The Changing Climate and Environment of the Interior of Western Canada

Observations over the past several decades show clear warming trends and patterns of widespread climatic change that have affected landscapes, ecosystems, and water cycling over this vast region.

The climate across western and northern Canada has been warming and showing other clear changes in recent decades. Rising temperatures and the loss of cold conditions continue to lead to declining snow and ice cover, thawing of frozen ground, and associated terrestrial ecosystem changes and altered water cycling. It is important to understand these changes in response to climatic variability and long-term change, and to address the question of what does the future hold? This is the focus of the Changing Cold Regions Network (CCRN), a Canadian network of university and federal government research scientists that aims to examine and better understand the behavior and variability of the climate and Earth system over the cold interior of western Canada, and ultimately predict the most likely future responses under different probable global climate scenarios. An initial objective of the CCRN is to characterize and evaluate the changes that have occurred in the recent past to establish a foundation for more detailed analysis. Here, some of the climatic and environmental changes that have been observed across the region are briefly presented and explored.

Southern Arctic Lowlands, Trail Valley Creek, NT

Sub-Arctic Taiga Shield, Baker Creek, NT

Southern Boreal Forest, Boreal Ecosystem Research and Monitoring Sites (BERMS), SK

Western Cordillera Continental Ranges, Lake O'Hara, BC

Mixed Grassland Prairie, St. Denis National Wildlife Area, SK

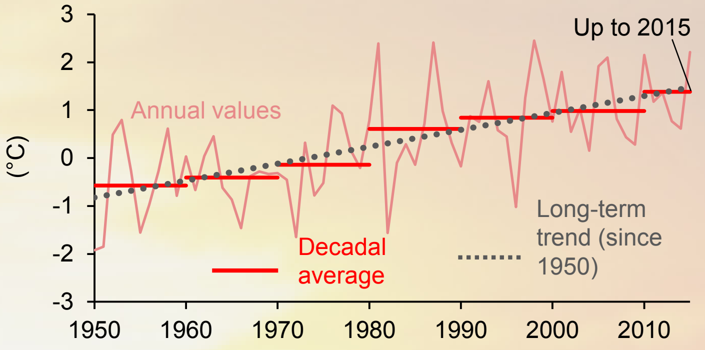
ECOREGIONS OF WESTERN CANADA'S INTERIOR

Western Canada's vast interior region, which includes the continental drainage systems of the Mackenzie and Saskatchewan Rivers, encompasses a wide range of ecoregions. These are all characterized as cold region environments, where the influence of seasonal or permanent freezing conditions plays a major role in the Earth system processes and functioning, and the responses to climatic change.

Temperature

Despite year-to-year variability, the average annual air temperature over western Canada has risen by about 2°C since 1950—this exceeds the global average increase for this period, which was about 1.2°C. The trend over western Canada has been based on quality controlled, standardized measurements at hundreds of stations across the region, collected by Environment and Climate Change Canada (ECCC) and archived in a National Climate Database. A large number of studies have used these data to conduct statistical analyses and examine trends and variability in the long-term annual and seasonal records. In addition to the annual warming trend, these studies have shown that winter temperatures over the region have risen on average by about 4°C, and in some areas by as much as 6°C or more. This warming is among the highest in the world for this period. In association, there have more warm spells and fewer cold spells, greater warming at night than during the daytime, and an earlier shift to above 0°C temperatures in springtime. As the greatest rise in temperatures has been for the daily minimums, and on a seasonal basis, during winter, another way of expressing the change is that the region is becoming less cold. Indeed studies have shown that the changes in extreme cold conditions (becoming far more infrequent) have been greater than those of extreme hot conditions (more frequent).

Difference in temperature from 1961–1990 average over the interior of western Canada

