# PCIC SCIENCE BRIEF: ON CHANGES TO GLACIERS IN WESTERN CANADA

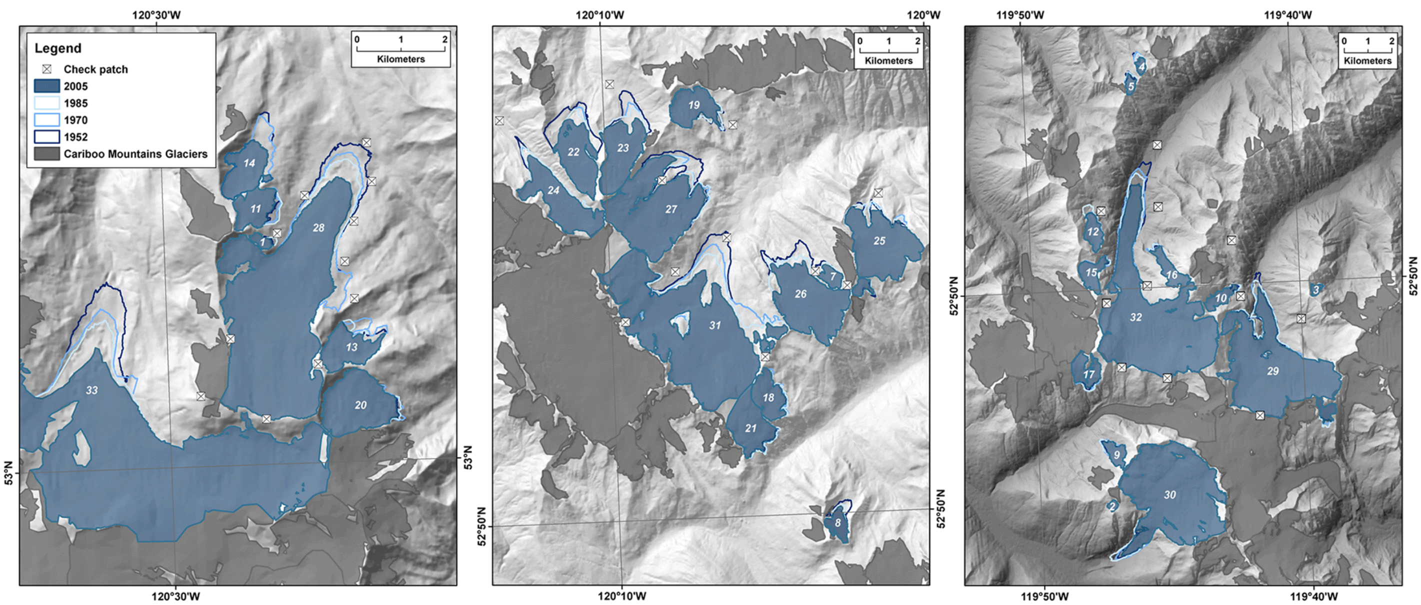


**Figure 1: Subset of 33 Cariboo glaciers in three subregions for four time periods, from Beedle et al. (2015).** These panels indicate the changes in glacier area over time for three subregions (left to right): Castle, Quanstrom and Premier. The Numbers are for identification purposes. Blue shading indicates glacier area as of 2005. Dark, medium and light blue lines indicate where the edges of the glaciers were in 1952, 1970 an 1985, respectively.

**Two recently published articles examine current and projected changes to glaciers in western Canada. The first paper, by Beedle et al. (2015) in *The Cryosphere* uses photographic methods to quantify changes to 33 glaciers in the Cariboo Mountains of British Columbia. They find that all glaciers receded over the 1952-2005 period, with a surface area loss of about 0.19% per year. From 1952 to 1985 this recession was slow, with about 0.05% of the total area covered by glaciers lost per year, and some glaciers advancing. However, the rate of lost glacial area increased eightfold, to about 0.41% per year, over the 1985-2005 period. The authors also find that both warming and decreased precipitation have played roles in the retreat of the glaciers.**

**The second paper, by Clarke et al. (2015) in *Nature Geoscience*, uses output from global climate models to drive a regional glaciation model in order to project possible future changes to glaciers in western Canada. They examine four different emissions scenarios and their projections for 2100 show a reduction of about 70% in glacier volume, relative to glacier volume in 2005. The projected reduction is dependent on the emissions scenario used. They find that most glaciers in the Interior and Rockies will be lost to the changing climate, but that some glaciers in coastal areas will remain in a smaller state. The authors also note that the largest losses in their projections occur around 2020 to 2040.**

Globally, glaciers are shrinking. We have seen an ongoing reduction in global glacier mass, with most observed glaciers receding over the period in which observations have been kept. The retreat of these glaciers will have impacts on the ecosystems and human communities that depend on them. In British Columbia, glaciers are an important part of many ecosystems because of their roles in hydrologic systems. Deglaciation would bring with it impacts not only for glacier ecosystems, but also downstream ecosystems[1], altering the timing and availability of fresh water supplied to rivers, lakes and the coast, and changing the availability of sediments, organic materials and nutrients. Water availability for communities in British Columbia could also be affected by deglaciation.

