation will increase following that relationship. Research using weather data from around the world has shown this to be true. A question that remains to be answered that is now drawing the attention of scientists is the extent to which the November 12th-15th event was affected by the global warming observed to date.

The events that unfolded this week have made the impacts of a strong atmospheric river event clear: flooding, debris flows leading to loss of life, displacement and the stranding of large numbers of people, infrastructure destruction and supply chain interruptions. The population of British Columbia continues to grow and more infrastructure will be built to accommodate their needs. This growth will intersect with a changing climate making both the mitigation of climate change and adaptation to it important to our region.

PCIC Responds to Media Requests Regarding Recent Flooding

Throughout this crisis, PCIC's research team has been answering media requests, to share their knowledge of the climate system with the general public and place the recent atmospheric river event in the context of our current understanding of the climate system. In discussion with a journalist from the Canadian Press, PCIC Director Francis Zwiers explained that, while human induced climate change is affecting the frequency and intensity of many kinds of extreme events, there is also a contribution from other human activities that change our vulnerability to risks posed by the climate. This is a point he echoed in comments on in an article for Radio Canada. The director was also interviewed by CBC Radio One Ottawa, in which he discussed event attribution, explained that the field of inferring risks from compound extreme events is still quite new and talked about how warming is expected to affect atmospheric river events. Speaking in the Globe and Mail in an article on the recent damage to highways from flooding and washouts, the lead of PCIC's Hydrologic Impacts theme, Markus Schnorbus, discussed how these events are in line with what research suggests will happen in a warming climate. Faron Anslow, the lead of PCIC's Climate Analysis and Monitoring theme, discussed atmospheric river events on CTV News. In a another CTV news article, the acting lead of PCIC's Regional Climate Impacts theme, Charles Curry, commented on the potential of an atmospheric river warning system.

PCIC's team has also been anticipating impacts from changes to extreme precipitation, flooding and landslide events and studying these to learn how changes to climate may affect them. Related work at PCIC has recently examined changes to extreme precipitation, projected increases in extreme streamflow in the Fraser River and projected changes in landslides in BC due to precipitation. This research shows that the rain falling in extreme precipitation events is increasing when considered across large continental regions, including North America, that events like this November's atmospheric rivers are projected to be both wetter and possibly longer lasting when they arrive and that periods of landslide hazards are projected to increase in frequency.

Comparing Climate Model Projections Across Canada

Each generation of climate models offer advantages over the generation that precedes it, providing increased resolution, improved representations of key physical and biogeochemical processes and updated emissions scenarios. Some of the latest models, used for the sixth phase of the Coupled Model Intercomparison Project (CMIP6), are more sensitive than the CMIP5 models to the greenhouse gas emissions used to run them. This means that they exhibit greater warming and larger overall changes to their simulated climate for a given amount of greenhouse gas emissions. These models show more warming globally and in projections of climate across Canada. This enhanced sensitivity is thought to be due to how the models simulate clouds and sea ice, which affects how much solar energy is absorbed by the climate system and converted to heat.

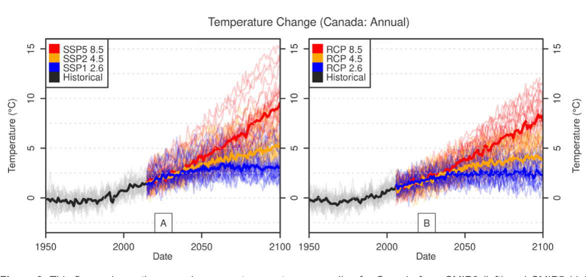

Figure 3: This figure shows the annual average temperature anomalies for Canada from CMIP6 (left) and CMIP5 (right) relative to 1971-2000. The three SSP emissions scenarios from CMIP6 are chosen to correspond to the three RCP emissions scenarios used for CMIP5. Individual climate model simulations are displayed with thin lines and the corresponding ensemble averages are shown in thick lines for each emissions pathway. Note that the CMIP6 simulations show more warming than the CMIP5 simulations. Note also that the transition from historical simulations to future projections occurs in 2015 for CMIP6 as opposed to 2006 for CMIP5.

