PCIC SCIENCE BRIEF: UPDATE ON DAILY TEMPERATURE AND PRECIPITATION CHANGES IN CANADA

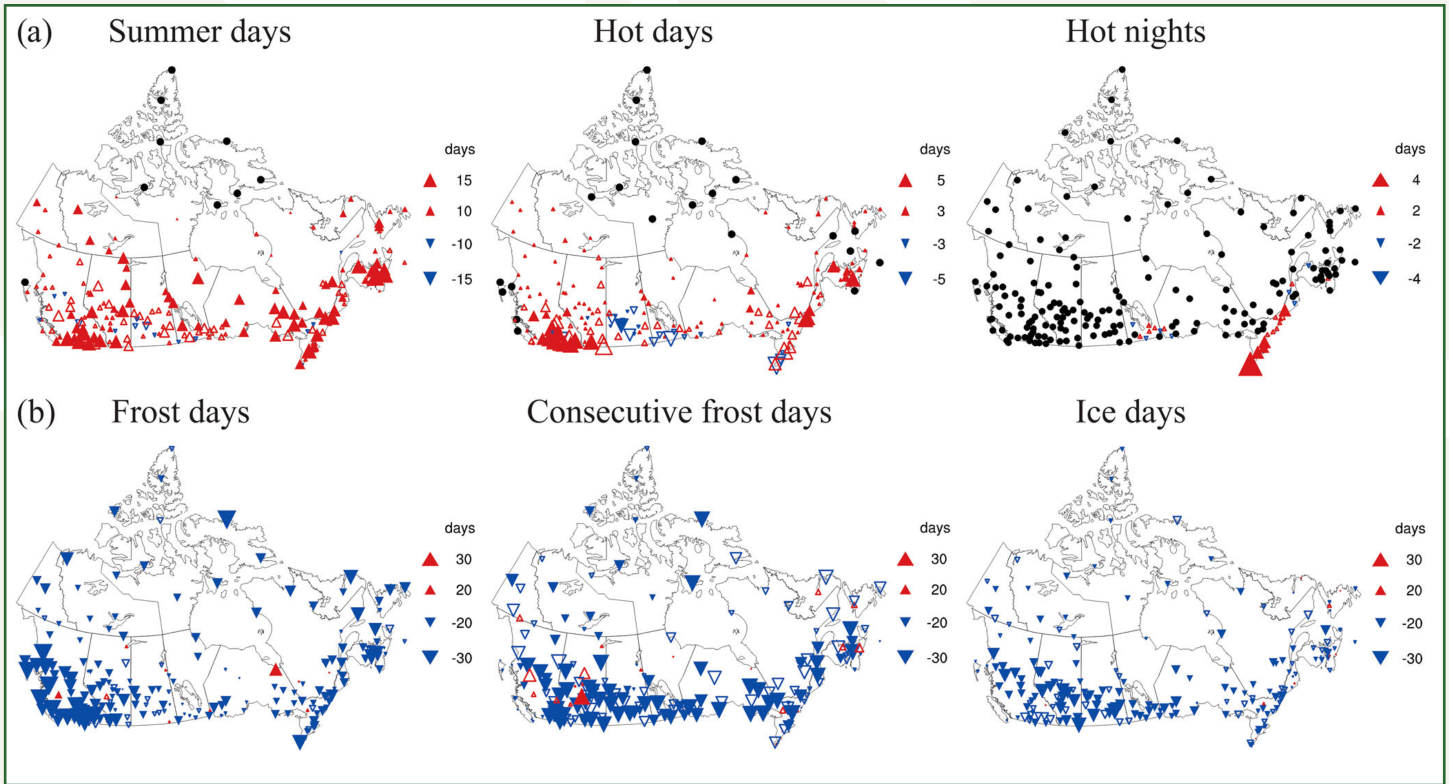

Figure 1: Trends in hot and cold temperature indices (from Vincent et al., 2018).
This figure shows the trends in (a) hot and (b) cold temperature indices at Canadian stations over the 1948-2016 period (in days per 69 years). Triangles indicate increases or decreases as per each panel's legend and black dots indicate locations where the condition has not occurred for at least five years over the whole period.