Because of their importance to communities and ecosystems throughout the province, it is important to have an understanding of how glaciers have reacted to climate change thus far and how they may be affected in the future. Examining the first question in *The Cryosphere*, Beedle and coauthors use aerial photography, combined with temperature, air pressure and precipitation data to determine how glaciers in the Cariboo Mountains have been affected by climate change since 1952. The use of aerial photography allows the authors to construct a record that goes back further in time than satellite glacier observations, which are limited to about the last 30 years.

The Cariboo Mountains are home to over 530 glaciers. Of these, the authors investigate changes in the areal extent of a subset of 33. These 33 glaciers were chosen both for their suitable photographic records and to create samples that are as representative as possible of the five different size classes of glaciers in the region. The overall selection is weighted toward the larger glaciers, in part because these are more important for changes to overall regional glacier volume and their meltwater contributions. Beedle et al. find that the area of these 33 glaciers shrunk by 10.6 ± 2.9% between 1952 and 2005 (Figure 1). This translates to a loss of about 15.11 square kilometres (km$^2$). The spatial extents of individual glaciers were reduced by between 0.5 ± 1.6% and 31.7 ± 1.4% over this period. Prior to 1985, some glaciers receded while others advanced, but each of the 33 glaciers examined shrunk after 1985. Glaciers with greater surface area that reside at higher elevations shrunk less than other glaciers.

The authors also compare the changes in aerial extent that they observe with those of an earlier study by Bolch et al. (2010) that used a combination of aerial photography and satellite images. Beedle et al. estimate a loss of 6.8% (53 km$^2$) in the areal extent of glaciers in the Cariboo Mountains over the 1985-2005 period, compared to the loss of 13.5% (114 km$^2$) reported by Bolch et al. The authors attribute this largely to an overestimation of glacier extent in data from earlier manually digitized photos from a 1985 survey used by Bolch et al. For comparison, the size of the city of Vancouver is just under 115 km$^2$.

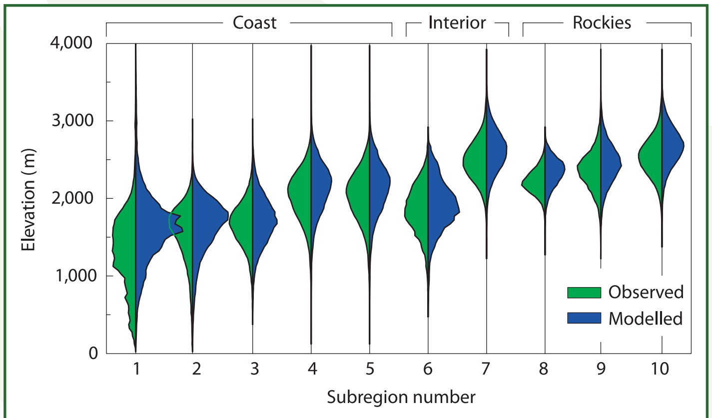


**Figure 2: Observed and modelled glacier area by elevation for 2005, from Clarke et al. (2015).**
The curves above compare the observed (green) and modelled (blue) area of glaciers at different elevations for 10 sub-regions in western Canada in 2005. Thicker curves indicate greater area.

For changes to glacier volume, the authors were limited to seven glaciers, due to image quality and snow cover. They found that five of the seven glaciers they examined continuously thinned and receded over all periods, while two glaciers shrunk over the 1952-1985 period and remained stable from 1952-2005. In aggregate, the glaciers lost the equivalent of about 0.195 km$^3$ of water over the 1952-1985 period and this melting increased to the equivalent of 0.345 km$^3$ of water over the 1985-2005 period. The authors extrapolate from these values to estimate the potential losses over the whole Cariboo region. If the authors' results are representative of the region, this would mean that glaciers in the Cariboo region lost the equivalent of about 4.027 km$^3$ of water over the 1952-1985 period and 7.580 km$^3$ over the 1985-2005 period. To put the size of these changes into perspective, a cubic kilometre is the volume of 400,000 olympic swimming pools.

