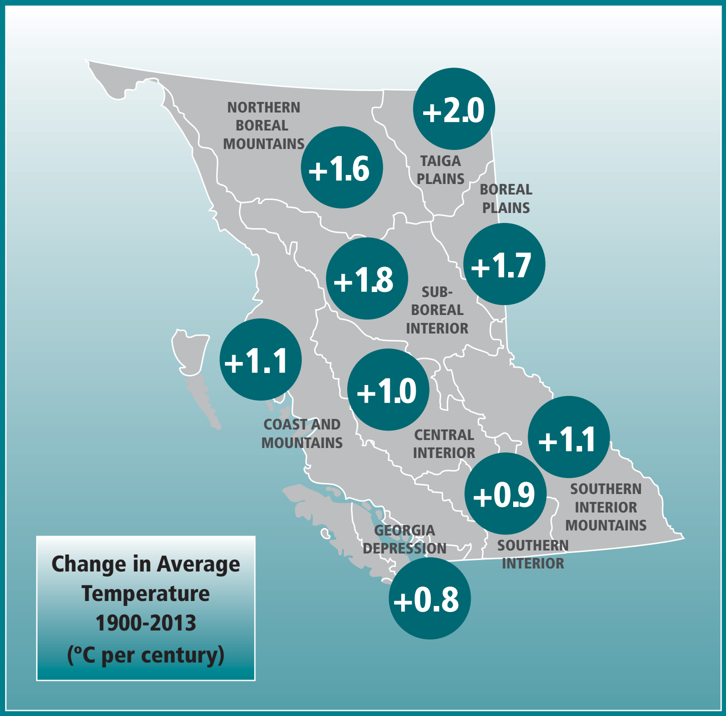

Indicators of Climate Change for British Columbia

2016 Update

British Columbia
Ministry of Environment

Indicators of Climate Change for British Columbia

2016 Update

BRITISH COLUMBIA | Ministry of Environment

Revised

JUNE 2016

ABOUT THE COVER

Air temperature is an important property of climate and the most easily measured, directly observable, and geographically consistent indicator of climate change. Historical data show that the average annual temperature increased in most parts of British Columbia between 1900 and 2013. Temperatures increased by 0.8°C to 2.0°C throughout BC. Northern and interior regions of BC have warmed more rapidly than coastal regions. Atmospheric warming of this magnitude affects other parts of the climate system, including precipitation, air, wind and ocean currents, and the hydrological cycle. Climate change affects ecosystems and species, and has both positive and negative impacts on human communities.

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CONTENTS

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Indicators of Climate Change for British Columbia

Both the UN Intergovernmental Panel on Climate Change and the US National Academy of Science have concluded that the global atmosphere is warming. They agree, moreover, that most of the warming observed over the last 60 years can be attributed to human activities that release greenhouse gases into the atmosphere.

Atmospheric warming affects all parts of the climate system, including precipitation, air, wind and ocean currents, cloud cover, and the hydrological cycle. Climate change in turn affects other closely related physical systems, as well as biological systems, and the human communities that depend on these systems.

This report documents how the climate in British Columbia has changed during the 20th and early part of the 21st centuries and the rates at which these changes are occurring. It outlines some of the potential impacts of these changes on freshwater, marine, and terrestrial ecosystems and on human communities.

2015/2016 UPDATES

Portions of this report have been updated in 2015 and 2016 with new data and analysis. Each section is labelled to indicate whether the content is from the 2002 version or current.

CLIMATE CHANGE TRENDS

The trends described in this report are based on a set of environmental indicators that represent key properties of the climate system, or important ecological, social, or economic values that are considered sensitive to climate change. The report describes changes in these indicators over time. Past trends are based on analysis of historical data.

Details of these trends are presented in the body of this report, but some highlights are as follows:

Past trends

Analysis of historical data indicates that many properties of climate have changed during the 20th and early 21st centuries, affecting marine, freshwater, and terrestrial ecosystems in British Columbia.

- **Average annual temperature warmed by 1.4ºC per century across the province.**
- **The northern regions of BC warmed more than the provincial average.**
- **Night-time temperatures increased across all of BC in all seasons.**
- **The night-time minimum average temperature in winter in BC increased by 3.1ºC per century.**
- **Annual precipitation has been increasing across the province overall.**
- **Lakes and rivers become free of ice earlier in the spring.**
- **The bulk of river flow is occurring earlier in the year.**

- **Average sea level has risen along most of the BC coast.**
- **Sea surface temperatures have increased along the BC coast.**
- **Water in the Fraser River is warmer in summer.**
- **More heat energy is available for plant and insect growth.**

Projected impacts

Climate models and scenarios suggest that the climate in British Columbia will continue to change throughout and beyond the 21st century. This will have ongoing impacts on ecosystems and communities. Some of the impacts we may experience by the final decades of the 21st century are:

- **Average annual temperature in BC may increase by 1.7°C to 4.5°C from 1961-1990 temperatures.**
- **Average annual precipitation may increase by 4 to 17 percent from 1961-1990 levels.**
- **Most small glaciers in southern BC will likely disappear.**
- **Some of the smaller rivers in southern BC may dry up during the summer and early fall.**
- **Salmon migration patterns and success in spawning are likely to change.**

The indicators presented in this report document some of the changes that have occurred during the past century or more. Many more potential indicators remain to be explored. For example, climate change influences the frequency of extreme weather events, the extent of permafrost, ecosystem structures and processes, and species distribution and survival. It will continue to affect provincial infrastructure, forestry, energy and other industries, insurance and other financial services, and human settlements. In addition, the impacts may vary from one region, ecosystem, species, industry, or community to the next. Research into the regional impacts of climate change is ongoing, and this report is therefore designed to be updated and expanded as new information becomes available.

FOR MORE INFO

Information on historical trends is available on the Environmental Reporting BC website (gov.bc.ca/environmentalreportingbc). More information on projected impacts is available through the Plan2Adapt online tool (www.pacificclimate.org/analysis-tools/plan2adapt)

RESPONDING TO CLIMATE CHANGE

The impacts of climate change on British Columbians will depend on the time, the place, and the individual. For example, homeowners may see a warmer climate as a benefit if it means lower home heating bills. Resort operators may see it as a cost if it means a shorter ski season. Farmers may see it as a benefit if it allows them to introduce new crops, and as a cost if it increases the need for irrigation. Overall, however, the risk of negative impacts increases with the magnitude of climate change.

Much attention has been paid over the last decades to slowing down the rate of climate change by reducing greenhouse gas emissions. Success in this area has been mixed. Even if mitigation efforts are successful in reducing greenhouse gas emissions, they cannot prevent the impacts of climate change. The greenhouse gases humans have already added to the atmosphere will likely continue to drive sea level rise and other aspects of global climate change for centuries to come. British Columbia and other jurisdictions will therefore have to adapt.

In Canada, the federal, provincial, and territorial governments are developing adaptation frameworks and strategies. British Columbia's Adaptation Strategy was developed in 2010 and is available online. Many municipal governments are incorporating potential climate change impacts into long-term plans for drinking water supply, drainage, storm-water infrastructure and land-use.

A greater understanding of climate change trends and impacts is expected to help British Columbians prepare for and adapt to climate change at the same time as the province works to reduce the scale of future impacts through renewable energy, energy efficiency, sustainable transportation, new technology, water conservation, and other sustainable practices.

GLOBAL TRENDS

Where current global trends and future global projections are mentioned throughout the body of this report the information is from the Intergovernmental Panel on Climate Change (IPCC) AR5 report (available at www.ipcc.ch/). The key topics and trends that are referred to are easiest to find in the shorter report titled: *Climate Change 2014 Synthesis Report; Summary for Policymakers* (available at http://www.ipcc.ch/report/ar5/syr).

About the data and trends

This report was originally written in 2002 to document changes over the previous century in some of the key properties of the climate system and in some ecological, social or economic values that are considered sensitive to climate change. Sections of this report were brought up to date in 2015 and 2016, using new information about changes in temperature and precipitation from 1900 to 2013. These changes are referred to as trends.

Where possible, the report identifies trends for each region of the province. The geographical unit used is the ecoprovince – an area delineated by similar climate, topography, and geological history. Trends are identified when the changes are found to be statistically significant at the 95 percent confidence interval, which means that there is a less than 5 percent probability that the results ocurred by random chance.

For these updates the Pacific Climate Impacts Consortium (PCIC) assessed trends in annual and seasonal means of daily minimum, maximum, and mean temperature, precipitation, growing degree days, heating degree days, and cooling degree days. Trends were computed for the interval from 1900 through 2013 and for both BC as a whole and the nine terrestrial ecoprovinces of BC. PCIC also supplied assessments, based on remote sensing data, of glacier change from roughly the 1980s through the early 2000s through a collaboration with the University of Northern British Columbia (UNBC). PCIC also assessed trends in snow, river flow, sea level, and sea surface temperature.

Ecoprovinces of British Columbia

DATA

One reason to update BC's climate indicators is the increase in the amount of data available since the original analysis. Data quantities have increased both through the passage of time, but more importantly through the development of a comprehensive database of observations in BC. The Ministry of Environment's Climate Related Monitoring Program (CRMP) has negotiated an agreement to allow PCIC to assemble, store, and deliver data collected by BC Ministries, BC Hydro and RioTinto AlCan. The data set also includes de-activated historical networks. This assessment was conducted using the data from CRMP and Environment Canada. Altogether, the dataset comprises 6721 measurement locations and roughly 400 million observations, roughly double the data available in 2002. The data from Environment Canada, BC Hydro, the Ministry of Forests Lands and Natural Resource Operations Wildfire Management Branch, and Ministry of Transportation's observational network are incorporated in near real time for future analysis. For this analysis, only temperature and precipitation measurements were used from the station observational dataset.

This analysis requires stations with relatively long records. The early part of the analysis (early 1900's) are based on a sparse network of stations so any understanding of the detailed climate at that time is less certain than for more recent years when there are more stations distributed broadly across the province. This issue is most critical for precipitation. Precipitation distributions are hard to estimate across a larger area, and this is further complicated by British Columbia's complex topography. In this report we have chosen to report trends for the full period for precipitation, but acknowledge that the statistical uncertainty in the trends may not fully capture the uncertainty that arises from changes in the observational network over time. However, the trends reported here are broadly consistent with other analyses carried out at a coarser spatial resolution and at individual stations.

The changes to glaciers that have occurred in the past several decades and which are projected to occur with climate change were intensively studied through the Western Canadian Cryospheric Network which involved researchers from most universities in British Columbia. This report, relies on two separate studies; the first looked at the change in volume of the glaciers in British Columbia from roughly 1985 until winter 1999-2000. The second investigated the changes in glacier area from the period 1985 through 2005. Both resultant datasets cover all glaciers in British Columbia and thus provide an excellent snapshot of both the state of glaciers in the early 2000s as well as the changes those ice masses underwent during a very warm climatological period.