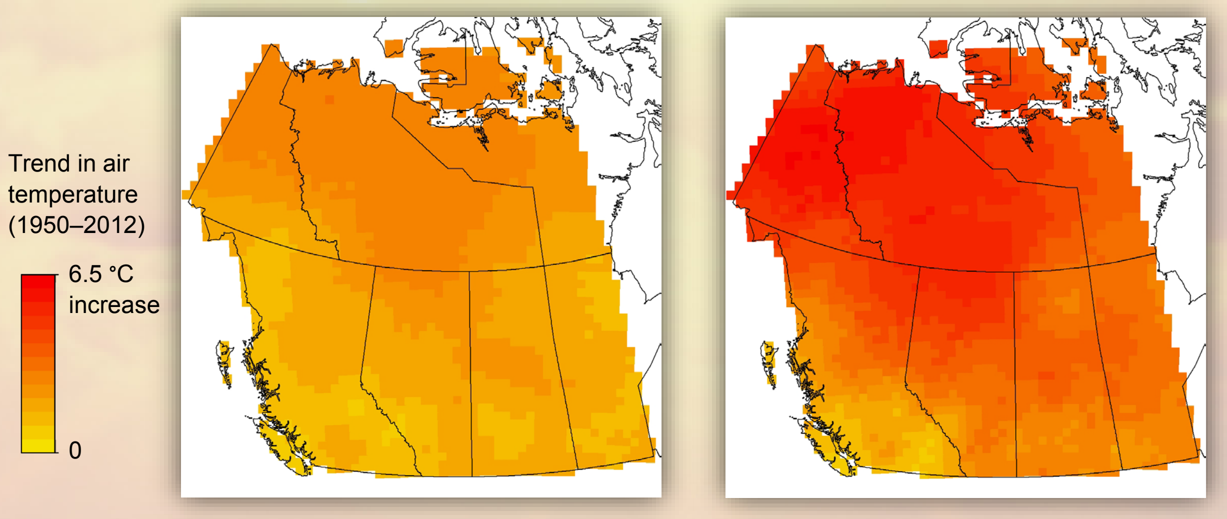


TEMPERATURE TRENDS OVER TIME

The long-term trend over the past 65 years has been a steady rise in average temperatures. Each decade has been warmer than the last, with a total rise of just over 2°C since 1950.

Data Source: ECCC (http://www.ec.gc.ca/dccha-ahccd/)

Annual average **Wintertime average**



REGIONAL WARMING PATTERNS

Spatial and seasonal patterns reveal that the greatest warming has occurred during the winter months and in the northern areas, where increases of more than 6°C have been observed since 1950.

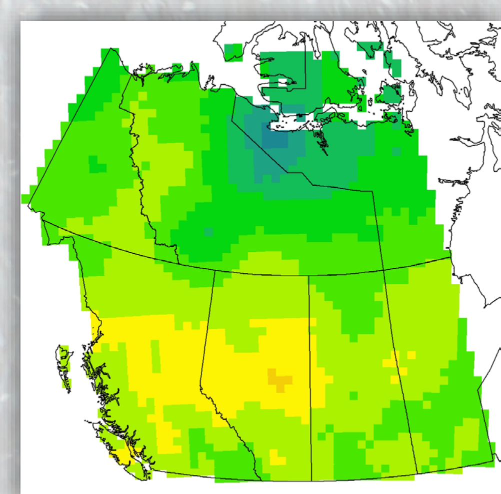
Data Source: ECCC (http://www.ec.gc.ca/dccha-ahccd/)

Precipitation and Snow Cover

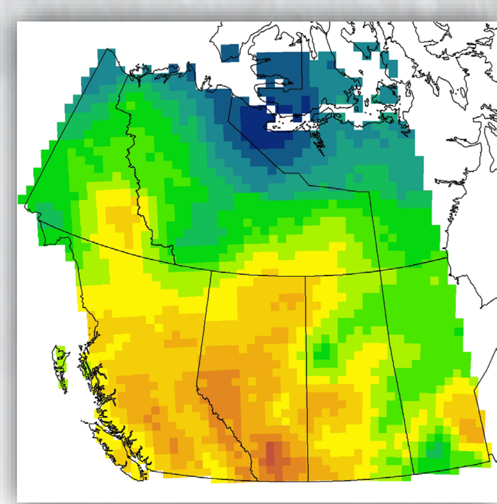
Observations from ECCC's network of climate stations show that, on average, there has been a slight increasing trend in precipitation amounts across western Canada since 1950. However, the patterns have been more variable, both seasonally and geographically, than those of temperature. Overall, the amount has increased by about 14% (or 50 mm), but in northern areas, the increase in precipitation locally has been as much as 60% (200 mm). In wintertime, a clear distinction between increases in the north and decreases in the south has been observed, where some parts of the southern Canadian Prairies have experienced a decline in winter precipitation by as much as 50% or more. Seasonal changes like these have important consequences in terms of the accumulation of winter snowpacks or the flow water in of streams and rivers, for example. Further to this, warmer temperatures have resulted in an increasing fraction of precipitation falling as rain rather than snow (with shifts locally by as much as 20%), especially in the spring and fall shoulder seasons.