The authors find that these changes to the Cariboo glaciers were likely due to increased temperatures and decreased winter precipitation. Temperatures in the region increased after 1985, increasing during the season when glaciers lose mass and doubling during the season when glaciers accumulate mass. Beedle et al. also note that their

1. For a more comprehensive overview of the effects of deglaciation on the coastal temperate rainforest ecosystems of the Pacific Northwest, see O'Neel et al., 2015.
2. For an overview of these projected impacts, see IPCC, 2014: Summary for policymakers. In: *Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

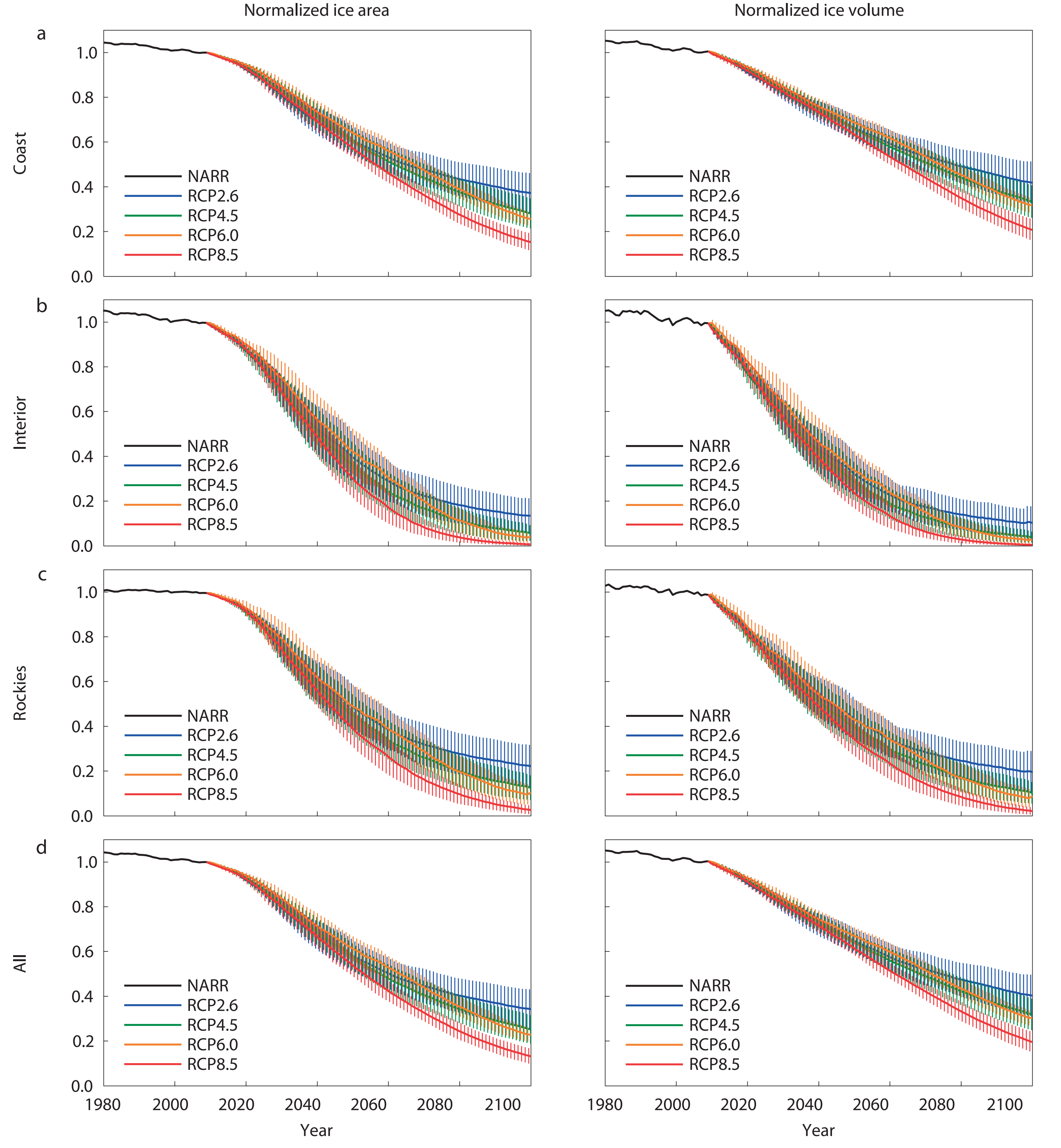


**Figure 3: Projected change in glacier area and volume for western Canada, from Clarke et al. (2015).**
These panels indicate the change in glacier area (left) and volume (right) for 2100 relative to 2005 for four regions: a) the Coast, b) the Interior, c) the Rockies, d) all of western Canada. The black line indicates estimates obtained by driving the glacier model with reanalysis[3] data, whereas the coloured lines indicate projections using the four emissions scenarios.