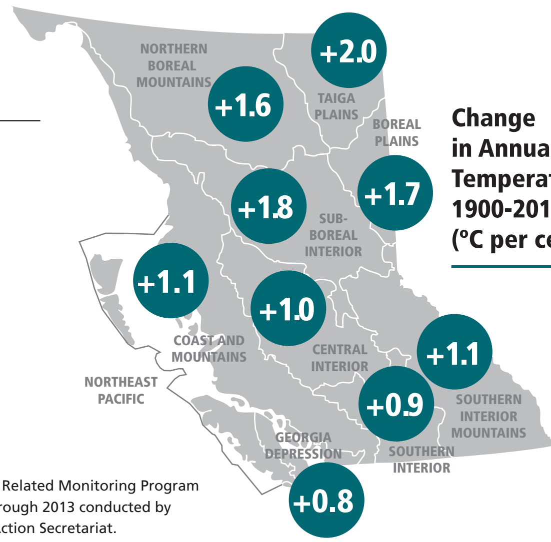
INTERPRETING THE TREND INFORMATION

- **This report presents only those results that were found to be significant at the 95 percent confidence interval. This means that there is a less than 5 percent probability that the results arose randomly.**
- **Where the data do not reveal a trend that is statistically significant at the 95 percent confidence interval, the report presents this as "NS" to indicate that the trend is not statistically significant.**
- **If there is insufficient data to calculate a trend the report presents no result.**

Revised 2015

Indicator: AVERAGE TEMPERATURE

Average temperature increased over all of BC from 1900 to 2013. Winter is warmer on average than it was 100 years ago. Higher temperatures drive other changes in climate systems and affect physical and biological systems in BC. They can have both positive and negative impacts on human activities.



Change in Annual Temperature, 1900-2013 (°C per century)

SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat.
NOTES: All statistically significant trends are positive and indicate warming.

ABOUT THE INDICATOR

This indicator measures changes in average annual temperature and average temperature in each of the four seasons. Trends are based on available data from 1900 to 2013 for each of the nine terrestrial ecoprovinces. Seasonal trends are based on averages for spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

ANNUAL TEMPERATURE TRENDS

The province of BC has warmed an average of 1.4°C per century from 1900 to 2013, higher than the global average rate of 0.85°C per century. Southern coastal regions of BC have warmed 0.8°C per century, roughly equivalent to the global average rate. The Northern regions of BC have warmed 1.6°C to 2.0°C per century or twice the global average.

Average global temperatures increased by 0.85°C from 1880 to 2012 according to the Intergovernmental Panel on Climate Change (IPCC). The higher rate of warming in BC is consistent with findings in the IPCC reports that mid and higher latitudes in the Northern Hemisphere are warming faster than the global average and that land areas warm faster than the ocean. The IPCC 2014 *Climate Change Report Summary for Policy Makers* identifies the years from 1983 to 2012 as likely the warmest 30 year period in the last 1400 years in the Northern Hemisphere.

SEASONAL TEMPERATURE TRENDS

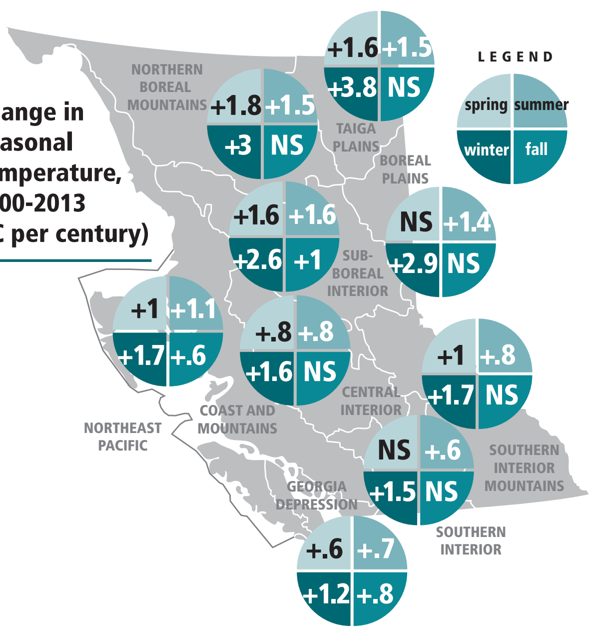
Most of the annual warming trend has occurred in the winter in BC. The average temperature increase in winter across the province is 2.2°C per century. Winter temperatures in the north of BC have increased by 3.0°C to 3.8°C per century. In the North-Central region, winters are 2.6°C to 2.9°C warmer than they were a century ago. In central, interior and southeastern BC, average winter temperatures have warmed 1.5°C to 1.7°C per century.

There is a province-wide warming trend in the spring and summer. The spring warming trend was 1.8°C per century in the Northern Boreal Mountains ecoprovince. The northeastern plains warmed 1.6°C per century in the spring. Spring has warmed by 1.0°C per century in both the coastal and southern interior mountains. Summer temperatures in most of northern BC have warmed 1.4°C to 1.6°C per century. In southern and central BC summer temperatures have warmed 0.6°C to 0.8°C per century.

There is no statistically significant province-wide warming trend in the fall. However, the coastal regions warmed by 0.6°C to 0.8°C per century in the fall and the sub-boreal interior warmed by 1.0°C per century. There was no significant trend for the rest of the province in the fall.

The date when each season arrives varies from one part of BC to the next, depending on climate, latitude, and elevation. Spring comes earlier to the coast, to southern BC, and to valley bottoms, for example, than it does to the north and alpine areas. The seasonal trends described in this document are based on calendar months, and as such may not reflect the way that disparate seasons are experienced in different parts of BC.

Change in Seasonal Temperature, 1900-2013 (°C per century)



SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat. NOTES: All statistically significant trends are positive and indicate warming. NS indicates that trend is not statistically significant.

WHY IS IT IMPORTANT?

Air temperature is one of the main properties of climate and the most easily measured, directly observable, and geographically consistent indicator of climate change. Atmospheric warming affects other parts of the climate system, and in BC is linked to sea surface warming and increased precipitation in some regions.

Changes in climate can affect other physical processes, including the duration of ice on rivers and lakes, the proportion of snow to total precipitation, and temperature in freshwater ecosystems. Such changes can in turn affect biological systems. Water temperature, for example, affects the date of emergence of the young of many aquatic species. Warming may drive broad-scale shifts in the distribution of ecosystems and species. Trees may be able to grow in areas once too cold for them. Some alpine meadows may disappear as high-elevation areas become warmer. Beneficial and pest species may appear further north, or higher in elevation, than their historic range.

The impacts of warmer temperatures will vary from one part of BC to another and from one season to another. They will have both positive and negative impacts on human activities.

Warmer springs may promote earlier break up of lake and river ice, and resulting changes in river hydrology including possible flooding. They may mean a longer season for warm-weather outdoor recreation activities and a longer growing season for crops.

Warmer summers may increase rates of evaporation and plant transpiration. Reduced moisture may contribute to dust storms and soil erosion, increased demand for irrigation, loss of wetlands, slower vegetation growth, forest fires, and the conversion of forest to grasslands. It may contribute to declines in ground-water supplies and in water quality in some areas. Higher temperatures may increase temperatures in freshwater ecosystems, creating stressful conditions for some fish species.

Warmer winters may mean that less energy is required to heat buildings. They may mean a shorter season for skiing and other winter sports and losses in the winter recreation sector.

WHY IS TEMPERATURE INCREASING?

Air temperature in BC is strongly affected by El Niño and other natural changes in air and ocean currents (see Appendix), which cause year-to-year and decade-to-decade variability in weather and climate across the province. The warming trends observed during the 20th and 21st century are above and beyond trends that could have been produced by such natural variability, and almost certainly reflect long-term climate change. The rate of warming is greater in more northerly regions. As air temperature increases, snow and ice melt, exposing more of the ground and sea surface. While snow and ice tend to reflect solar energy back into space, newly exposed rocks, soil, and water tend to absorb and retain it as heat.

The IPCC has concluded that most of the observed global atmospheric warming of the last 50 years is due to increases in atmospheric greenhouse gas concentrations. Greenhouse gas emissions resulting from a variety of human activities, including the burning of fossil fuels and the clearing of land for agriculture and urban development, are responsible for this increase.

WHAT CAN WE EXPECT IN FUTURE?

Average annual temperature across BC will continue to vary from year to year in response to natural cycles in air and ocean currents. However, what are now considered to be relatively warm years will almost certainly increase in frequency.

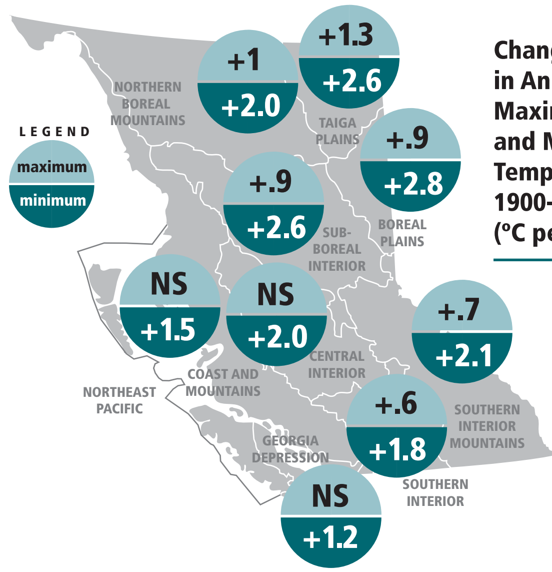
Plan2Adapt projects further warming in BC of 1.7ºC to 4.5ºC by the 2080s compared to the 1961-1990 historical average. The interior of the province will warm faster than other areas and will experience higher rates of warming than in the past. The north will continue to warm at rates considerably greater than the global average. Ocean temperatures have a moderating effect on the climate of the coast, which will warm more slowly than the rest of BC. More information about expected future climate indicators in BC is available at Plan2Adapt (www.pacificclimate.org/analysis-tools/plan2adapt).

Although temperature increases of a few degrees may seem small, they are associated with important physical and biological changes. A rise in average temperature of 5ºC about 10,000 years ago was enough to melt the vast ice sheets that once covered much of North America.

Revised 2015

Indicators: MAXIMUM AND MINIMUM TEMPERATURE

Night-time minimum temperatures in BC are warmer on average than they were a century ago. The increase in minimum temperature is particularly noticeable in the winter season and the northern regions of BC. In winter and spring, higher minimum temperatures may reduce heating costs and in some parts of BC may also increase the frequency of freeze-thaw cycles. In the summer they may prevent buildings from cooling down during the night.



Change in Annual Maximum and Minimum Temperature, 1900-2013 (°C per century)

SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat. NOTES: All trends are positive and indicate warming. NS indicates that trend is not statistically significant.

ABOUT THE INDICATORS

The indicators measure change in the annual average daily (day-time) maximum temperature and the annual average daily (night-time) minimum temperature. They also measure changes in maximum and minimum temperature in each of the four seasons. Trends are based on available data from 1900 to 2013. Seasonal trends are based on averages for spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

TRENDS IN MAXIMUM TEMPERATURE

From 1900 to 2013, annual day-time maximum temperatures increased in BC by an average of 0.7°C per century. Annual day-time maximum temperatures increased by 1.0ºC to 1.3ºC per century in the Taiga plains and Northern Boreal Mountains ecoprovinces. In the Sub-Boreal and Boreal Plains ecoprovinces the annual day-time maximum temperatures increased by 0.9ºC per century. In three other ecoprovinces (Georgia Depression, Coast and Mountains, Central Interior) the data do not reveal statistically significant trends in annual maximum temperature.

Seasonal data indicate that day-time maximum winter temperatures increased across most of BC. The average winter day-time maximum temperature increased by 1.9ºC per century. Maximum day-time spring temperatures are increasing in the north of BC, but data do not reveal a statistically significant trend in the southern half of the province. For all of BC, data do not reveal a trend in day-time maximum temperature in the summer and fall.

The greatest increases in maximum day-time temperatures are found in the north. Winter day-time maximum temperatures increased by 3.0ºC to 3.3ºC per century in the Boreal Plains and Taiga Plains ecoprovinces. In the Sub-Boreal Interior and the Northern Boreal Mountains ecoprovinces the winter day-time maximum temperatures increased by 2.3ºC to 2.6ºC per century. In the three interior ecoprovinces the winter day-time maximum temperature increased by 1.2ºC to 1.6ºC per century.