As Canada's climate continues to change, trends in mean temperature and precipitation are evident, but so to are trends in indices based on temperature and precipitation observations. These are of interest to a wide range of sectors and this Science Brief covers a recent paper on changes to these indices in Canada.

Publishing in the journal *Atmosphere Ocean*, Vincent et al. (2018) use daily weather station data from across Canada to compute 35 temperature and precipitation indices over the 1948-2016 period for all of Canada, and over the 1900-2016 period for locations in southern Canada.

They find that the changes in the indices that they examine are consistent with warming, with greater warming seen in indices of cold temperatures. They also find that changes in the precipitation indices they examine vary by location.

The authors find that very warm temperatures in both summer and winter have increased across Canada and that the number of summer days have increased at most locations in southern Canada.

The growing season has become longer, and both growing degree days and cooling degree days have increased. Very cold temperatures have decreased across the country in both summer and winter, and heating degree days have decreased.

Regarding sectors, the authors find the following. Increasing warm temperature extremes may bring health impacts. An increase in warm conditions may be advantageous for summer tourism, but adversely affect winter sports and tourism. Longer growing seasons and warmer weather at higher latitudes may offer some benefits for agriculture, but may also bring risks from new pests and diseases, as well as reduced water availability due to reduced snowfall. Fewer freeze-thaw days may also reduce maple syrup production. Warming conditions may also reduce the energy required for heating but would also increase energy demand for cooling. Warming conditions may increase the length of the shipping season, but could also have negative effects on the maintenance of roads in some areas of central Canada due to more frequent freeze-thaw cycles.

Introduction

Canada's changing climate has the potential to have a wide range of impacts on a variety of sectors, both public and private. In order to better understand what these impacts may be and to prepare for them, Canadians require an understanding of not just general trends in temperature and precipitation, but also changes in specific quantities of interest, such as changes in temperature and precipitation extremes, heating and cooling demands, and the length of the growing season.

On Changes to Temperature and Precipitation Indices in Canada

Anthropogenic climate change is affecting Canada. The country is warming at about twice the global rate, with glaciers receding, decreased duration of snow cover and an increasing proportion of spring precipitation that is falling as rain rather than snow. This warming is greater in the north and greater during the winter season. The potential impacts from the country's changing climate are wide ranging, with implications for human health, tourism, water availability, agriculture, energy consumption patterns, shipping and infrastructure, among many other areas.

The changing climate of Canada is reflected in British Columbia. Canada has warmed by about 1.7 °C in the annual mean over the 1948-2016 period and BC has warmed by about 1.9 °C. Canada has warmed by about 3.3 °C in the winter and BC has warmed by about 3.7 °C. The sectors above are present in BC and are, broadly speaking, susceptible to climate change impacts.

In order to prepare for these impacts, stakeholders in BC require not only information on mean trends of past and projected future climate change, but also information about quantities of interest to their sectors. For example, those in agriculture may benefit from information about changes to water availability and growing season length, whereas those operating in tourism may be interested in the number of warm, summer days or seasonal snow conditions, and those doing energy planning might find changes in the timing and amount of energy needed for heating and cooling to be of interest.

Writing in *Atmosphere-Ocean*, Vincent et al. (2018) use data from weather stations across Canada to compute and examine trends in a set of climate-related indices that are meant to capture quantities of interest based on temperature and precipitation. They also comment on how changes in these indices may impact the sectors above. This research follows from earlier work that has identified changes in temperature and precipitation trends in Canada[1], as well as changes in a number of related indices[2].