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Broader general trends of glacier loss over the recent historical period are reflected in this regional example. Looking toward the future and extending our focus from the Cariboo mountains to western Canada, we might then ask how glaciers in this larger region may fare in a world that continues to warm.

To examine this latter question, Clarke et al. (2015) perform a modelling study to investigate glacier changes under several different potential trajectories of anthropogenic greenhouse gas emissions. Publishing in the journal *Nature Geoscience*, they use a high-resolution regional glaciation model, driven by output from six global climate models under four different greenhouse gas emissions scenarios[4] in order to obtain projected changes to the glaciers of western Canada by the year 2100. These glaciers are largely in British Columbia, with some glaciers in Alberta's Rockies and spilling over into Alaska. Their study is the first to use such a high-resolution model that accounts for the physics underlying glacier dynamics over such a large region. This allows the authors to determine whether individual glaciers will be lost to a changing climate or preserved, but at a higher elevation.

In order to have confidence in the model, the authors first test its ability by comparing its simulations to observations. Clarke et al. first run the model from a state of having no ice to a state of rough equilibrium with the climate of the early 1900s in which glaciers have formed. They then use historical data and reanalysis data[3] to drive the model for a little over a century. They compare the 2005 observations of the elevation distribution of glacier area with those simulated for the same year (Figure 2). Though the model tends to slightly overestimate the area of glaciers on the coast and slightly underestimate those in the interior and in the Rockies, this bias in area results in only a small bias in simulated historical changes in glacier volume. Overall the simulations match the observations quite well, as can be seen from the similarity of the curves representing observed (green) and modelled (blue) area at each elevation and region in Figure 2.

Having confirmed that the model is capable of simulating the evolution of glaciers over the past century, the authors use the model to make projections of future glacier states. The authors drive their glacier model with the output from global climate models that are run using four different scenarios. The projections that the model provides suggest that western Canadian glaciers will shrink and, in many cases, disappear entirely. Compared to glacier volume in 2005, the projections indicate a loss of about 70% ± 10% by 2100. For area, the projected loss is 75% ± 10% by 2100.

Though the highest emissions scenario translates to the greatest glacier loss, with reductions of more than 80% to area and volume in all regions, the projections show significant reductions in glacier area and volume, with losses of 50% or more, for even the lowest emissions scenario. The amount of glacier loss differs by region and site, but in general the Interior region shows the largest losses, the coast region shows the smallest and the Rockies lie in between for all emissions scenarios (Figure 3).

In the projections, the resulting discharge from these melting glaciers tends to peak somewhere between 2020 to 2040. Discharge peaks are much less pronounced in the coast region under the RCP 8.5 emissions scenario and they are not present at all in the Vancouver Island subregion (for which the uncertainty is high due to the small number and size of the glaciers). The period of increasing and peak discharge represents the addition of water resources to glacier-fed rivers in the province. Importantly, after peak glacial contribution, the effects will decline, potentially exacerbating other conditions that may induce low summer stream flow.

Beedle, M.J., B. Menounos and R. Wheate, 2015: Glacier change in the Cariboo Mountains, British Columbia, Canada (1952–2005). *The Cryosphere*, **9**, 65-80, doi:10.5194/tc-9-65-2015.

Clarke, G.K.C., A.H. Jarosch, F.S. Anslow, V. Radić and B. Menounos, 2015: Projected deglaciation of western Canada in the twenty-first century. *Nature Geoscience*, **8**, 372–377, doi:10.1038/ngeo2407.

O'Neel, S. et al., 2015: Icefield-to-Ocean Linkages across the Northern Pacific Coastal Temperate Rainforest Ecosystem. *BioScience*, **65**, 5, 499-512, doi:10.1093/biosci/biv027.

van Vuuren et al., 2011: The Representative Concentration Pathways: An Overview. *Climatic Change*, **109**, 1-2, 5-31, doi:10.1007/s10584-011-0148-z.

3. A reanalysis is a representation of the historical climate that is created from historical observations that are "assimilated" into a model, often a global weather forecast model, but here a Limited Area Model that is run in a hindcast mode. For more information on the North American Regional Reanalysis, see: http://www.emc.ncep.noaa.gov/mmb/rreanl/.
4. The Intergovernmental Panel on Climate Chance uses four new trajectories of atmospheric greenhouse gas concentration, known as Representative Concentration Pathways (RCP) for its Fifth Assessment Report. The four trajectories are denoted by the change to radiative forcings that would result from each concentration, e.g. RCP 4.5 would result in an increase of 4.5 Watts per square meter as compared to the preindustrial period (taken to be the year 1750). For more information on CMIP5 and the RCPs, see: van Vuuren et al., 2011: The Representative Concentration Pathways: An Overview. Climatic Change, 109 (1-2), 5-31 doi:10.1007/s10584-011-0148-z.

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