In the spring the northern ecoprovinces (Sub-boreal Interior, Boreal Plains, Taiga Plains, Northern Boreal Mountains) warmed by 1.1ºC to 1.5ºC per century. The southern half of BC showed no trend in the spring for changes in day-time maximum temperature.

In the Georgia Depression ecoprovince there was no trend in the data for day-time maximum temperature for any season.

TRENDS IN MINIMUM TEMPERATURE

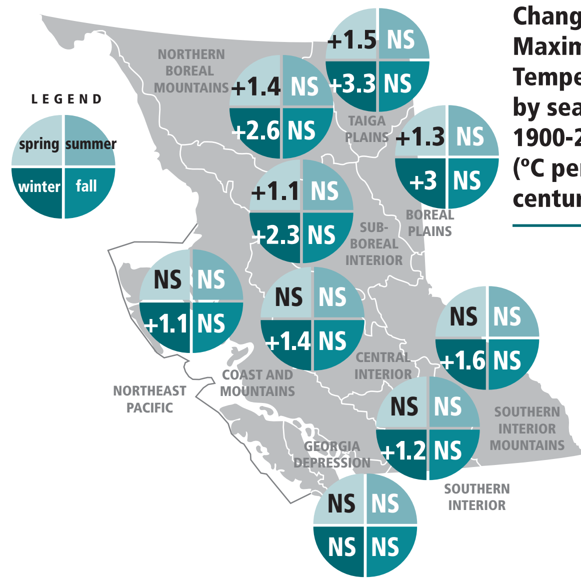
Annual night-time minimum temperatures increased across BC an average of 2.0°C per century from 1900 to 2013. The greatest increase in minimum temperature has been recorded in the Boreal Plains ecoprovince, where daily minimum temperature increased at a rate equivalent to 2.8°C per century. In the Taiga Plains and Sub-Boreal Interior ecoprovinces the annual daily minimum temperature increased 2.6°C per century. On the coast (Georgia Depression and Coast and Mountains) the annual night-time minimum temperatures increased 1.2°C to 1.5°C per century.

Seasonal data indicate that night-time minimum temperatures increased across all of BC for all seasons. The average night-time minimum temperature increased in winter for the province at 3.1°C per century.

In the Boreal Plains the night-time minimum temperature increased at the greatest rate for all ecoprovinces, in all seasons. In the winter, in the Boreal Plains ecoprovince, the night-time minimum temperature increased by 4.8°C per century, in spring it increased by 2.2°C per century, in summer by 2.4°C per century and in fall by 1.9°C per century. In contrast, in the Georgia Depression ecoprovince, the night-time minimum temperature increased at a rate equivalent to 1.2°C in the winter, 1.2°C in the spring, 1.5°C in the summer and 0.8°C in the fall. In the interior (Central Interior, Southern Interior and Southern Interior Mountains) the night-time minimum temperature increased by 2.4°C to 2.9°C per century in the winter, in the spring it increased by 1.7°C to 1.8°C per century, in the summer by 1.9°C to 2.0°C per century and in the fall by 1.1°C to 1.3°C per century.

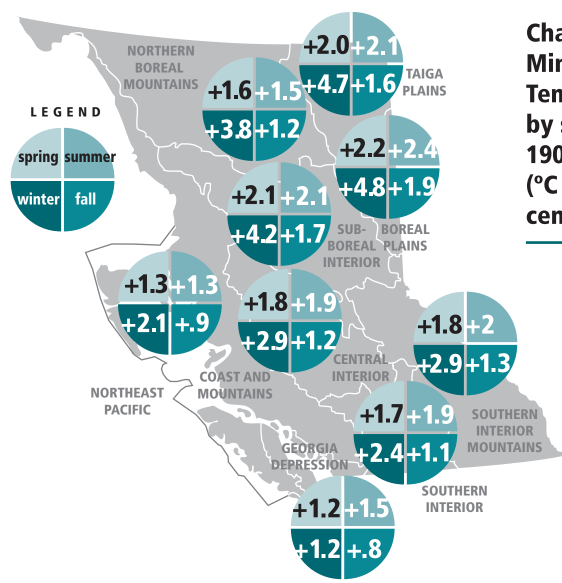
The night-time minimum temperature increased in the winter in the Taiga Plains ecoprovince by 4.7°C per century, and in the Sub-Boreal Interior ecoprovince by 4.2°C per

Change in Maximum Temperature, by season, 1900-2013 (°C per century)



SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat. NOTES: All statistically significant trends are positive and indicate warming. NS indicates that trend is not statistically significant.

Change in Minimum Temperature by season, 1900-2013 (°C per century)



SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat. NOTES: All statistically significant trends are positive and indicate warming.

century. In both ecoprovinces the summer night-time minimum temperature increased by 2.1°C per century.

WHY IS IT IMPORTANT?

The strong, increasing trends in minimum temperature, especially during the winter, have likely made the greatest contribution to the general warming trends across the province. In regions and in seasons where trends in both minimum and maximum temperatures were observed, minimum temperatures increased faster than maximum temperatures over the record period. As a result, the temperature range during the average day has decreased.

The Intergovernmental Panel on Climate Change (IPCC) has concluded that the increase in minimum temperatures has lengthened the freeze-free season in many mid-and high-latitude regions. Higher night-time minimum temperatures in fall, winter, and spring may enhance the growing conditions for both valuable and pest plant and insect species and decrease heating costs. In summer, they may increase heat-related stress in humans and other species because buildings and habitats may not be able to cool down adequately at night. In some parts of BC, freeze-thaw cycles may increase in frequency.

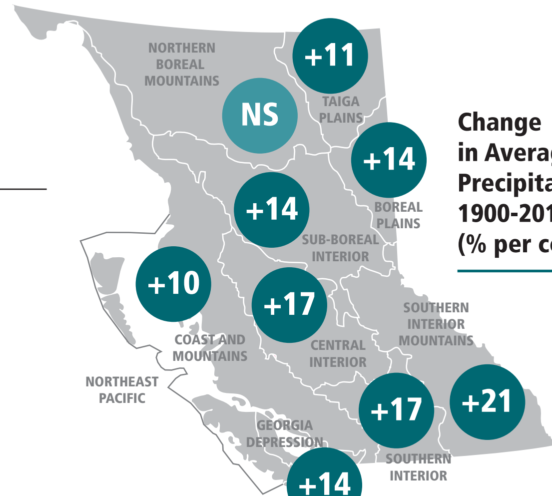
WHAT CAN WE EXPECT IN FUTURE?

Climate models project that in the 21st century, night-time lows in many areas will continue to increase more than day-time highs. A number of models suggest that in the Northern Hemisphere the gap between the daily maximum and the daily minimum will decrease in winter and increase in summer.

Revised 2015

Indicator: PRECIPITATION

Average precipitation increased over most of southern BC from 1900 to 2013. More water may be available to recharge groundwater aquifers, maintain river flows, and replenish soil moisture. Hydroelectric power generation, irrigation, and domestic water use may benefit. In some seasons, increased runoff may increase the chance of landslides and debris torrents, or exceed the capacity of municipal drainage and sewage systems.



Change in Average Precipitation, 1900-2013 (% per century)

SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment.
NOTES: All statistically significant trends are positive and indicate increasing precipitation. NS indicates that trend is not statistically significant.

ABOUT THE INDICATOR

The indicator measures changes in annual average daily precipitation at weather stations across BC. It also measures changes in average daily precipitation in each of the four seasons. Trends are based on data from 1900 to 2013. While these trends are reported for the whole period from 1900 to 2013, at the beginning of that time period the network of weather stations was relatively sparse through BC. The statistical uncertainty in the trends may not fully capture the uncertainty that arises from changes in the observational network over time. However, the precipitation trends reported here are broadly consistent with other analyses carried out at a coarser spatial resolution and at individual stations.

Seasonal trends are based on averages for spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

ANNUAL PRECIPITATION TRENDS

Province-wide average annual precipitation has increased by 12 percent per century. Average annual precipitation increased by 17 percent per century in the Southern Interior and by 21 percent per century in the Southern Interior Mountains ecoprovinces.

Precipitation in the Central Interior increased by 17 percent per century. Precipitation increased in the Coast and Mountains ecoprovince by 10 percent per century. In the Georgia Depression ecoprovince, precipitation increased by 14 percent per century.

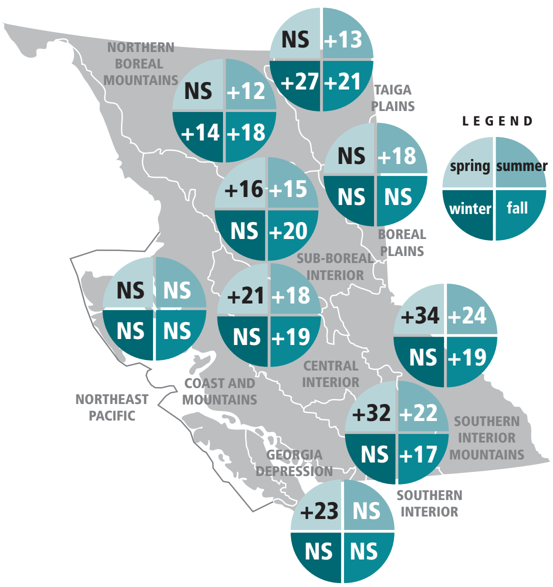
In the Sub-Boreal Interior and the Boreal Plains ecoprovinces average annual precipitation has increased by 14 percent per century. The data do not indicate a statistically significant trend for the Northern Boreal Mountains.

SEASONAL PRECIPITATION TRENDS

Trends in seasonal precipitation are varied through BC. Through most of the province, the data do not indicate statistically significant trends in winter precipitation. And, the data do not indicate seasonal trends in the Coast and Mountains ecoprovince.

In the Georgia Depression ecoprovince, precipitation has increased by 23 percent per century in the spring, and the data do not indicate

Change in Seasonal Precipitation, 1900-2013 (% per century)



SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment.
NOTES: All statistically significant trends are positive and indicate increasing precipitation. NS indicates that trend is not statistically significant.

any seasonal precipitation trends in other seasons. In the Boreal Plains ecoprovince, precipitation has increased by 18 percent per century in the summer and the data do not indicate any seasonal trends for any other seasons.

In the interior and southern coast of BC, precipitation is increasing in the spring months. In the Taiga plains and the Northern Boreal Mountains ecoprovinces, the precipitation trends indicate an increase in precipitation in the winter, summer and fall, but not in the spring. In the four interior ecoprovinces in BC there is a trend towards increasing precipitation in the spring, summer and fall, but not in the winter.

The date that each season arrives varies from one part of BC to the next, depending on climate, latitude, and elevation. The seasonal trends described here are based on calendar dates, and may therefore fail to reflect the seasons well for some parts of BC.

WHY IS IT IMPORTANT?

Precipitation is a fundamental aspect of climate and a key indicator of climate change. It is highly variable across BC as a consequence of topography and natural climate variability. Mountain slopes that face the prevailing westerly winds receive considerably more rain than leeward slopes or adjacent valleys.

Natural and human systems are adapted to such variability. Climate change, however, may mean a shift to warmer, wetter years, more frequent wet years, greater year-to-year variability, and more extreme precipitation events. Long-term changes in the amount, form, and timing of precipitation have significant impacts on freshwater and terrestrial ecosystems as well as on human activities. The impacts will vary depending on season, and some impacts may carry over from one season to the next.

In general, an increase in precipitation suggests that more water is available for natural systems, to recharge groundwater aquifers, maintain river flows, replenish soil moisture, maintain wetlands and marshes, and support plant growth. Human activities that depend on water supply – including hydroelectric power generation, irrigation, domestic water use, and some industrial processes – may benefit. Increased precipitation may also be responsible in some areas and in some seasons for increased flooding and damage to ecosystems and infrastructure. Increased year-to-year variability in precipitation may have adverse impacts on wetlands and other ecosystems and make water planning more complex.