Climatic changes such as the observed warming (especially in winter and spring), the reduction in winter precipitation in some areas, and the shift from snowfall to rainfall have caused significant changes to the seasonal snow cover across the region. Measurements are available from hundreds of long-term observing stations going back to the 1950s or earlier, while satellite observations provide regional coverage since as far back as the 1970s. Analysis of these datasets show that there have been widespread reductions in the maximum snow depth (of as much as 0.5 m or more since the mid-20th century) and in the duration of snow cover, mainly as a result of earlier melting in springtime. The satellite records have shown a clear pattern of decreasing spatial extent of snow cover, especially in the later spring months, and confirm the reduction in seasonal duration of snow cover, which has declined by as much as one to two months across the region. Some studies have confirmed that this decline is of even greater magnitude than the reduction in ice cover extent and duration seen over the Arctic Ocean over the same period.

Annual total

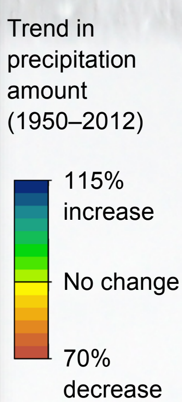


Wintertime total



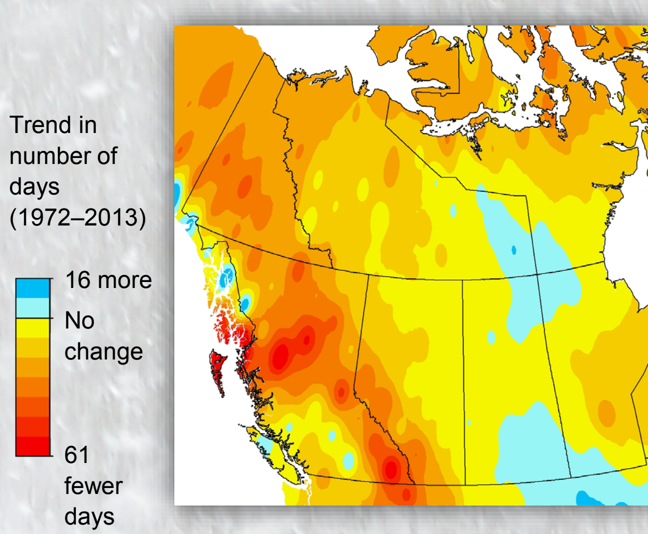
REGIONAL CHANGES IN PRECIPITATION

Spatial patterns of change have been more varied seasonally and geographically than for temperature. Winter precipitation has declined considerably in south-western Canada.



Data Source: ECCC (http://www.ec.gc.ca/dccha-ahccd/)

Change in the number of days with winter snow cover



DECLINING SNOW COVER

The duration of winter and springtime snow cover has been steadily declining, giving a reduction in the snow cover period of as much as one to two months over most of western Canada since the early 1970s.

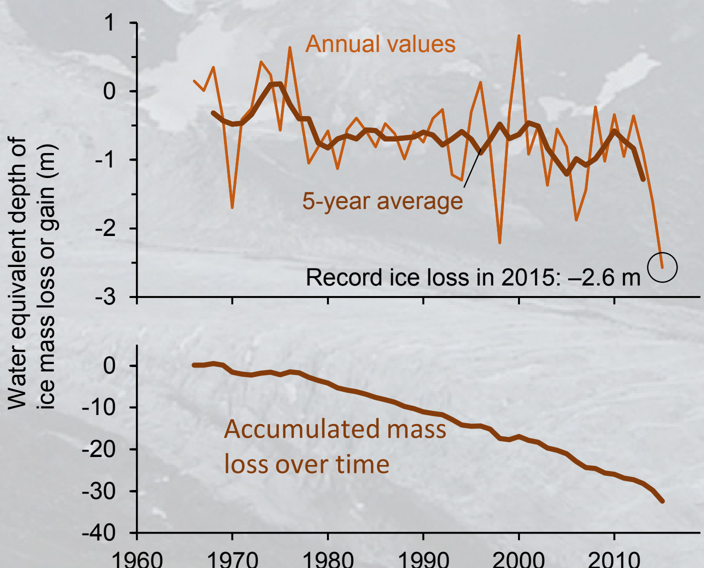
Data Source: US National Oceanic and Atmospheric Administration weekly snowcover dataset (data documentation at http://climate.rutgers.edu/snowcover/docs.php?target=vis)