Changes in Temperature Indices

The authors used temperature observations from 338 stations across the country and precipitation data from 464 stations, with more station data being available in the southern part of the country. They divided up their data into a 5° by 5° grid[3] and, using provincial boundaries, into

1. For more information on earlier work on temperature and precipitation trends in Canada, see Zhang et al. (2000) and references in Vincent et al. (2018). For an updated and comprehensive overview of changes to Canada's climate, see Bush and Lemmen (2019).
2. For more information on earlier work examining climate indices in Canada, see the references in Vincent et al. (2018).
3. The length of a degree varies with latitude, due to the shape of the Earth. The Earth is an oblate spheroid: loosely, its shape is a sphere that is very slightly "flattened," such that the radius at its equator is slightly greater than the radius at its poles. The physical distance between degrees of longitude decreases poleward as lines of longitude converge. The physical distance between degrees of latitude increases slightly poleward due to the oblate nature of the planet. Near Vancouver, a degree of latitude is about 111 kilometres and a degree of longitude is about 73 kilometres. Near Fort Nelson, the degree of latitude is a little longer, but still about 111 kilometres, while a degree of longitude shrinks to about 59 kilometres. At Alert, Nunavut, a degree of latitude grows to nearly 112 kilometres, while a degree of longitude is a little under 15 kilometres. Because the length of a degree changes with latitude, the area of a 5° × 5° grid varies accordingly.