- Where winter precipitation falls as snow – in the interior and north of BC, for example – an increase in precipitation may help local economies based on skiing and other winter recreation activities, but increase the cost of road maintenance and accidents. Snow build-up during the winter may increase the amount of water released into streams and rivers in spring and summer when the snow melts.
- Where winter precipitation falls as rain – on the coast, for example – an increase in precipitation may increase winter runoff, exceeding the capacity

of municipal drainage and sewage systems and reducing water quality.

WHY IS PRECIPITATION INCREASING?

Atmospheric warming is a component of climate change. Warmer air can hold more water vapour, pick up water faster from the earth, lakes, and oceans, and carry more moisture to the land, where it falls as rain or snow. Thus atmospheric warming is associated with a global increase in precipitation over land.

In BC, prevailing winds carry moisture inland from the Pacific Ocean. As the air rises over coastal mountains, it cools, releasing moisture. Average surface temperatures of the ocean and the land increased during the 20th century. As a result, winds carry more moisture from the ocean to the coast and the interior of the province.

WHAT CAN WE EXPECT IN FUTURE?

Average annual precipitation across BC will continue to vary from year to year in response to natural cycles in air and ocean currents. Relatively wet years, however, will almost certainly increase in frequency through the end of the century.

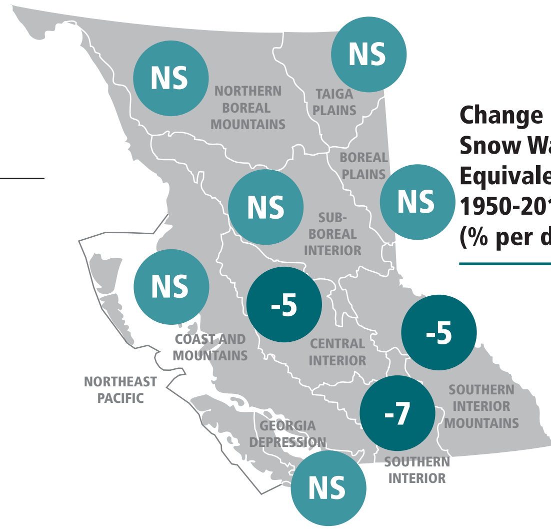
Climate models project that average annual precipitation in the mid-latitudes of the Northern Hemisphere will continue to increase. Precipitation is projected to increase by 4 to 17 percent by the 2080s compared to the 1961-1990 historical average, according to PCIC's Plan2Adapt tool. Winter precipitation is projected to increase from 5 to 23 percent in the province as a whole by the 2080s. As temperatures increase, more winter precipitation will fall as rain rather than snow. More information about future climate in BC can be found online at Plan2Adapt (http://www.pacificclimate.org/analysis-tools/plan2adapt).

Annual averages for precipitation do not tell us a lot about how and when that precipitation occurs. According to the IPCC, frequency and intensity of heavy precipitation events has likely increased in North America since 1950 due to climate change. The frequency and intensity of heavy precipitation events is likely to increase in BC through the 21st century. This could result in an increase in extreme precipitation events (heavy rain and snow) and the possibility of increased localized flooding.

Revised 2016

Indicators: SNOW

The water content and the depth of snow is decreasing, resulting in higher snow density in some parts of BC. Changes in snowpack affect the amount of water that is stored over the winter and released to groundwater aquifers, streams, and rivers in the spring and summer. These changes may affect the timing of snowmelt and local heat exchange processes.



Change in Snow Water Equivalent, 1950-2014 (% per decade)

SOURCE: Data provided by the River Forecast Centre, Ministry of Forests, Lands and Natural Resource Operations, and Ministry of Environment. Analysis by PCIC, 2016, for Ministry of Environment. Notes: All statistically significant trends are negative and indicate decreasing SWE. NS indicates that trend is not statistically significant.

ABOUT THE INDICATOR

The indicators measure changes in snow depth and snow water equivalent (SWE), the amount of water that is contained in the snow pack. Together, the measures provide information about snow density. Trends are based on data collected at provincial snow survey stations in spring (April 1) between 1950 and 2014. Most stations are located between 1,000 and 2,000 metres above sea level.

SNOW TRENDS IN BRITISH COLUMBIA

Trends in SWE and snow depth in BC are not uniform across the regions studied.

In the Southern Interior Mountains, SWE decreased at a rate of 5 percent per decade. Snow depth decreased at a rate of 7 percent per decade.

In the Central Interior, SWE decreased at a rate of 5 percent per decade. Snow depth decreased at a rate of 10 percent per decade.

In the Southern Interior SWE decreased at a rate of 7 percent per decade. Snow depth decreased at a rate of 11 percent per decade.

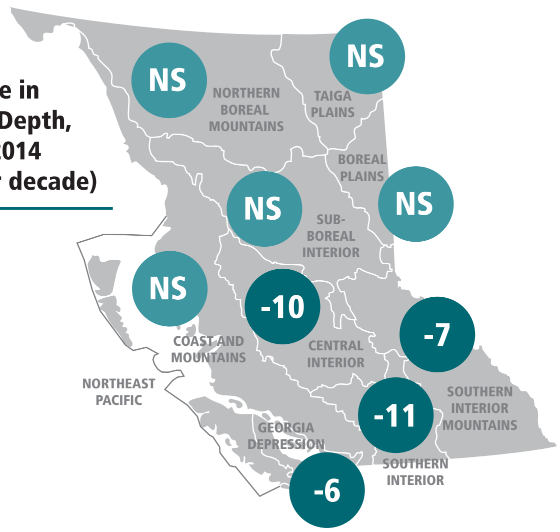
In the Boreal Plains, Georgia Depression, the Northern Boreal Mountains, and Taiga Plains ecoprovinces, there have not been significant SWE trends. Snow depth in the Georgia Depression decreased by 6 percent per decade.

Together, SWE and snow depth provide information about snow density. In general, as SWE increases for the same volume of snow, or as depth decreases while SWE remains constant, density increases. Snow density has increased in four ecoprovinces; the three where snow depth decreased at a faster rate than SWE, and the one where SWE showed no significant trend but depth decreased.

WHY IS IT IMPORTANT?

Snow acts as a temporary storage system for winter precipitation, and SWE is a measure of how much water is stored as snow. When snow melts in spring and early summer, this water becomes available to recharge groundwater aquifers, fill reservoirs, and replenish soil moisture.

Many rivers in BC are snowmelt-fed, meaning they are characterized by a surge of water when snow melts in the spring and early summer. This influx of meltwater helps keep temperatures at a comfortable level for fish and other aquatic organisms. In many parts of BC, it also ensures that enough water is available in summer for irrigation,



SOURCE: Data provided by the River Forecast Centre, Ministry of Forests, Lands and Natural Resource Operations. Analysis by PCIC, 2016, for Ministry of Environment. Notes: All statistically significant trends are negative and indicate decreasing snow depth. NS indicates that trend is not statistically significant.

hydro-electric power generation, industry, fisheries, and domestic water use.

Snow depth affects the capacity of snow to act as an insulator. In general, the deeper the snow, the greater its insulating value. Changes in snow depth may therefore affect the local rate of heat exchange between the land and water and the atmosphere, and the rate and time at which ice melts.

Snow density can affect the timing and rate of melting. Denser snow is closer to its melting point. Increasing density may signal earlier or more rapid spring melting. Heavy rainfall on top of dense, wet snow can trigger rapid melting and flooding and damage to ecosystems and infrastructure.

The geographical extent of snow cover is as important as its physical characteristics. Satellite data show that in the Northern Hemisphere, the extent of early spring snow cover has decreased by about 10 percent from pre-1970 values. This has adverse implications for recreational winter sport activities and related economies. It may also contribute to local warming as exposed ground absorbs and retains heat.

WHY IS THE SNOWPACK CHANGING?

Snow accumulation and its characteristics are the result of air temperature, precipitation, storm frequency, wind, and the amount of moisture in the atmosphere. Changes in these and other climate properties can therefore affect snowpack.

Winter warming is the most likely cause of increasing snow density. As winter temperatures warm, more winter precipitation is likely to fall as heavy “wet” snow. Rain or sleet may compact snow already on the ground. Warmer air temperatures can cause snow already on the ground to melt onto itself.

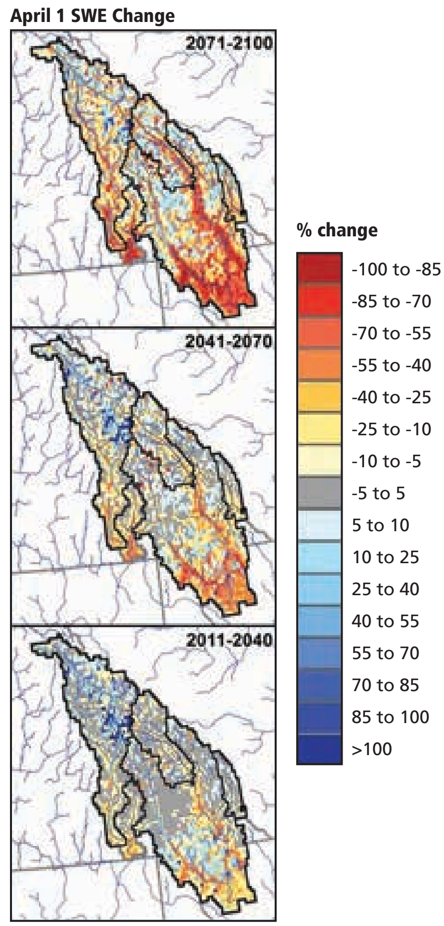
Temperature also affects the altitude of the snowline in mountainous areas and hence the total size of the area above the snowline. As temperature increases, the area above the snowline shrinks. This in turn affects the proportion of total precipitation that falls and is stored as snow and the amount of runoff in spring and summer.

The Intergovernmental Panel on Climate Change (IPCC) has concluded that there is a highly significant correlation between increases in surface temperatures and decreases in the extent of snow and ice in the Northern Hemisphere.

WHAT CAN WE EXPECT IN FUTURE?

The amount of precipitation that falls as snow will continue to vary from year to year in response to natural climate cycles. Climate models project, however, that as the Earth continues to warm, the extent of snow cover in the Northern Hemisphere will continue to decrease during the 21st century. The IPCC has concluded that in mountainous regions of North America, particularly at mid-elevations, higher temperatures could lead to a long-term reduction in peak snow-water equivalent, with the snowpack building later in the year and melting sooner.

Projected Change in Snow-Water-Equivalent in the Canadian Portion of the Columbia River Basin, 2011-2100

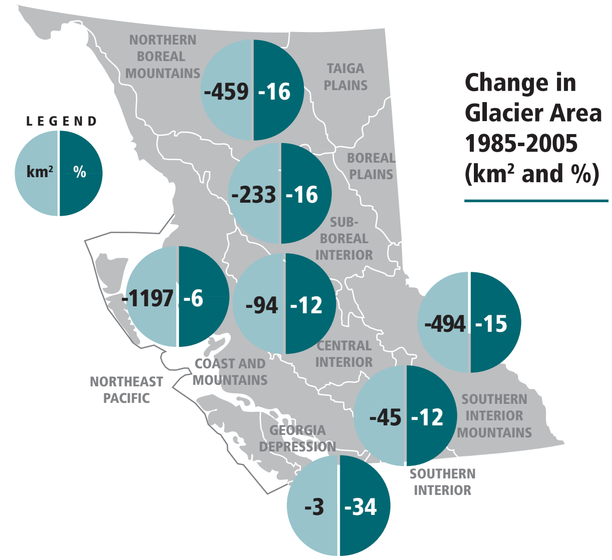


Projections of April 1 snowpack for three future periods show reductions at lower elevations and increases at higher elevations as the 21st century progresses. The snowpack retreats to higher elevations, reducing its area progressively through the century. The lowest elevations are projected to lose the majority of their snowpack by volume by the end of the century while higher elevations will see modest gains in snow. Overall, less water will be stored as snow in the future and this storage will occur at higher elevations than historically. SOURCE: Adapted from Werner, et al. (2013).