Mountain Glaciers

Glaciers are sensitive indicators of variations in the regional climate, with their advance or retreat depending on the balance between the accumulation and the melt of snow and ice each year and over longer periods. In western Canada, glaciers and icefields occur extensively throughout the mountain regions, covering an area of roughly 50,000 km^2. Mapping of their extents over time and monitoring of their surface elevation has shown glaciers have been mostly retreating—some by as much as several kilometers since the early 1900s—and thinning, and that the rate of their retreat has accelerated in more recent years. These changes can readily been seen at places such as the Athabasca Glacier in Jasper National Park, where tourists can get a first hand look at the glacier's current front and the position of its terminus at various dates over the past century. Several reference glaciers, including Peyto Glacier in Banff National Park, have been the sites for long-term, intensive monitoring of their mass balance (total accumulation minus total loss of ice and snow each year, averaged over the glacier surface). Records from these glaciers show seasonal and interannual variability in mass balance, but indicate mostly negative conditions (mass loss), with recent increasing rates of loss.

Retreat of the Peyto Glacier, AB

Mass balance record since 1965 for Peyto Glacier



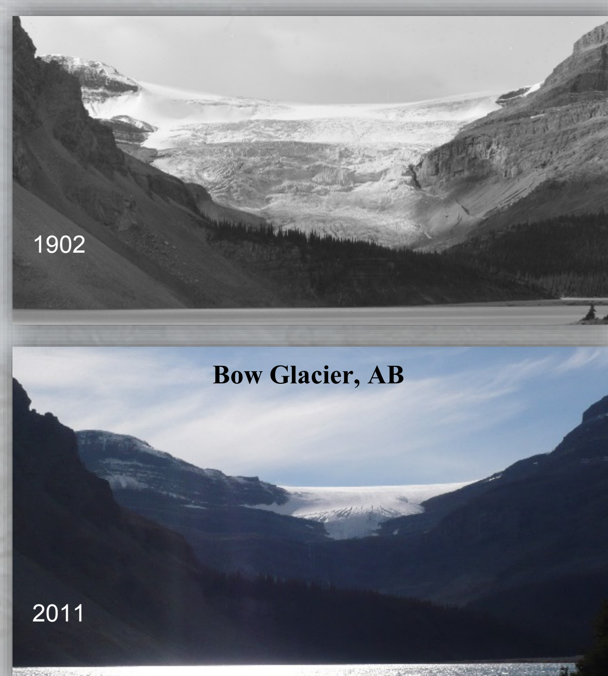
DOCUMENTED GLACIER MASS LOSS AND RETREAT

Like many glaciers in the Rocky Mountains, and western Canada in general, Peyto Glacier has been losing mass and continuously retreating at its terminus and along its margins. The net mass balance of Peyto Glacier has been predominantly negative since measurements began in 1965, losing over 32 m of water equivalent depth over the entire surface, and 2015 set a record for ice loss.

Data Source: Geological Survey of Canada, Natural Resources Canada

DIMINISHING GLACIERS

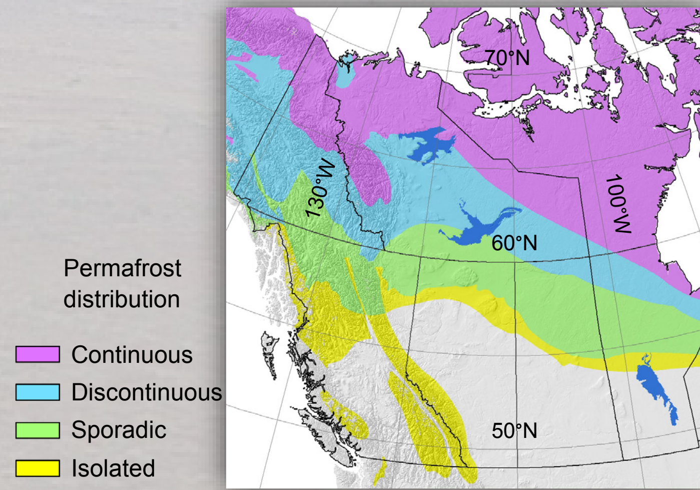
The retreat of glaciers across western Canada is stunning—for instance, comparison of historic and contemporary photos such as these for the Bow Glacier along the Icefields Parkway in Banff National Park reveal dramatic change.