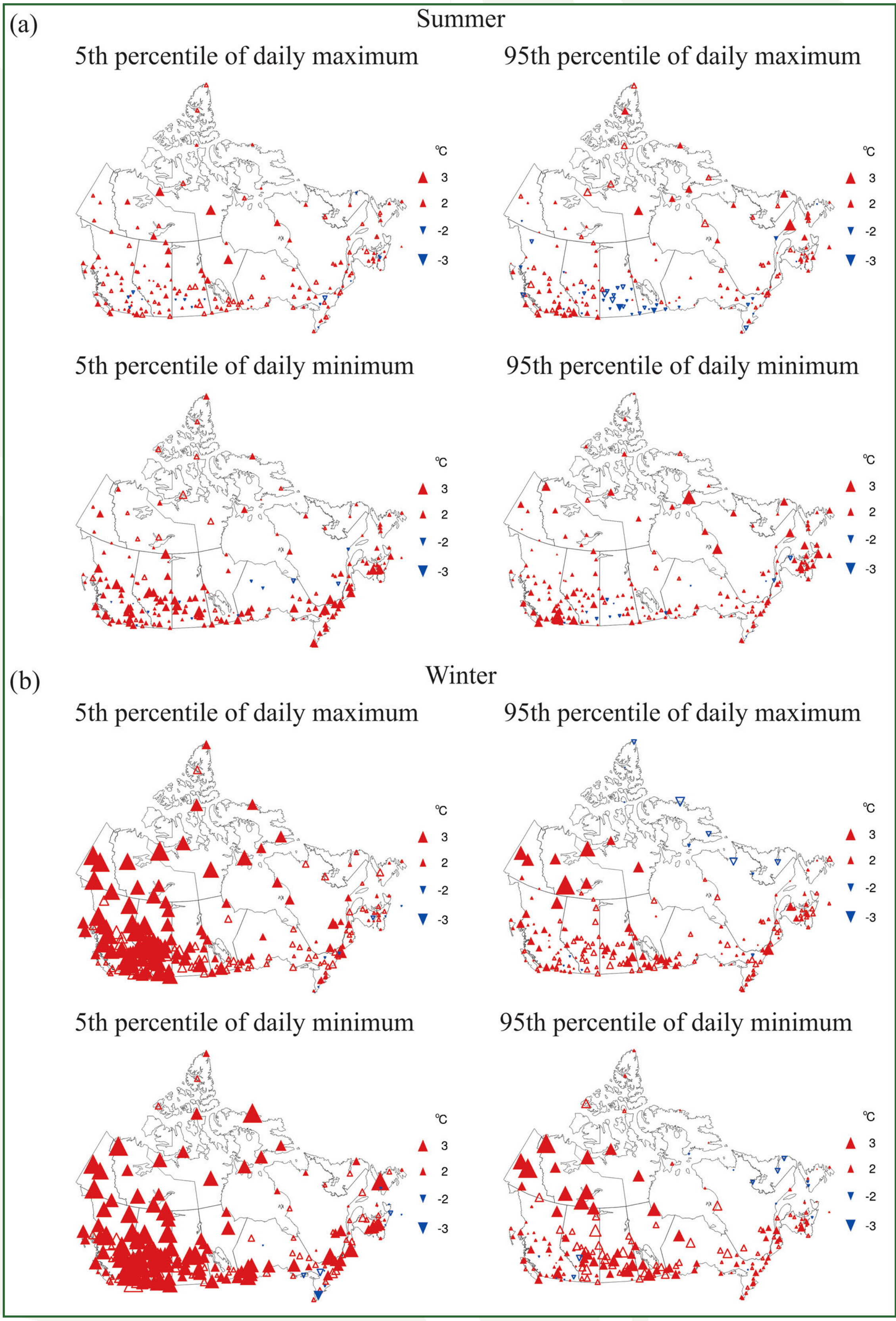

Figure 2: Trends in the maxima and minima of daily temperature (from Vincent et al., 2018).
This figure shows the trend in the 5th percentiles (left panels) and 95th percentiles (right panels) of maxima and minima of daily temperature for (a) summer and (b) winter. (In °C per 69 years.) Triangles indicate increases or decreases as per each panel's legend.

six regions: Northern, British Columbia, Prairies, Ontario, Quebec and Atlantic.

Vincent and coauthors find that, over the 1948-2016 period, Canada has become somewhat warmer during its warmest periods, but also much less cold during its coldest periods[4] (Figure 1). The number of summer days per year, defined as days with a high temperature over 25°C, have increased by about 6.9 days when averaged over the southern part of the country and about 5.8 days in BC. The number of hot days per year, with a high over 30°C, have also increased at a small number of stations in southern Canada, and by about 3.3 days in BC, while the annual number of hot nights, with a temperature over 22°C, hasn't changed significantly. The 95th percentile of daily maximum temperatures (loosely, the daytime high temperature on very hot days) and the 95th percentile of daily minimum temperatures (loosely, the nighttime high temperature on very warm nights) have also increased over the summer and winter (Figure 2), though the winter trends are much larger. In BC, only the winter trend is statistically significant. Cooling degree-days, which are often taken as a measure of energy demand for cooling, and are calculated[5] by summing the number of degrees above 18°C from those days with mean temperatures above 18°C, increased across the southern part of the country and in BC.

Some of these trends are not uniform across the country. For instance, the 95th percentile of daily summer maximum temperatures and the number of hot days decreased slightly in some parts of the prairies, which the authors say may be due to the exceedingly high temperatures seen in that region over the 1930s and 1940s.

In general, the high temperatures on warm nights have increased more than the high temperatures on hot days, by about 1.3°C compared to 0.9°C. This trend is also seen in winter high temperatures. Vincent et al. repeated their analysis for the 1900-2016 period for southern Canada only and found similar results, including slight negative trends in hot days and summer days in some parts of the prairies.

The authors' results also show that, averaged across the country, the frost-free season (the maximum number of consecutive days with temperatures above 0°C) has increased in length by about 20 days over the 1948-2016 period (Figure 3), starting earlier in the year and ending later. This trend is larger in BC, with an overall increase of about 31.2 days. The length of the growing season also increased over this period, by about 15 days nationally and by just over 19 days in BC (Figure 3). Growing degree days, calculated in a similar manner to cooling degree days, by summing the number of degrees above 5°C from those days with mean temperatures above 5°C, which are meant to indicate the amount of heat energy available for crops to grow, also increased nationwide and across BC.

Examining trends in cold conditions, the authors find that they have become much less cold. The number of frost days each year, with a minimum temperature of 0°C or colder, have decreased by an average of 15.0 days across the country, over the 1948-2016 period (Figure 1) and the frost-free season (the maximum number of consecutive days with temperatures above 0°C) has lengthened by 20.1 days. BC has seen a much larger shift, with the largest reduction in frost days in the country, at 25.9 days, and the largest increase in the frost-free season at 31.2 days. The same is true for the number of consecutive frost days, which have decreased by about 18.6 days in both BC and in the national average. The number of ice days each year, where the maximum temperature does not go above 0°C, which have decreased by about 11.2 days in BC and 11.7 days across Canada.