PCIC researchers recently examined the output of CMIP5 and CMIP6 models across Canada and broken down into six sub-regions, including British Columbia. They looked at several climate indices as a function of time and as a function of warming level.

PCIC's team found that projected changes in many temperature and some precipitation indices for Canada in future time periods are larger in CMIP6 than in CMIP5 due to stronger climate responses to similar forcing. It is worth noting that this effect is partly explained by a small subset of models having a high sensitivity. It remains to be seen whether this sensitivity in this subset of climate models reflects the response of the Earth's climate system to greenhouse gas emissions. In the meantime, these models do capture a variety of aspects of the climate system and it would be useful to have their output for study and analysis.

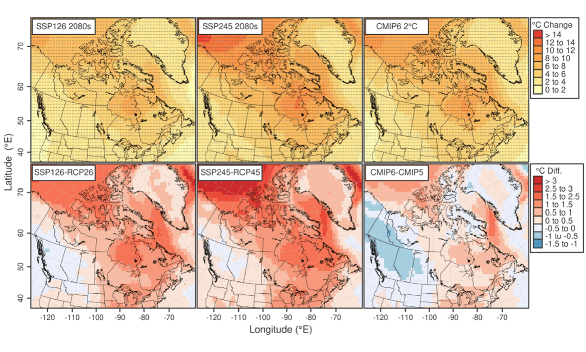

Figure 4: This figure shows projected changes in average winter minimum temperature for the 2080s (left and middle panels) and at 2°C of global surface air temperature increase (right panels). The top row shows the ensemble median differences between the CMIP6 future projections and historical simulations of the 1971-2000 period. The top left panel shows projected changes in winter minimum temperature from GCMs following the SSP1-2.6 emissions scenario while the top middle panel shows GCMs following SSP2-4.5. The top right panel displays anomalies from climate models following any of the three SSP emission scenarios that reach a warming of 2°C. The bottom row shows the differences (CMIP6 - CMIP5) between the CMIP6 anomalies of the top row, and corresponding 2080s projections from CMIP5 for the comparable RCPs (2.6, bottom left, and 4.5, bottom middle). The bottom right panel shows the differences between CMIP6 and CMIP5 GCMs for all three RCPs that reach 2°C of global warming—note that this temperature-dependent comparison produces a much smaller difference than comparing the two generations of models for a given time period as is done in the bottom-left and bottom-center panels. All temperatures are as marked on the legends on the right and stippling in the top row indicates areas where at least 80% of the models agree on the sign of the projected change.

PCIC researchers found that using temperature-dependent projections—e.g., looking at all of the projections for say, 2°C of warming—reduced the differences between CMIP5 and CMIP6 as compared to simply comparing the average model output from each CMIP for a given time period. This allows the output from more models to be used together, as long as all of the simulations from that model reach the given temperature. The authors also found that, for specified levels of global temperature change, the regional responses of temperature and precipitation are quite similar between CMIP5 and CMIP6, which means that similar information is available from each CMIP regarding impacts from given levels of warming across Canada. This work has been accepted for publication and will be forthcoming in the journal *Atmosphere-Ocean*.

Modelling the Temperature of the Nechako

The Nechako River, a tributary of the Fraser River Basin, is a valuable habitat for a variety of fish species, including different types of salmon, trout and sturgeon. The river is fed from the Nechako Reservoir, held behind the Kenny Dam. As part of reservoir management operations, water is released from the Nechako Reservoir into the river via the Skins Lake Spillway, 75 kilometres west of the dam, during the salmon migration period to manage water temperature so that migrating salmon are not exposed to excessively warm water. To understand the potential impact of climate change and to aid in reservoir management operations on the Nechako River system, a linked hydrological, hydrodynamic and water quality model has been developed by PCIC researchers.

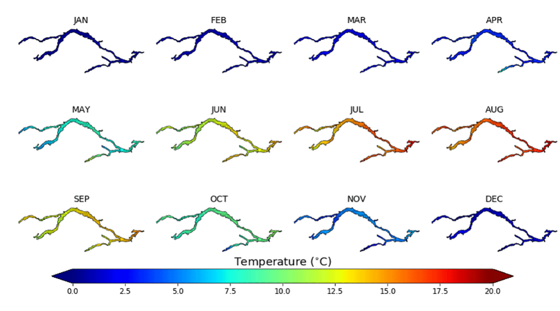

Figure 5: This figure shows the simulated averages for the annual cycle of the Nechako Reservoir's water surface temperature over the 1986-2017 period. Temperatures are as indicated by the colours in the legend.