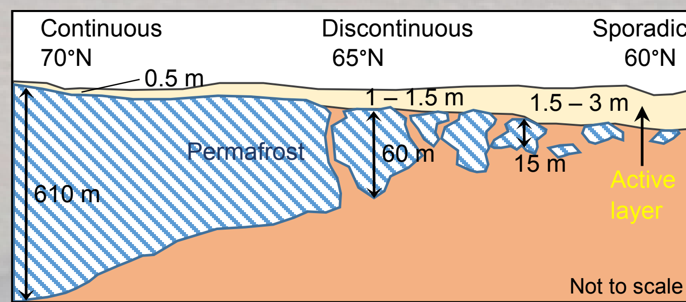


Historical photo: Vaux Family (Whyte Museum of the Canadian Rockies)

Permafrost

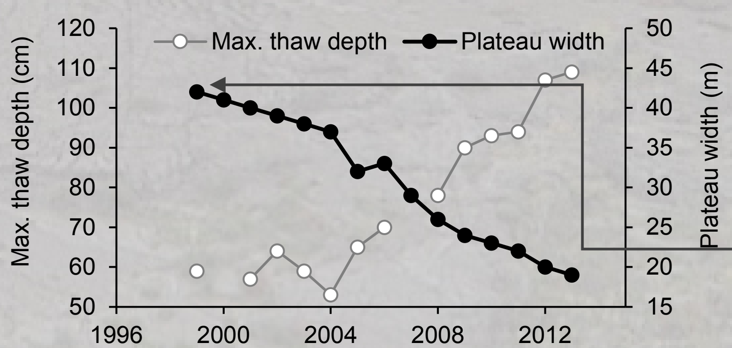
Permafrost is defined as ground that is at or below 0°C for at least two consecutive years, and it occurs extensively across western Canada's interior and Canada as a whole. Observations show widespread warming and thawing of permafrost. Ground temperature records from boreholes are collected at hundreds of monitoring sites over northern Canada by the Geological Survey of Canada and other organizations. Data from this network and observations from many local studies across the region show that in the northernmost areas where it is continuous, permafrost is warming rapidly toward the melting point (by up to several degrees Celsius since the 1980s), and in more southern areas where it is discontinuous and sporadic, it is thawing and becoming increasingly fragmented, causing major impacts to the landscape. The active layer, or depth of seasonal thaw, is increasing everywhere. This permafrost degradation is a major concern for the stability of infrastructure such as buildings, roadways, and pipelines (land cover disturbances and forest clearings tend to enhance local thawing rates and depths). This is also leading to thaw-induced forest cover collapse in many areas and changing the water cycling above and below the surface due to altered flow pathways and liquid water storage. Thus, permafrost underlain watersheds, particularly those near 0°C, are very sensitive to warming.

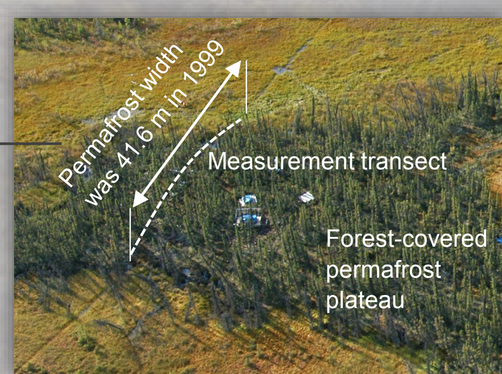




OCCURRENCE OF PERMAFROST OVER WESTERN CANADA

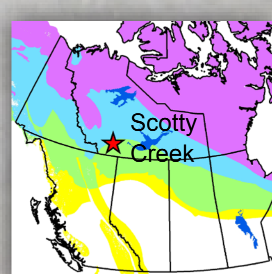
At its southern limits in this region, permafrost occurs as shallow, sporadic, and discontinuous frozen ground with a mean temperature near 0°C. It transitions to continuous, deep, and colder permafrost northward, while the active layer of seasonal thaw becomes thinner.