Revised 2015

Indicator: GLACIERS

All glaciers in BC retreated from 1985 to 2005. In the short term, retreating glaciers add water to glacier-fed streams and rivers. In the long term, this retreat will decrease late summer to early autumn runoff for these rivers.



SOURCE: Bolch et al. (2010) NOTES: All changes are negative and indicate decreasing area.

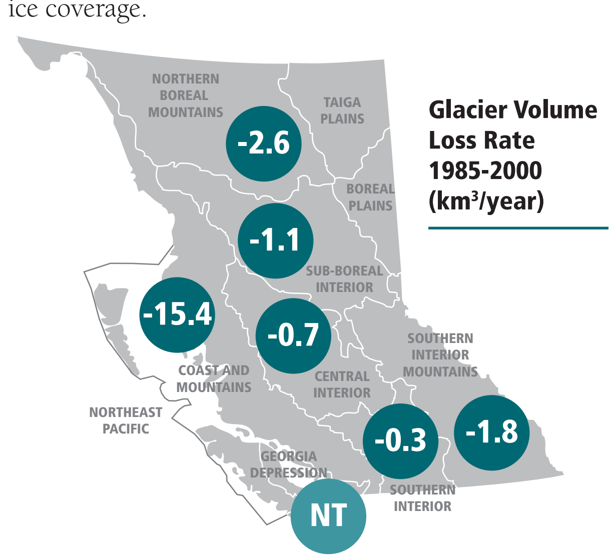
ABOUT THIS INDICATOR

Glaciers advance and retreat in response to changes in climate over time scales from decades to centuries. Glaciers thus respond to long-term changes in climate. This report includes two indicators of change in glacier coverage in BC. The first indicator is a measure of the change in area covered by glaciers in BC. Glacier area change was assessed by comparing the mapped extents of glaciers from the BC Terrain Resource Information Management (TRIM) program in 1985 with Landsat satellite imagery from 2005. The second indicator is the rate of change in the volume of glacier ice. Glacier volume change was assessed by differencing the topography measured during the TRIM campaign from the topography measured during the shuttle radar tomography mission (SRTM) in 2000.

Note that there are no glaciers in the Taiga Plains or Boreal Plains ecoprovinces of BC, so no results are reported for those regions.

GLACIER AREA CHANGES

From 1985 to 2005 the glacier coverage in the province as a whole decreased by 2525 km². Most of the glaciers in BC are in the Coast and Mountains ecoprovince, so while there was a large area of ice coverage lost, it corresponded with a smaller percentage area loss than southern and central regions of BC. The glaciers in the Georgia Depression ecoprovince are primarily on Vancouver Island, and those had the greatest percent area loss in the province. The area of glaciers in this region is small, however, so this represents a small change in the overall glacier ice cover of BC. The Central Interior ecoprovince lost 12 percent of the area of glacier ice coverage from 1985 to 2005. The Northern Boreal Mountains, Sub-Boreal Interior and Southern Interior Mountains lost 15 to 16 percent of the area of glacier ice coverage.



SOURCE: Data from Schiefer et al. (2007) NOTES: All changes are negative and indicate loss of volume. NT indicates that there was no trend.

TRENDS IN GLACIER VOLUME LOSS RATE

From 1985 to 2000 the province of BC lost 21.9 km^3 per year of ice from glaciers. As the Coast and Mountains ecoprovince has the most ice by volume, it also experienced the greatest volume loss rate. The Northern Boreal Mountains have the second largest area of ice in the province and are currently experiencing the second largest volume loss. We see from the temperature indicators that this is also where the most dramatic warming is occurring and this is likely driving the volume loss. The volume loss rate in the Sub-Boreal Interior and Southern Interior Mountains ecoprovinces equaled 1.1 and 1.8 km^3 per year, respectively.

Although the glaciers on Vancouver Island (Georgia Depression ecoprovince) had the greatest percentage area change, they are small glaciers so estimates of the volume loss rate are uncertain. The estimated volume change is near zero for the period, but confidence in this number is low.

WHY IS IT IMPORTANT?

Glacial meltwater feeds many mountain streams and rivers in BC, including the Cheakamus River, Pemberton Creek, Slesse Creek, Homathko River, Lillooet River, and Squamish River. In glacier-fed rivers, the highest flows tend to occur in early or mid-summer, depending on latitude, and glacier runoff can account for a significant portion of the available water supply.

Glacier retreat is therefore likely to cause changes in the flow timing and temperature of some streams and rivers. These changes – along with other climate-driven changes to hydrological systems (see “Freezing and Thawing”) – will likely have significant impacts on freshwater and estuarine ecosystems and on aquatic species. They will affect other biological systems and human activities that depend on water.

In the short term, melting glaciers will likely discharge more water into some BC streams and rivers. This may provide short-term benefits to hydroelectric power generation, water-based recreation, irrigation, fisheries, and other water users. Higher flows may also, however, increase stream turbidity and damage fish habitat and riparian areas.

In the longer term, glacier retreat will likely mean reduced water volume in glacier-fed streams and rivers, especially during the summer months. In water-short regions, this could generate increased competition between various water users.

WHY ARE GLACIERS MELTING?

The advance or retreat of a glacier represents the integration of many climate-related events that may occur over a period as short as one year or as long as centuries.

Climate models suggest that for most glaciers, changes in temperature, rather than changes in precipitation, control the evolution of glacier ice volume. Although winter precipitation fuels the growth of a glacier, a warm summer can melt large gains from more than one previous year. The IPCC assesses that warmer temperatures associated with climate change are the cause of world-wide glacial melting.

WHAT CAN WE EXPECT IN FUTURE?

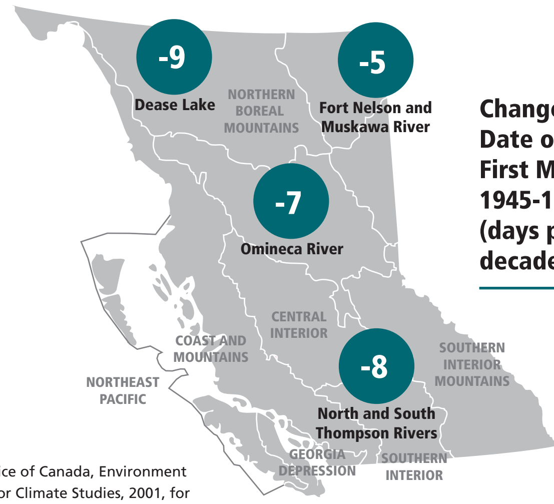
Glaciers and ice caps are projected to continue their widespread retreat through the 21st century. Globally, the actual rate of retreat will depend on the rate at which the temperature increases. The retreat of most glaciers will accelerate, and many small glaciers may disappear. Areas that are currently marginally glaciated are likely to become ice-free in future.

In BC, glaciers will continue to retreat throughout the province. The smaller glaciers in the southern ecoprovinces are likely to disappear by the end of the 21st century. Even glaciers with a high proportion of their surface at high elevations will continue to retreat.

2002 edition

Indicators: FREEZING AND THAWING

Ice on lakes and rivers in BC melts earlier now than it did several decades ago. When ice melts earlier in the spring, it can affect lake productivity, aquatic ecosystems, and winter activities.



Change in Date of First Melt, 1945-1993 (days per decade)

SOURCE: Data from Meteorological Service of Canada, Environment Canada. Analysis by Canadian Institute for Climate Studies, 2001, for Ministry of Water, Land and Air Protection. NOTES: A negative trend means that water bodies start to melt earlier in the year.

ABOUT THE INDICATORS

The indicators measure changes in the dates on which key freezing and thawing events occur on lakes and rivers in British Columbia. They are:

- date of first melt
- ice-free date (when rivers and lakes are completely free of ice)
- first date of permanent ice
- date of complete freezing

Trends are based on data from six (and for one indicator, seven) stations. The records span 27 to 51 years, and most cover approximately three decades.

MELTING AND FREEZING TRENDS

Lakes and rivers now start to melt earlier in spring, on average, than they did several decades ago. First melt has become earlier by 9 days per decade in Dease Lake, 5 days per decade in Fort Nelson, 7 days per decade in Omineca River, and 8 days per decade in the Thompson River region.

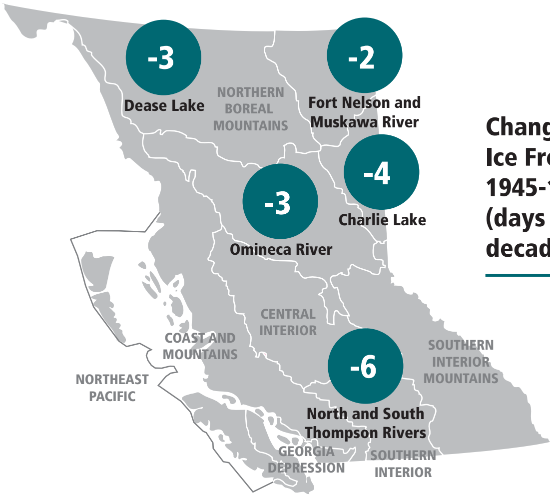
Lakes and rivers also become free of ice earlier, on average, than they did several decades ago. The ice free date has become earlier by 6 days per decade in the Thompson River region, 3 days per decade in Omineca River, 4 days per decade at Charlie Lake, north of Fort St. John, 3 days per decade at Dease Lake, and 2 days per decade at Fort Nelson.

Lakes and rivers in northern BC may freeze later in the fall, on average, than they did several decades ago. At Charlie Lake, the first permanent ice appears 5 days per decade later. At Fort Nelson, lakes freeze over completely 4 days per decade later. These trends are not replicated in adjacent stations and are considered weak.

The Intergovernmental Panel on Climate Change (IPCC) has concluded that the annual duration of lake and river ice in the mid-latitudes of the Northern Hemisphere probably decreased by about two weeks during the 20th century, or at a rate of 1 to 2 days per decade. It is difficult to compare the BC trends with this global average because the BC trends are based on data collected during a shorter, relatively warm period. The BC trends likely reflect climate variability rather than climate change.

WHY IS IT IMPORTANT?

The duration of ice on lakes and rivers is important for transportation. Vehicles involved in winter logging and oil and gas exploration can move about more easily when water bodies are frozen. Skiers and snowmobilers can use frozen lakes and rivers as backcountry roads.



Change in Ice Free Date, 1945-1993 (days per decade)

SOURCE: Data from Meteorological Service of Canada, Environment Canada. Analysis by Canadian Institute for Climate Studies, 2001, for Ministry of Water, Land and Air Protection.
NOTES: A negative trend means that water bodies are ice-free earlier in the year.

The duration of ice can also affect the productivity of freshwater ecosystems. The temperature of most lakes varies depending on depth. When lakes are cold – at high latitudes, at high elevations, or in winter – water at the bottom of the lake is warmer than water at the top. When lakes are warm – in low- to mid-elevations and latitudes, and in summer – water at the bottom of the lake is colder than water at the top. In spring and fall, many lakes go through a period in which temperature differences and thermal stratification disappear. This allows the water, and the nutrients, oxygen, and micro-organisms it contains, to mix throughout the lake, increasing productivity.