The team first drove the model using a combination of observed and reanalysis data and compared the model output with observed data from 1986 to 2017. They also compared the reservoir's water temperature and outflowing water temperature with data collected in the summers of 1994, 2016 and 2017. They found good agreement between the simulations and observations. Subsequent analysis of these simulations show that 84 % of the total inflow into the Nechako reservoir originates from watersheds draining the eastern slopes of the Coast Mountains. The model simulations also show that tributaries flowing into the north arm of the Nechako reservoir supply cooler water than those flowing into the southern arm. The surface water temperature is uniform across the reservoir during winter, spring and fall (Figure 5). From May through September, there is a weak temperature gradient between west-end of the reservoir and its eastern end. Surface water is typically warmer at Kenney Dam than elsewhere in the reservoir during summer months due to the absence of water circulation at this location. Currently water is not released at this location.

To provide for a suitable water temperature for salmon in the river, a cold-water release facility at Kenney Dam had been suggested in previous studies. This facility would supply the Nechako River with cold water drawn from depth. Releasing water with a temperature of 10°C was suggested as a way to reduce the occurrence of extremely warm water temperatures (above 20°C) during the salmon migration period. In this context, PCIC's team examined the annual cycle of the water temperature at Kenny Dam at different depths to see where water of this temperature would be available. They found that the temperature of deep water remains between 4°C to 5°C year-round. During the ice season, the surface water temperature is at 0°C. It then warms up and mixes with the deep water following the disappearance of surface ice after about 40 days. The surface water temperature continues increasing with the warming air temperature and reaches a maximum of 18°C which coincides with the salmon migration period. The summer stratification starts late spring and lasts until early November. Then surface water mixes again with the deeper water due to increased wind and low surface water temperature. During the period over which the temperature is managed, the thermocline layer (between mixed surface water and the cooler water below) lies at a depth of between 10 metres and 30 metres, and water temperature below 10°C are available, on average, at depths below 20 metres.

In upcoming work this model will be used to explore the reservoir response to projected future climates and alternative management strategies.

Transportation Module on Climatedata.ca

PCIC has been coordinating the development of a Transportation Sector Module on ClimateData.ca as part of a collaborative initiative, led by the Canadian Centre for Climate Services, to increase climate adaptation knowledge and showcase climate services relevant for the Canadian transportation sector.

Transportation authorities across Canada are grappling with the impacts of climate change, including more frequent and more intense precipitation events, extremes in temperatures, and variable freeze-thaw cycles, all of which require information about the changing climate to adapt. The ClimateData.ca Transportation Sector Module aims to provide transportation experts with access to reliable and sector-relevant climate information to help inform adaptation action in the sector. It provides easy access to transportation-relevant climate datasets, information, and case studies demonstrating the use of climate data in adaptation efforts for the Canadian transportation sector.

The module is now publicly available on the website. The Transportation Sector Module will continue to be updated and expanded.

- Go to the Transportation Sector Module of ClimateData.ca.

Past and Upcoming Talks at the Pacific Climate Seminar Series

The Pacific Climate Seminar Series continued with a talk on October 27th by PCIC Post-Doctoral Scientist Dr. Qiaohong Sun, who spoke on *Observed changes to precipitation extremes and their attribution at the global, continental and regional scale*.

The final talk of this fall will be given on December 1st by Professor Ted Shepherd, from the University of Reading. Professor Shepherd will be discussing *Storylines as a way of bringing meaning to climate change at the local scale*. The talk will be held virtually between noon and one p.m. Pacific Time.

- Read more about Dr. Sun's talk on our website.
- An abstract, speaker bio and registration information for Professor Shepherd's talk is available on our website.