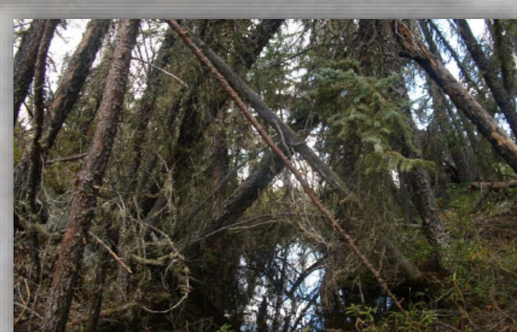




THAWING GROUND AND FOREST COLLAPSE

At Scotty Creek in the Northwest Territories, thawing of forest-covered permafrost plateau areas is occurring at an accelerating rate and leading to the collapse of vast areas of black spruce forest. These dramatic changes strongly affect the water cycling through these landscapes, and as the ground thaws and subsides, the trees become waterlogged and die.





Data Source: Cold Regions Research Centre, Wilfrid Laurier University

Boreal Forest and Sub-Arctic Tundra Vegetation

Terrestrial vegetation communities are sensitive indicators of climatic and environmental change, responding to multiple drivers, and in turn, significantly influencing regional climate and water cycling. Vegetation communities across western Canada have been slowly responding to warming and other climatic changes over the past decades. Studies have pointed to infilling and recruitment of open canopy forest stands at the northern limits of the Taiga Forest, while the southern transition zone of the Boreal Forest and Prairies has experienced dieback of certain species due to recent drought. Extreme wildfires in the region have burned large areas of forest, with record burned areas recently occurring in the Northwest Territories (2014) and Saskatchewan (2015). In the mountain areas, pine beetle infestation has affected large areas of forest, particularly in British Columbia. At northern and high-elevation locations, shrub tundra vegetation has undergone substantial changes, with increases in growth and productivity, and rapid expansion of areas of woody shrub vegetation. These shifts have important effects on the accumulation and distribution of snow and its melt in spring, the surface–atmosphere energy exchange, soil thermal regime, and water cycling over vast regions.

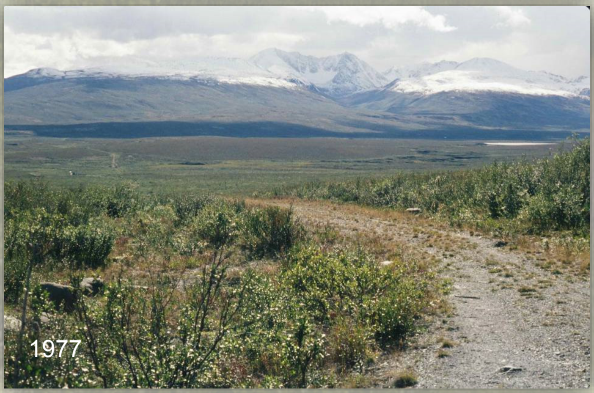
Forest cover change over western Canada since 2000

Tree canopy cover (year 2000): 100% – 0

Forest cover loss (2000–14)

Forest cover gain (2000–12)

Selwyn Mountains, NT



CHANGING BOREAL, TAIGA, AND MONTANE FORESTS

Remote sensing of forest canopy cover in western Canada indicates that forest cover losses have been more widespread than gains. Large wildfires have led to temporary forest cover losses across much of the Boreal Forest, while insect outbreaks and human development have caused recent forest declines in the montane forests of British Columbia and Alberta.

Data Source: University of Maryland, Global Forest Change Data (https://earthenginepartners.appspot.com/science-2013-global-forest)

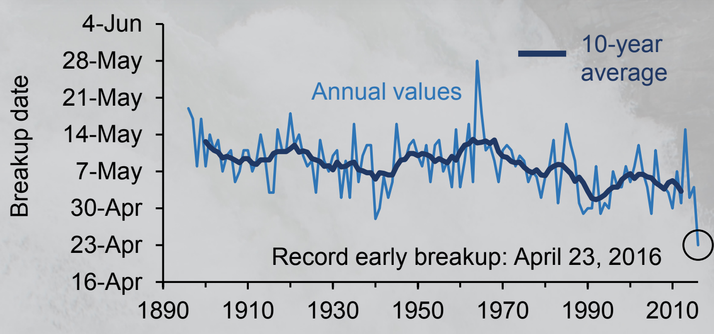
EXPANSION OF SHRUB TUNDRA

Shrubs, such as these at left in the Northwest Territories, are becoming taller, denser, and more pervasive across much of the subarctic. This has an important influence on soil moisture, ground thaw, and trapping of blowing snow and then its melt in spring.