Vincent et al. find that the 5th percentiles of winter maximum temperature and minimum temperature—which can be thought of as the coldest daytime and nighttime high temperatures, respectively—have increased by 3.2°C and 3.5°C, a change that is quite large compared to related indices (Figure 2). The changes in BC are similar, at 4.3°C for the 5th percentile of winter maximum and 5.1°C for the corresponding minimum. The 5th percentiles of summer maximum temperature and minimum temperature have also increased, albeit to a lesser extent. The authors repeat their analysis for the 1900-2016 period over southern Canada and find a similar pattern of overall warming for cold extremes and greater warming during the coldest periods. This reduction in cold temperatures is accompanied by a reduction in heating degree-days. Heating degree days are somewhat like cooling degree days, in that they are often taken to be a measure of energy demand, but for heating instead of cooling. They are calculated by summing

4. The increased temperature during the coolest periods and at higher latitudes is due to several factors, including reductions in the snow and ice that reflect incoming solar radiation, and increased heat transport from southern latitudes by large weather systems. The increase in daily minimum temperatures is thought to be primarily due to diurnal variations in the depth of the planetary boundary layer. During the day, the sun warms the Earth's surface, causing air near the surface to warm and rise, making a layer of air called the planetary boundary layer. At night, when temperature minimums generally occur, the surface cools, reducing this convection and the planetary boundary layer shrinks dramatically. Because there is less air in this surface layer at night, it is easier to warm and thus, more sensitive to changes in heat forcings (such as the forcing due to atmospheric greenhouse gases) at that time. For more on this, see Davy et al. (2017).