In lakes that currently undergo thermal stratification in summer, a longer ice-free period means that stratification develops earlier in the year and lasts longer. Periods of mixing during spring and fall may be reduced in length. Increasing temperatures mean that some lakes that currently freeze over in winter may no longer do so. They may move from a regime that includes winter stratification to one that includes winter mixing.

The IPCC has concluded that changes in thermal regimes and lake-mixing properties may have a significant effect on the concentration of dissolved oxygen in the deeper layers of many lakes, and consequently on available fish habitat. They may also affect primary productivity – the growth of phytoplankton – in the upper layers of these lakes, with impacts on fish production. The direction and magnitude of these effects will vary depending on the unique characteristics of the lake.

Many aquatic systems are sensitive to temperature, and thawing and freezing events may mark milestones in their life cycles. A longer ice-free season may mean a longer growing season for these organisms. It may allow some species to move into new areas that were previously not habitable to them.

WHY IS THE ICE MELTING EARLIER?

Climate affects the formation, thickening, and melting of ice – processes that reflect the beginning and end of the cold season and its severity. Air temperature is the main influence on the rate of heat loss and gain from water bodies and the timing of freeze-up and melt. Other contributing factors include cloudiness, solar radiation, wind speed, humidity, precipitation, the depth and composition of snow on top of the ice, and water temperature. All of these factors reflect local climate conditions.

During the past century, almost all regions of BC have experienced warmer spring temperatures (see "Average Temperature"). Earlier dates of first melt and ice breakup are consistent with these trends.

The IPCC attributes the reduction in the duration of ice during the 20th century to climate change. The BC trends, however, are based on short data records. Most begin during a slightly cooler period – the 1940s and 50s – and end during a warmer period – the 1990s. They are therefore very likely to have been influenced by natural climate variability. If longer records were available, they would probably show slower rates of change in BC.

WHAT CAN WE EXPECT IN FUTURE?

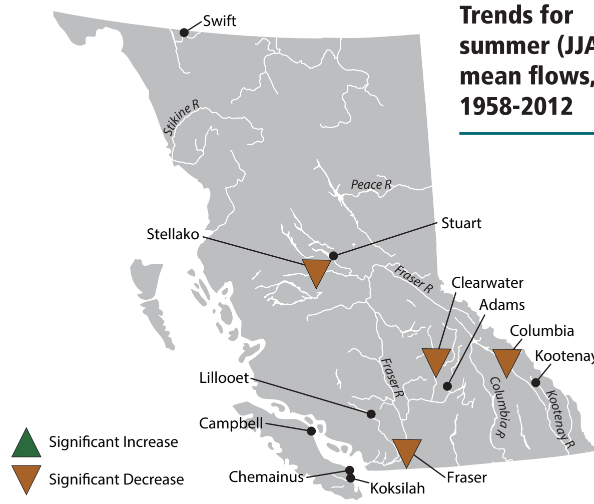
Climate models project that globally, atmospheric warming associated with climate change will continue to be more pronounced in winter and spring than in summer and fall. This warming will likely continue to cause earlier thawing of ice on provincial lakes and rivers.

Revised 2016

Indicators: TIMING AND VOLUME OF RIVER FLOW

Seasonal changes in the timing and volume of river flow have occurred in several locations. The bulk of water flow is occurring earlier in the year on average. At many locations, river flow has decreased in late summer and early fall. This could contribute to water shortages for humans and ecosystems.

Trends for summer (JJA) mean flows, 1958-2012



June, July, August (JJA) mean flow trends between 1958 and 2012.
SOURCE: Data from the Water Survey of Canada, Environment and Climate Change Canada (1958-2012). Station list see Appendix C. Analysis by PCIC for Ministry of Environment, 2016.

ABOUT THE INDICATORS

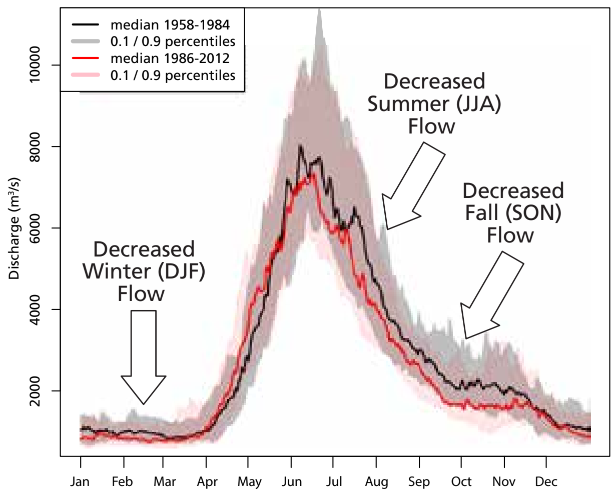
The indicators measure changes in the timing as well as volume of water. Timing is quantified as trends in the dates by which one-half of the total annual volume of each river has passed. Volume changes are quantified by trends in seasonal minimum, maximum, and mean flows. To better assess trends in rivers for more of the province, and for rivers that are rainfall- or snowmelt-fed, daily river flow measurements were analyzed for basins across the province over a 55-year period from 1958 to 2012. In some places it was also possible to analyze a 101-year period from 1912 to 2012.

TRENDS IN RIVER FLOW IN BC

Long-term records are available for five sub-basins of the Fraser River watershed (Adams, Stellako, Stuart, Lillooet, and Clearwater) and the Fraser River at Hope, which drains roughly a quarter of the province. At the Stellako and Fraser at Hope, the date when half the annual water volume has passed advanced nine and six days respectively over 1912 to 2012, while in the Adams the date became seven days later over the 101-year record. Minimum daily flow increased at four of the six sites which, for the Fraser River watershed and its sub-basins, occurs in late winter prior to the onset of spring melt. Three sites demonstrated significant decreases in mean summer (June, July and August) flow, ranging from a 16% to 40% decrease and two sites (Stellako and Lillooet) had significant decreases in minimum flow in late summer (July, August, and September) by 31% and 39%, respectively. Annual minimum, late spring maximum, and spring mean showed increased flow for some sites. All other indicators showed declining trends.

Data was available at stations on the Chemainus, Koksilah, Stellako, Stuart, Clearwater, Adams, Fraser, Lillooet, Columbia, Kootenay, and Swift for the more recent 1958 to 2012 record. Of these rivers, the Chemainus and Koksilah are rainfall-fed, while the others are snowmelt-fed. Declines were seen in most metrics for most rivers, reinforcing the pattern found over the 101-year record with fewer stations. Late spring maximum flows (April, May, June) decreased at the Koksilah and Columbia (at Donald) and late summer minimum flows (July, August, September) decreased at four stations (Chemainus, Stellako, Clearwater, and Fraser). Mean summer flow volume (June, July, August) also decreased between 17% and 39% at four stations (Stellako, Clearwater, Fraser,

Changes to Fraser River Flow between 1958 and 2012



Comparison of flow of the Fraser River at Hope for two equal-length time periods, 1958-1984 and 1986-2012, showing median and 10th and 90th percentiles. Seasonal flows have decreased between the first and the second time period during winter (December, January, February), summer (June, July, August), and fall (September, October, November). SOURCE: Data from the Water Survey of Canada, Environment and Climate Change Canada (1958-2012), Fraser River at Hope (08MF005), augmented with data received from Alan Chapman in 2007, which were adjusted for extractions via the Nechako Reservoir. Analysis by PCIC for Ministry of Environment, 2016.

and Columbia). Because summer flow makes up a relatively small proportion of total annual flow, these large percentages have smaller impacts on total annual flows. However, mean annual flow decreased by 16% in the Fraser at Hope, which is important considering the expanse of BC this basin covers. Over this same period, precipitation showed a statistically non-significant decline of 3% (+/-17%) per century. The discrepancy between the declining river flow and modest to no declines in precipitation indicates the influence of rising temperatures over this period. Warmer temperature leads to greater rates of evapotranspiration which reduces water available for streamflow. Maximum daily flow did not change significantly at any of the stations examined, whereas minimum daily flows decreased at two sites (Columbia and Koksilah) and increased at one (Swift River). Over this period, only one indicator at one river showed significant increases in flow; the Swift River's annual minimum flow. All other significant trends show flow reductions. Comparing average daily streamflow for the Fraser River at Hope for two 27-year periods illustrates the type of changes driving seasonal streamflow trends for many stations across BC. Flows are modestly reduced in winter, increased during spring, and strongly decreased during summer and fall in the latter 1986-2012 period versus the earlier 1958-1984 period. These data have been naturalized to correct for water diverted from the Fraser River catchment to the Nechako reservoir, which started in 1958.

WHY IS IT IMPORTANT?

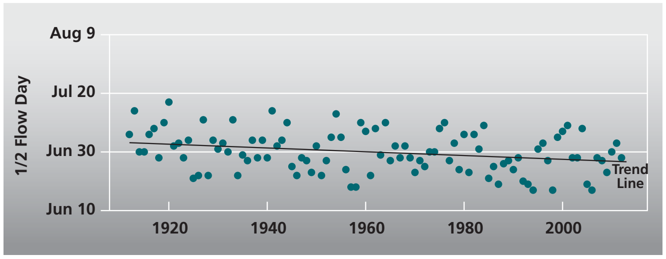
Changes in the timing and volume of flow can affect both natural ecosystems and human communities. Lower flows in summer and later in the season may reduce the amount of water available for agriculture, hydroelectric power generation, industry, and communities in some parts of the BC interior. This is a potentially significant problem in drier areas such as the Okanagan basin, where most streams are already fully allocated to water users and water shortages already exist. Low late-season flows are especially a concern in years when below-average spring and summer rainfall coincides with below-average summer flows. Lower flows are also associated with declining water quality including warmer water temperatures (see "River Temperature") which further threaten the health of aquatic ecosystems and their organisms such as salmon (see "Salmon in the River").

WHY HAS RIVER FLOW CHANGED?

Many factors affect trends in these indicators, such as changes in temperature, precipitation, and evapotranspiration. They also depend on the location, size, elevation, and regime of a basin, be it predominately rainfall- or snowmelt-fed and whether substantial glacier cover exists. Thus, trends in river flow are not uniform over the province for every indicator. Ten of the 11 stations evaluated are part of the Reference Hydrometric Network where direct human influence and land use change have not significantly altered the flow regime over time.

Detecting changes in streamflow and attributing them to the effects humans have had on climate is

Change in Timing of One-half of Fraser River Annual Flow, 1912-2012



The half flow day is defined as the day of the calendar year on which one-half of the total annual water flow has occurred. The solid line indicates that there is a trend at the 5% significance level. Data from the Water Survey of Canada, Environment and Climate Change Canada, augmented with data received from Alan Chapman, adjusted for extractions via the Nechako Reservoir. Analysis by PCIC for Ministry of Environment, 2016. See Appendix C for methodology and references.

more difficult than attributing changes in temperature and precipitation. Soil moisture and runoff changes are difficult to isolate from the difference in precipitation and evaporation alone. Other factors, such as changes in land use, stream management, water withdrawal and varying water use efficiency by plants under different levels of CO_2, also play a role. In BC, snow storage and melting are important to runoff. Winter temperature has increased significantly across the province over the past century leading to less winter precipitation falling as snow and earlier melting of winter snow cover. The earlier passage of the majority of water in snowmelt-fed rivers in the nearby US is detectably different from natural variability since the 1950s and can be attributed to human-caused warming. There is some evidence that declining April 1 Snow Water Equivalent (SWE) in British Columbia has a detectable human influence in simulations that compare human-caused warming with natural variability. This change is consistent with the expected influence of warming on the hydrological cycle. Warming is substantial in a study of the Fraser, Peace, Columbia, and Campbell basins and attributable to human causes. Natural variability alone is not a likely explanation for the observed SWE changes.