Photographs: Peter Kershaw, University of Alberta

Freshwater Ice Cover and River Discharge

Yukon River at Dawson City, YT

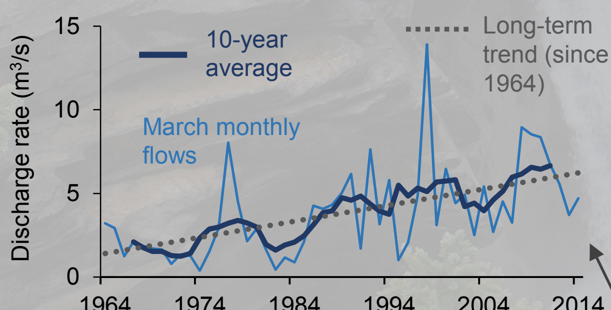


EARLIER RIVER ICE BREAKUP

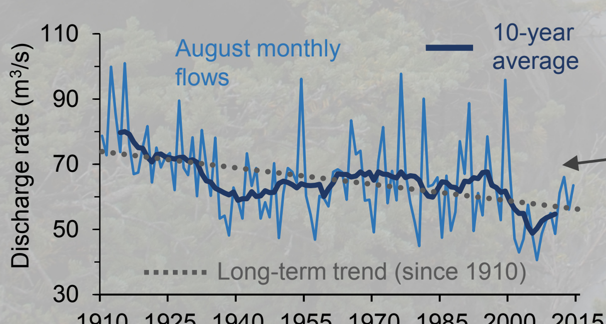
The date of river ice breakup on the Yukon River at Dawson City, like many rivers in western Canada, has shown a trend toward earlier timing in spring, especially since about the mid-1960s. 2016 set a record for early breakup, which occurred nearly one week earlier than the previous record in 120 years of observations.

Data Source and photo: www.yukonriverbreakup.com

Hay River near Hay River, NT



Bow River at Banff, AB



Stream and river discharge represents the combined response of a watershed to rainfall, snow and glacier melt, and internal water storage change, and it is influenced by climate and the physical and biological characteristics of the landscape. The Water Survey of Canada operates a network of hundreds of discharge monitoring sites across the country, providing year-round (or seasonal) daily measurements of flow and other observations such as the timing of river and lake ice cover formation and breakup. One of the clearest changes that has been observed across the region is a trend to earlier timing of spring flows and ice cover breakup, which have begun from one to several weeks earlier in association with warming conditions and earlier snowmelt. There has also been a widespread increasing tendency in fall and winter discharge of streams in many areas and especially across the northern parts of the region. Other hydrological changes have varied seasonally and annually, including increasing and decreasing flows, or stationary conditions over time, and have not generally been consistent over the entire region or over the long-term. This is because the responses to climatic and environmental changes, such as those described earlier in this document, are complex and spatially variable, reflecting multiple process interactions that may be compensatory to some degree. A challenge is to decipher the complex interactions and signals of change.

COMPLEX REGIONAL RIVER FLOW VARIATIONS

Hydrological changes over the interior of western Canada have shown complex patterns that vary regionally across the different climate zones and ecoregions—and over time. These are just a few examples of the types of changes in recent decades.