5. For example, a day with a mean temperature of 20°C would contribute two cooling degree-days to the annual total.

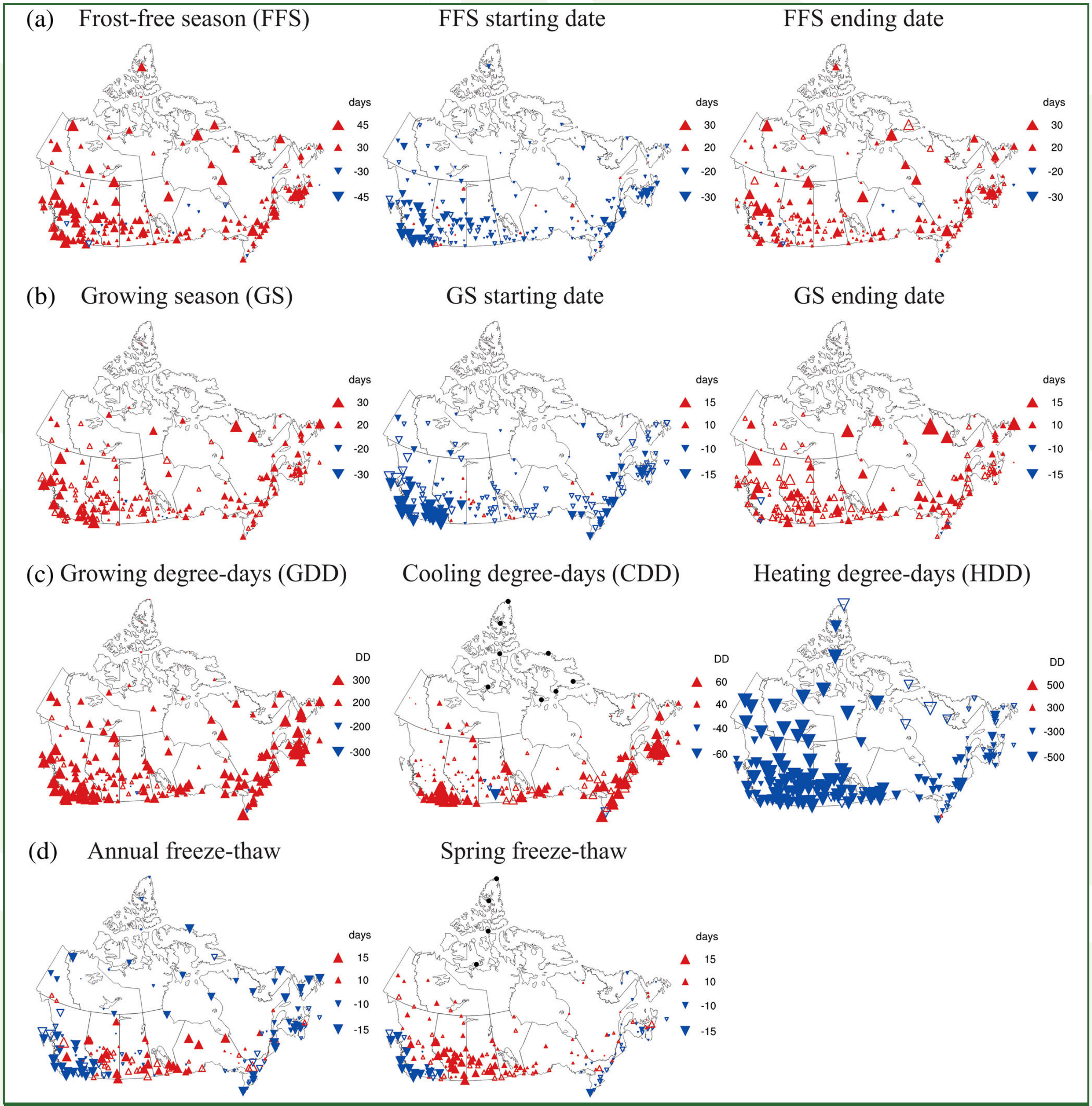

Figure 3: Trends in frost, growing-related , degree-day and freeze-thaw indicators (from Vincent et al., 2018).
This figure shows the trends in (a) frost-free season related, (b) growing-season related, (c) degree day and (d) freeze thaw indicators at Canadian stations over the 1948-2016 period (units in days or degree-days per 69 years). Triangles indicate increases or decreases as per each panel's legend and black dots indicate locations where the condition has not occurred for at least five years over the whole period.

the number of degrees below 18°C on those days with a mean temperature less than 18°C. Heating degree days in BC have reduced sharply, at roughly twice the Canadian average. The shift in the number of annual freeze-thaw days (days with minimum temperatures less than or equal to 0°C and maximum temperatures above 0°C) has been inconsistent across the country, with decreasing trends on the coasts, and, to a lesser degree , in the north, but increasing trends throughout the prairies and Ontario. The trends for spring freeze-thaw days (over the January-April period) are broadly similar, except that they show no overall trend in the north and smaller trends in Ontario and along the eastern seaboard. Both freeze-thaw days and spring freeze-thaw days show significant reductions in BC.

Changes in Precipitation Indices

Vincent et al. find that the trends in the precipitation indices they examine are less consistent spatially and over time. The number of days with at least a millimetre of rainfall each year and the number of days with heavy rainfall (defined as days with rainfall in the 90th percentile) have increased across the country over the 1948-2012 period, by about 7.4 days and 1.3 days, respectively (Figure 4). While BC hasn't seen a statistically significant increase in days with heavy rainfall, the number of days with at least a millimetre have increased by 11.3, the largest increase in Canada. There has been no statistically significant change in the highest one-day rainfall, snowfall, highest one-day precipitation (snow and rain) events, or the length of the maximum number of consecutive dry days.

Regarding snowfall, only BC and northern Canada show statistically significant trends in days with at least a millimetre of snowfall and days with heavy snowfall, though the trends are in opposite directions in each area. In BC, days with snowfall each year have reduced by about 6.3 and days with heavy snowfall have shrunk by about 1.3, whereas in the north, these have increased by about 7.3 days and 2.2 days, respectively.

Sectoral Impacts of Changes in Daily Temperature and Precipitation Indices

The authors chose the indices that they examined for their relevance for potential climate impacts. After laying out the changes to these indices, Vincent et al. discuss what some of the potential impacts for specific sectors may be. Beginning with health, the authors note that the increase in extreme warm conditions, such as the 95th percentile of hottest summer days and nights, may have health impacts and that such hot extremes are expected to increase as Canada's climate continues to change. Increasing maximum and minimum temperatures may be a double-edged sword for tourism, benefitting summer tourism activities such as camping and golf, as the length of the warm season expands, and harming winter tourism, as activities including skiing and snowmobiling become possible for shorter periods. Decreases in snowfall and heavy snowfall in western Canada may also exacerbate this.