STAFF PROFILE: JAMES HIEBERT

James Hiebert is the lead of PCIC's Computational Support Group, the team that writes the scientific software and effective web applications that make all of our products and services available to our stakeholders. James is also the steward of PCIC's computer and data resources, making sure that our data is protected with multiple layers of redundancy. This is challenging because of the amount of data and the diverse needs and use cases of PCIC's large audience. "It's a challenge of the imagination," James begins. "It's one thing to have the data, it's another to be able to make it reliably available to our users at all times." The Computational Support Group rises to this challenge, making PCIC's data and tools available around the clock, year-round.

James's background is in software development and computer science. James describes the discipline by saying, "It's really fun for my type of brain as there's an endless stream of puzzles to solve and there's a great payoff when you solve them." Outside of PCIC, James is an outdoor enthusiast and says, "I was initially resigned to the fact that my personal and professional life would be divorced from each other." But this changed in graduate school when saw the opportunity to support Earth scientists in the technical realm and in software development. So, James began working in ocean mapping at the National Oceanic and Atmospheric Administration (NOAA). There, he could see the immediate difference that his efforts made. This made clear to James one of the strengths of software development, "it is creative, but you also have so much leverage—even a small team can write something that can help millions of people." From NOAA, James moved to PCIC out of a general interest to help people. In the sciences, use cases and needs are constantly changing, "You're inventing something new every day," James explains. This also highlights one of PCIC's strengths, "Everything we do is so specific, we greatly benefit from having a dedicated team of software professionals." These tools are also built robustly and are meant to be updated. James comments on this: "It's easy to write a tool once that consumes a static set of data, but at PCIC we've created a really robust coupling between back-end data and front-end applications using that data, and we can easily improve elements. Our overall process has robustness built into the core of it. This has resulted in long-term payoffs for software maintenance."

PCIC's user base has a variety of needs, and this is reflected in the diverse products that PCIC offers. "We're bolstering our products that directly serve the building sector," James explains, "with the expansion of the weather files we offer to all of Canada and the ongoing development of the engineering Design Value Explorer tool." The group is also working on a data portal for Canada's Western Arctic, and this development is paying dividends for other PCIC tools, such as the BC Station Data Portal, which will be updated with similar interface code. This will make a sleeker and more responsive design. The benefits from these tools are clear, from their widespread adoption, to the publications that reference the data portal each year: "If we look at the publications that cite our data portal, there are dozens every year from tech reports from the government to research papers, and theses. The fact that we have so many people using these tools shows how easy they are to use, how accessible our data is due to its interface, and the fact that it's available without licensing restrictions." Reflecting on this, James comments, "This shows that the process is working."

PCIC STAFF NEWS

In December, PCIC is pleased to welcome Eric Yvorchuck to the Computational Support Group as the newest Programmer/Analyst. Eric has previously been with PCIC as a co-op student in the role of an Assistant Programmer. His new position includes a number of responsibilities, including some ongoing work on the Data Analytics for Canadian Climate Services project that he previously contributed to as a co-op student.

PUBLICATIONS

Li, C., Z. Wang, **F. Zwiers** and X. Zhang, 2021: Improving the estimation of human climate influence by selecting appropriate forcing simulations. Accepted, *Geophysical Research Letters*, doi:10.1029/2021GL095500.

Sobie, S.R., **Zwiers, F.W.**, and **C.L. Curry**, 2021: Climate model projections for Canada: A comparison of CMIP5 and CMIP6. Accepted, *Atmosphere-Ocean*, doi:10.1080/07055900.2021.2011103.

Sobie, S.R. and **T.Q. Murdock**, 2021: Projections of snow water equivalent using a process-based energy balance snow model in southwestern British Columbia, Accepted, *Journal of Applied Meteorology and Climatology*.

Sun, Q., **F. W. Zwiers**, S. X. Zhang and J. Yan, 2021: Quantifying the human influence on the intensity of extreme 1- and 5-day precipitation amounts at global, continental, and regional scales. *Journal of Climate*, doi: 10.1175/JCLI-D-21-0028.1.

Tan, Y., S. Yang, **F.W. Zwiers**, Z. Wang and **Q. Sun**, 2021: Moisture budget analysis of extreme precipitation associated with different types of atmospheric rivers over western North America. *Climate Dynamics*, https://doi.org/10.1007/s00382-021-05933-3.

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