WHAT CAN WE EXPECT IN FUTURE?

Future streamflow in the Fraser, Peace, upper Columbia, and Campbell rivers have been investigated up to 2098 using multiple Global Climate Models corrected to match the characteristics of observed temperature and precipitation data for British Columbia. These climate scenarios were used as inputs to a hydrologic model covering 100-gauge sites in the province.

During the 2050s (between 2041 and 2070) in the Fraser River, annual streamflow is projected to increase. Winter and spring flows are projected to increase, summer flows to decrease and smaller changes, in either direction, are projected in the fall. Mean annual peak flow is projected to occur between 5 and 15 days earlier. Most of the trends described above were analyzed for sub-basins of the Fraser River where the majority of long-term records are available over the 101-year period discussed earlier. In the 2050s in the Campbell River, changes in annual streamflow are expected to be negligible, but warmer temperatures in future are expected to result in a significant change in the hydrological regime relative to the 1970s (1961-1990). This watershed is expected to transition from being mixed rainfall- and snowmelt-fed to predominantly rainfall-fed, with increased flow during the winter season and decreased flow in spring and summer. Similar changes have already been observed in other coastal watersheds such as the Chemainus.

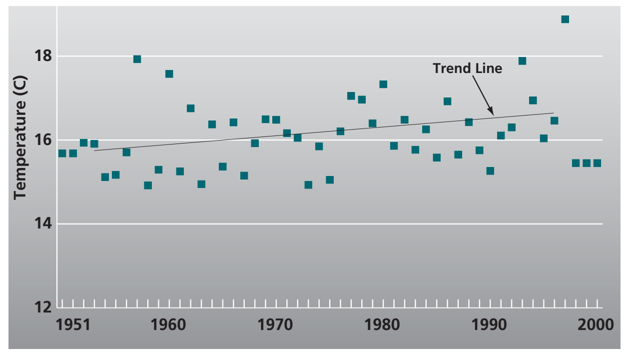
Total annual streamflow is expected to increase for the upper Columbia River for the 2050s, regardless of the model or emissions scenario investigated, but there are important seasonal changes that are expected to occur. Monthly streamflow is expected to increase during the late fall and winter period, the spring melt to occur earlier, and flow to be higher during spring and early summer and lower in late summer and early fall. Annual streamflow is expected to increase for the Peace River for the 2050s, regardless of the model considered. Monthly streamflow projections for the Peace River show consistently higher future discharge during fall and winter. Like the upper Columbia, there is some indication that the Peace River may experience an earlier onset of the spring melt and reductions in streamflow to occur during late summer and early fall. Some of the trends in observed data mimic the projected changes with climate change, suggesting that some effects are underway.

2002 edition

Indicator: RIVER TEMPERATURE

The average summer temperature of the Fraser River has warmed over the past five decades. River warming can have negative impacts on the health, distribution, and survival of salmon but positive impacts on aquatic species that can tolerate warmer water.

Change in Average Fraser River Temperature, 1953-1998



SOURCE: Historical temperature data from the Pacific Salmon Commission, 1941-1998. Historical weather data from Meteorological Service of Canada, Environment Canada 1953-1998. Analysis by John Morrison, Institute of Ocean Sciences, 2001 for the Ministry of Water, Land and Air Protection.
NOTES: Results are statistically significant. ($R^2 = 0.1151$, $p = .0226$).

ABOUT THE INDICATOR

This indicator measures changes in the average summer temperature of the Fraser River at Hell's Gate. It is based on daily measurements of water temperature taken from July 1 to September 15 for the years 1953 to 1998.

TRENDS IN RIVER TEMPERATURE

The temperature of the Fraser River at Hell's Gate in summer warmed during the period 1953 to 1998 at a rate equivalent to 2.2°C per century.

The Fraser River is subject to seasonal and year-to-year variations in temperature that are related to short-term natural climate variability. In general, summer river temperatures are warmer after an El Niño event and cooler after a La Niña event. Because the period of record is only 45 years, these short-term climate variations may have as much influence on the observed trend towards river warming as climate change.

The average temperature of the Columbia River at or near the international boundary during the summers of 1959 to 1997 also appears to have warmed, but the data are not sufficient to establish a trend. In addition, because the Columbia is a highly regulated river system, any apparent trend might be due to human-induced changes in the timing and volume of river flow, or to the temperature and volume of water reservoirs, rather than to climate change.

WHY IS IT IMPORTANT?

The Fraser River flows 1,370 kilometres from its headwaters in the Rocky Mountains to the Pacific Ocean. It supports ecologically important salmon runs, including the majority of Canadian sockeye stocks. Almost all runs must pass through Hell's Gate in their migration upriver to spawn. Warmer river temperatures are expected to affect salmon and other aquatic organisms.

In general, warm water temperatures reduce salmon fitness, survival, and reproductive success and promote potential long-term population declines (see "Salmon in the River"). Declines in Fraser River salmon stocks have negative impacts on provincial fishing and tourism industries and aboriginal and other communities that rely on fish. They affect predators such as bald eagles and bears and coastal ecosystem processes that depend on the nutrients provided by salmon carcasses.

In addition, many provincial salmon stocks are classified as at moderate to high risk of extinction. The United National Intergovernmental Panel on Climate Change (IPCC) believes that, without appropriate management, climate change will lead to changes in freshwater ecosystems that will cause some species currently classified as "critically endangered" to become extinct and the majority of species classified as "endangered" or "vulnerable" to approach extinction in the 21st century.

Over the long term, higher temperatures are expected to result in a shift in the distribution of salmon and other cold-water species to higher latitudes and elevations, together with increased population fragmentation in more southerly parts of their ranges. If other factors were to limit these range shifts, an overall reduction in the distribution of certain species would be the result.

River warming may have positive impacts on aquatic species that can tolerate warmer water temperatures. Native warm-water species may be able to expand their range into higher-altitude lakes and more northerly regions. For example, a 4ºC increase in average air temperature is projected to expand the ranges of smallmouth bass and yellow perch northward across Canada by about 500 kilometres. There is also an increased likelihood of successful invasion by non-native species that require warmer water temperatures.

WHY IS RIVER TEMPERATURE INCREASING?

River temperature is the result of complex interactions between the characteristics of the river itself, climate, and adjacent land-use practices.

Many streams and rivers in the Fraser system are snowmelt-fed. In these river systems, climate change is associated with earlier melting of ice in spring, an earlier spring freshet, and lower summer flow volume (see "Timing and Volume of River Flow"). The average summer temperature of the Fraser River is increasing because the average annual temperature is getting warmer and because there is less water in the river to heat. In addition, when snow melts earlier in the season, it reduces the buffering effect of the cold spring freshet on stream temperature in early summer.

Examination of weather records suggests that long-term changes in climate are responsible for 55 percent of the Fraser River warming. During the period studied (1953-1998), summer climate as measured upriver of Hell's Gate at Prince George and Kamloops changed in the following ways: air temperature increased; cloud cover decreased; solar radiation (the amount of sunlight reaching the ground) increased; wind speed decreased; and dew point temperature increased. Each of these changes favours river warming.

Changes in adjacent land use over the record period may also have affected river temperatures. Forestry, agriculture, industrialization, and hydro-electric generation tend to decrease the amount of vegetation cover along rivers and streams, exposing more of the river surface to the sun's heat. The impacts of these events are small, however, in comparison to the impact of climate.

WHAT CAN WE EXPECT IN FUTURE?

River temperatures will continue to vary from one year to the next in response to short-term natural climate variability. If the climate is warming, however, years with warmer river temperatures are expected to occur more frequently. In addition, river temperatures may more often exceed those that are optimal for fish.

Atmospheric temperature and other aspects of climate affect river temperature. Climate models project that air temperatures in British Columbia will increase by 1ºC to 4ºC from 1961-1990 historical average by the 2080s. The higher rate of warming is projected to occur over the interior – the region of the province that contains most of the rivers and streams that feed the Fraser River system.

2002 edition

SALMON IN THE RIVER

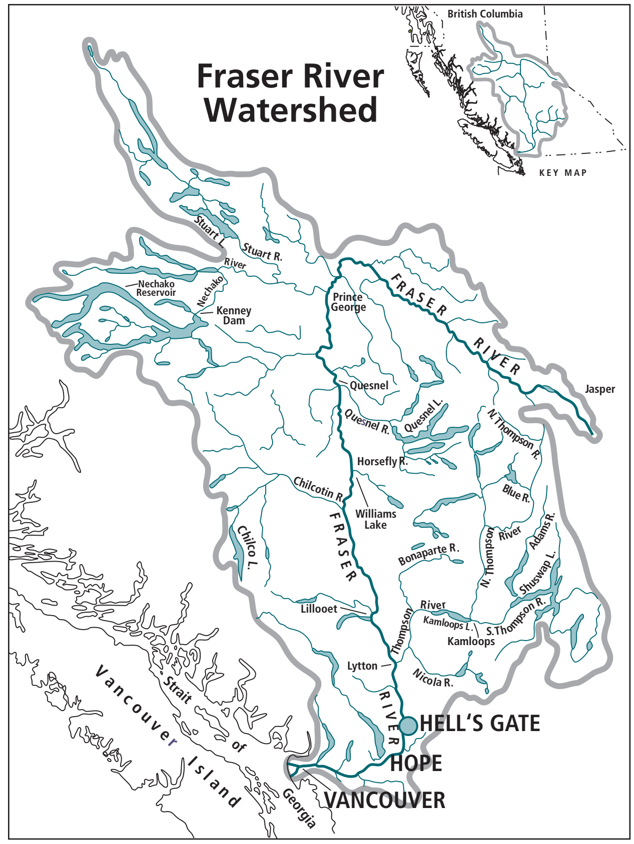
Tom Hall

Natural year-to-year variations in river flow and temperature affect the survival of sockeye salmon stocks. Long-term changes in river flow and temperature associated with climate change are therefore likely to have an impact on Fraser River sockeye populations over time.

Fish are sensitive to temperature, which regulates many of their physiological processes. When their environment is warmer, their metabolic rate increases, speeding up internal processes such as oxygen consumption, digestion, and mobility.

Salmon tolerate temperatures of up to about 24.5ºC but prefer temperatures from 12ºC to 15ºC. Because sockeye prefer colder temperatures than other salmon species, sockeye may be the species that is most sensitive to climate change. Temperatures above 15ºC can cause stress in sockeye, depleting their energy reserves, making them more susceptible to disease and reducing their capacity to produce viable eggs and sperm. Temperatures above 18ºC can impair their swimming ability. They can die from several days' exposure to temperatures between 22ºC and 24ºC or from brief exposure to temperatures above 24ºC.

> Warmer river temperatures are associated with increased mortality in migrating salmon stocks. Changes in river flow and temperature linked to climate change are expected to profound negative impacts on some salmon stocks.



Fraser River Watershed

SOURCE: Ocean Science and Productivity, Fisheries and Oceans Canada.