The results of Vincent et al. show that agriculture in Canada has seen an increased growing season, with warmer temperatures prevailing for longer periods and pushing ever farther north. They note that warming weather could bring benefits, such as allowing crops to be grown farther north, but it may also bring new pests and diseases, and the decrease in snow may reduce water availability. A reduction in freeze-thaw days may also reduce maple syrup production. The authors also discuss how the changing climate may shape energy demands, as a reduction in heating degree days, very cold days and frost days may reduce the need for energy for heating, though an increase in cooling degree days may increase cooling demands.

The warming climate may also affect shipping and road maintenance. Vincent et al. suggest that a longer frost-free season may allow ships to travel the Great Lakes and Saint Lawrence seaway for longer and that the Arctic shipping season may also lengthen as the north warms. Because freezing and thawing cycles can increase the need for road maintenance, the observed reduction in freeze-thaw days in coastal provinces and the increase in the interior of the country may cause a lesser and greater need for road maintenance in these areas, accordingly.

Summary

The work of Vincent et al. shows how Canada's climate is changing in terms of daily temperature and precipitation indices, over both the 1948-2016 period and, for southern Canada, since 1900. It reveals that, while the country is getting warmer, it is also getting much less cold at those times when cold conditions prevail. Their work shows that changes to precipitation indicators are much less clear and consistent.

These general features of are true of indicators in British Columbia as well. BC has seen an increase in summer days, hot days, the temperature during warm nights and the daytime highs during the winter, but no statistically significant change in hot nights or daytime highs during the summer. The coldest daytime and nighttime temperatures