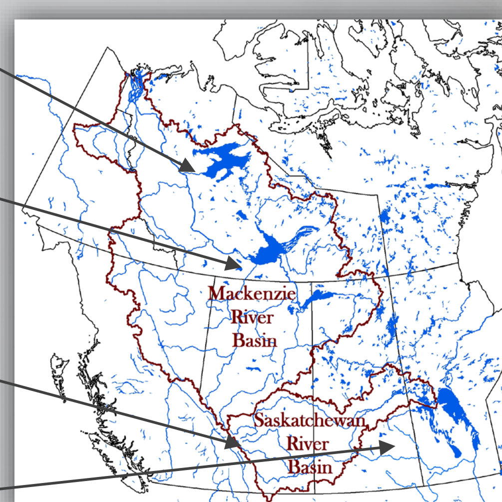
Data Source: Water Survey of Canada (http://wateroffice.ec.gc.ca/)

Resilience and limited change in large lake-dominated watersheds

Increasing fall, winter, and early spring flows in many basins, especially across the Taiga Plains and Shield

Declining late summer flows in the southern Rocky Mountains

Increasing late summer flows in some Prairie and Parkland basins



Occurrence of Extreme Events in Western Canada

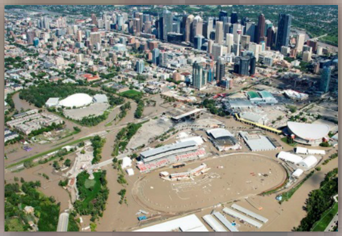
Weather extremes and natural disasters are a normal occurrence and have affected parts of western Canada's interior since its settlement and long before. However, in the past one and a half decades alone, since the turn of the century, the region has experienced some of the most devastating extreme events in its history, which appear to be becoming more frequent and widespread. Some of these have set records in terms of damage, costs, severity/ intensity, and spatial extent, while conditions have oscillated between opposing extremes (severe flooding and drought), in some cases within a very short period of time and close geographic proximity or at the same locations. These extremes have occurred against a backdrop of rapidly changing environmental conditions, described earlier, and have exacerbated pressures on our land, water, and vegetation, posing difficult challenges for management and long-term planning in the face of uncertain futures.

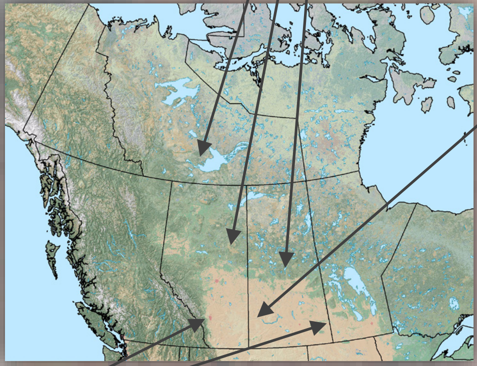
LARGE WILDFIRES

A sequence of three record-setting wildfire seasons has occurred in parts of western Canada: Northwest Territories (2014), Saskatchewan (2015), Ft. McMurray (2016). These fires each set records in terms of area burned, firefighting costs and damages, and/or number of evacuees, while in each case straining community resources and posing considerable risks to safety. Together, these resulted in many billions of dollars in damage and tens of thousands of people evacuated. The Ft. McMurray fire is now considered the most expensive natural disaster in Canadian history. Nevertheless, fires are part of the natural ecological cycles of the Boreal Forest, and forests burned during these extreme years are already showing signs of recovery.

Wildfire at Scotty Creek, NT, in July 2014

Flooding in the Town of Canmore and the City of Calgary in June 2013





WIDESPREAD, SEVERE DROUGHT

Western Canada has been subject to severe, widespread, and historically unprecedented drought conditions at several times in the 21st century. The 1999–2005 drought was one of the most costly natural disasters in Canadian history, with six billion of dollars lost and significant stresses to water resources. In 2015, severe drought conditions resumed, following a series of record wet years in parts of the Prairies. The drought covered a vastly large region with many areas experiencing record or near-record dry conditions, leading to wildfire occurrence, crop losses, low water levels in rivers and reservoirs, and major water shortages.

MAJOR FLOODING

The region has experienced disastrous flooding in the past several years. In June 2013, major flooding occurred in southern Alberta, resulting in six billion dollars of damages, over 100,000 evacuees, and several deaths. Until the Ft. McMurray wildfire, this had been the most costly natural disaster in Canadian history. Other major, and unprecedented, floods have occurred in the Assiniboine River Basin in Saskatchewan and Manitoba (2011, 2014), causing extensive damage, lost crops, and many evacuations.

Dustbowl conditions in southern Saskatchewan in April 2003

CCRN is working to improve our understanding of these changes and to use advances in climate modelling to predict likely future changes over the region. For more information and to learn more, visit our webpage at www.ccrnetwork.ca.

CCRN
Changing Cold Regions Network

NSERC
CRSNG