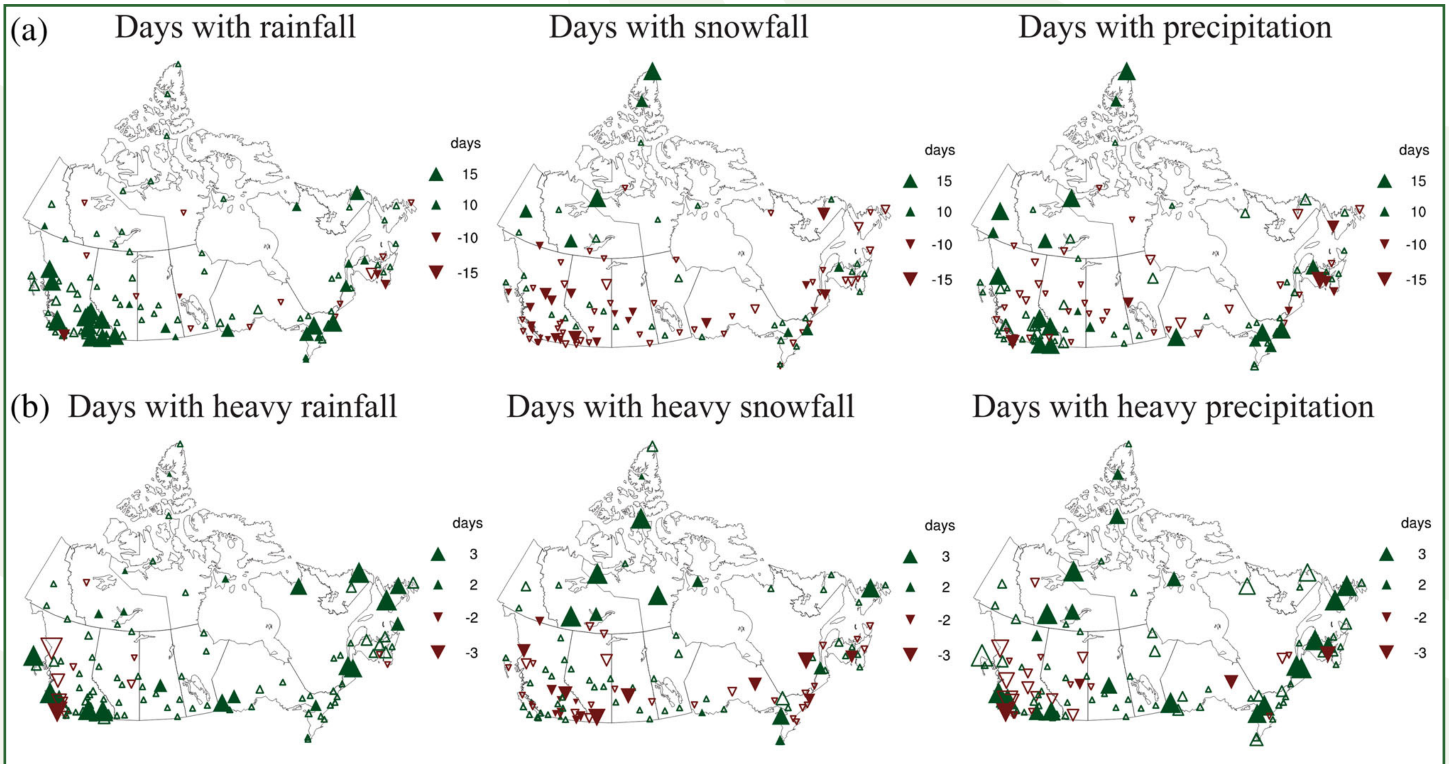

Figure 4: Trends in precipitation and heavy precipitation indices (from Vincent et al., 2018).
This figure shows the trends in (a) days with rainfall, snow and any precipitation and (b) days with heavy rainfall, snow or precipitation of any type at Canadian stations over the 1948-2016 period (in days per 69 years). Triangles indicate increases or decreases as per each panel's legend.

in the province have both warmed. The frost-free season has lengthened in the province alongside the growing season. BC has seen the largest increases in the country for days with at least a millimetre of rainfall, and days with heavy rainfall have also increased. While rainfall has increased in the province, both snowfall and heavy snowfall have decreased.

Projections[6] for the middle and end of the century in BC echo the changes that Vincent et al. find, with an increasing mean temperature, decreases in snowfall, snowpack and heating degree days, and increases in growing degree days, frost-free days and to the length of the dry season.

The sectors that the authors discuss exist in BC and the trends that they have identified at the national scale are broadly similar to those of the province. An increase in hot conditions may affect human health in BC. An increase in warm conditions may benefit summer tourism in the province, while a decrease in cold conditions may impact winter tourism. Increased temperatures, along with the increased length of the growing and frost-free seasons may mean that new varieties of crops may be grown and farther north, though warming may also bring new pests, diseases and decreases to water availability. A decrease in heating degree days and an increase to cooling degree days may cause a shift in the energy demands of the province. A reduction in freeze-thaw days could reduce the amount of maintenance for some of BC's roads. There are, of course, other sectors in BC that have not been considered that would also be impacted, such as forestry. The provinces biodiversity is also going to be affected by the changing climate in multiple ways that are outside of the scope of this science brief.

Vincent and co-authors show how the climate of Canada and the provinces comprising it have changed over the instrumental record. The Earth's climate will continue to change, dependent in large part on future greenhouse gas emissions, and the climates of Canada and BC will change with it. For more information on Canada's changing climate, BC's changing climate and adaptation planning, see the resources below[7].

6. To see projections of multiple indices for Canada, see PCIC's Climate Explorer tool: pacificclimate.org/analysis-tools/pcic-climate-explorer.

7. For more information on climate change in Canada, with information on each province, see Canada's Changing Climate Report at: changingclimate.ca/CCCR2019/. For more information on adaptation planning in British Columbia, see ReTooling for Climate Change at: ReTooling.ca, PCIC's Plan2Adapt tool, at: Plan2Adapt.ca and PCIC's Climate Explorer tool (link in footnote 6, above).

Bush, E. and D.S. Lemmen, (editors) 2019: *Canada's Changing Climate Report*. Government of Canada, Ottawa, ON. 444 pp.

Davy, R., et al., 2017: Diurnal asymmetry to the observed global warming. *International Journal of Climatology*, **37**, 1, 79-93, doi:10.1002/joc.4688.

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