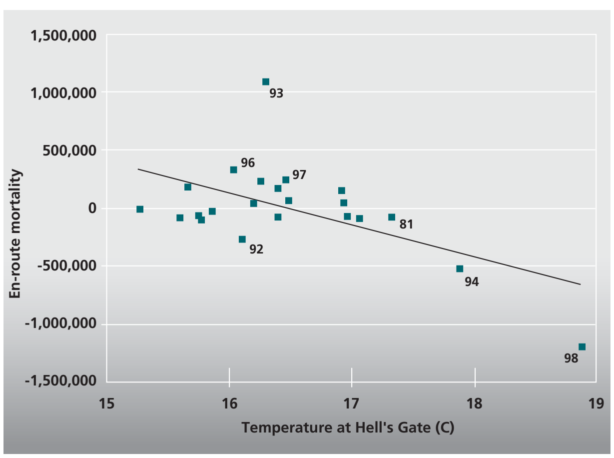
Each summer and fall, adult sockeye return from the ocean to spawn in more than 150 natal stream, river, and lake spawning areas in the Fraser River water-shed. Different stocks start their long swim upriver at different times. The summer run group, including stocks that originate in the Quesnel and Chilko rivers, starts its migration upriver in late July and August. The late run group, including Shuswap stocks, arrives at the mouth of the Fraser River in August, but typically waits four to six weeks before entering the river to start migration.

HOW DOES RIVER TEMPERATURE AFFECT SOCKEYE SALMON?

Most Fraser River sockeye stocks must pass through Hell's Gate, above Hope, in their migration upriver. Measurements taken at Hell's Gate show considerable year-to-year variability in river flow and temperature.

Research has established a link between water flow and temperature and mortality in Fraser River spawning stocks. Fish may die while in transit up the river ("en route mortality") or they may not spawn when they arrive at their spawning grounds ("pre-spawning mortality").

In several years during the past decade, en route mortality in several runs has been greater than 50 percent. Records from 1978 to 1998 indicate that en route losses have been greatest in years with warm river temperatures. The connection is particularly strong in the summer run group, which migrates when river temperatures are at their highest. In recent years the late run group has been starting migration early and is therefore also at risk.



Migration Success of Summer Run Sockeye and Temperature at Hell's Gate, 1978-1998.

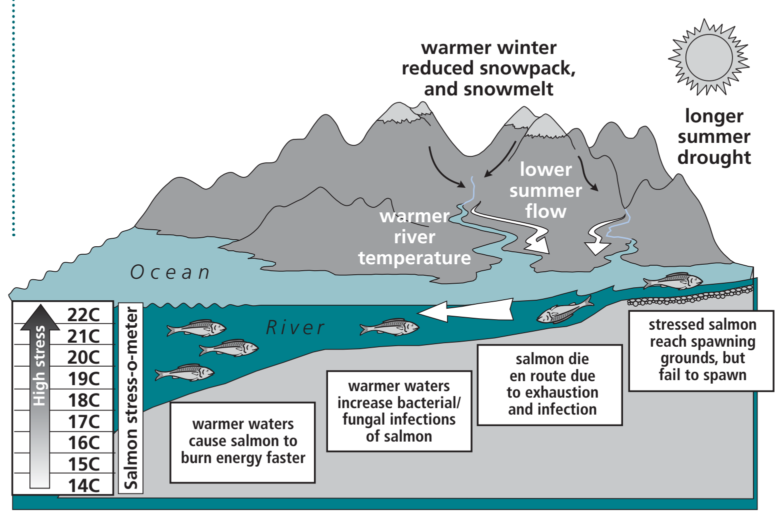
SOURCE: Data and analysis by S. Macdonald and J. Grout, Fisheries and Oceans Canada, 2001. NOTES: En route mortality is the difference between estimates of the number of fish entering the Fraser River, and the number reaching the spawning grounds. A negative number represents fish lost en route. A positive number represents uncertainties in estimation, and/or en route fishing activities. Results are statistically significant at the 95% level.

Pre-spawning mortality across all Fraser River sockeye stocks over a five-decade period ranged from 0 to 85 percent. Studies suggest a weak link between higher rates of pre-spawning mortality and warmer-than-average river temperatures.

Long-term trends in river flow and temperature associated with climate change are therefore reasons to be concerned about the prospects for many Fraser River salmon stocks. Records show that the Fraser River is now discharging more of its annual volume earlier in the year (see "River Flow and Timing'). Earlier spring runoff is associated with lower summer flows and higher water temperatures (see "River Temperature").

WHAT CAN WE EXPECT IN FUTURE?

While river flow and temperature will still vary from one year to the next, summers with lower flow and warmer temperatures will likely occur more often in the future. This is expected to have profound negative impacts on Fraser River sockeye stocks over the long term. More research is needed to determine whether stocks in more northerly rivers – the Skeena, Nass, and Somass – and the Rivers Inlet and Smith Inlet areas will experience the same temperature extremes and will face the same threats as a result of climate change.

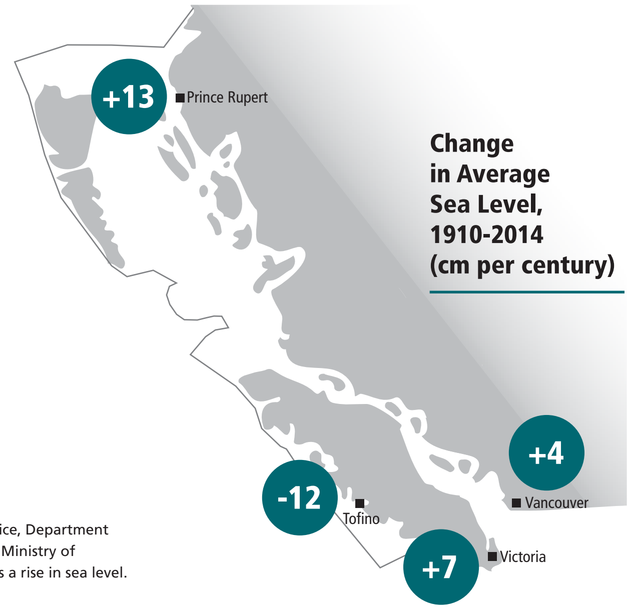


SOURCE: Burghner, R.L. 1991. Life History of Sockeye Salmon. In Pacific Salmon Life Histories. University of British Columbia, p.3-117. Graphic from Temperature Rising: Climate Change in Southwestern British Columbia, 1999.

Revised 2016

Indicator: SEA LEVEL

Average sea level has risen along most of the BC coast over the past century. Higher sea levels increase the risk of flooding of low-lying coastal areas, may contribute to increased erosion of coastlines, and may damage coastal ecosystems and infrastructure.



SOURCE: Data from the Canadian Hydrographic Service, Department of Fisheries and Oceans Canada. Analysis by PCIC for Ministry of Environment, 2016. NOTES: A positive trend indicates a rise in sea level.

ABOUT THE INDICATOR

This indicator measures changes in the average level of the sea relative to the adjacent land. It is based on records from 1910-2014 (with some gaps) from four tide gauges that monitor water levels, located along the British Columbia coast.

The trends identified for coastal BC reflect the combined impacts of climate change and vertical land movements caused by geological processes. The coast of BC is still rising from a process called post-glacial rebound, which refers to the rising of land due to past thinning and retreat of the massive ice sheet that once covered much of the province. In addition, the shifting of tectonic plates generates vertical land motion in coastal BC that is causing parts of Vancouver Island to rise.

SEA LEVEL TRENDS

Average relative sea level rose at the rate of 13.3 centimetres per century at Prince Rupert, 6.6 centimetres at Victoria, and 3.7 centimetres at Vancouver. In contrast, relative sea level fell at Tofino at the rate of 12.4 centimetres per century. These trends reflect the combined impacts of vertical movements of the shoreline and a rise in average global sea level.

The variation in sea level change between the four sites is largely explained by different amounts of vertical land motion. The southwest coast of Vancouver Island is rising at about 25 centimetres per century, while the vertical land motion of Prince Rupert is negligible, thus explaining the approximately 25 centimetres difference in sea-level change between Tofino and Prince Rupert.

Tide gauge measurements from around the world suggest that global sea level rose about 1.7 millimetres per year (17 centimetres per century) on average during the 20th century. Over the past two decades, tide gauge and satellite measurements indicate that the rate of global sea-level rise has increased to about 3.2 millimetres per year (32 centimetres per century).

WHY IS IT IMPORTANT?

Rising sea level will likely contribute to increased flooding of low-lying coastal areas. This may threaten wetlands, beaches, dunes, and other sensitive coastal ecosystems, and sites of cultural importance to Aboriginal peoples. It may also strain drainage and sewage systems in some coastal communities. Salt water may intrude into groundwater aquifers, making the water they contain unfit for household

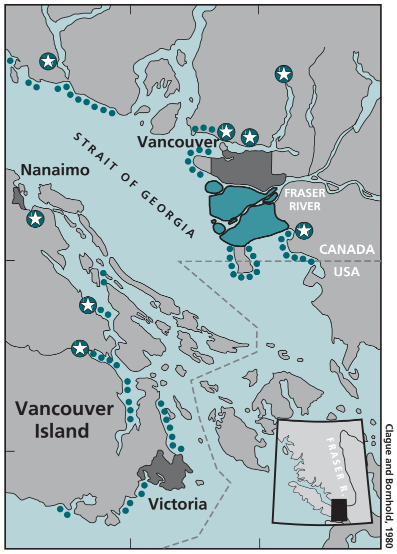
Coastal Regions at Risk

LEGEND

Shoreline vulnerable to erosion

Fraser River delta

Other low-lying areas



SOURCE: Clague and Bornhold. 1980. Graphic from Temperature Rising, 1999.

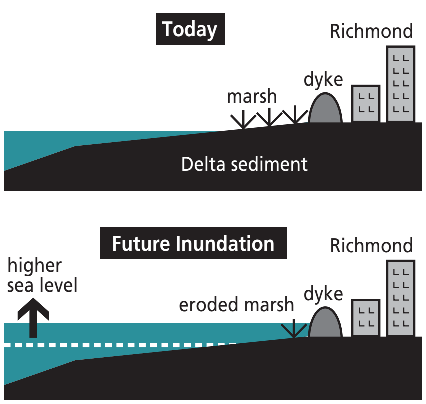
or agricultural use. Even before they are actually inundated, low-lying agricultural lands may become too saline for cultivation.

Higher mean sea level and more frequent extreme high-water events, such as king tides, will increase the likelihood that storms will damage waterfront homes, wharves, roads, and port facilities and contribute to coastal erosion.

Areas particularly at risk are the Fraser River delta, where 100 square kilometres of land are currently within one metre of sea level, and Prince Rupert, which experiences extreme high water events more frequently than other areas of the coast.

Changes in the height and direction of prevailing ocean waves, storm waves, and storm surges as a result of climate change may also have serious impacts on some coastal areas.

Shoreline Inundation



SOURCE: Clague J.J. and B.D. Bornhold. 1980. Morphology and littoral processes of the Pacific Coast of Canada. In The Coastline of Canada: Littoral Processes and Shore Morphology; Geol. Survey of Canada Paper 80-10, p.339-380. Graphic from Temperature Rising, 1999.

WHY IS SEA LEVEL RISING?

The rise in average global sea level observed during the 20th century is very likely due to climate change. As the atmosphere warms, sea water warms and expands in volume. Thermal expansion is a major influence on past changes in sea level. It is expected to make the greatest contribution to a rising sea level over the next century.

Sea level also changes when the overall volume of water in the ocean increases or decreases. As glaciers, ice caps, and ice sheets lose mass from melting and calving, water previously stored on land as ice and snow is added to the ocean. This additional water is expected to contribute substantially to a rise in global sea level over the next century.

Processes not related to climate change also influence relative sea level. These include vertical movements of the land and short-term natural changes in ocean temperature and circulation patterns. For example, El Niño events can cause water levels to increase by a few tens of centimetres in winter months.

WHAT CAN WE EXPECT IN FUTURE?

Climate models project a further rise in global mean sea level of 26 to 98 centimetres by 2100. The rate and magnitude of this rise in sea level will not be uniform over the globe. It will vary from one basin to another, reflecting variations in the amount of ocean warming and the way in which ocean currents redistribute heat and mass.

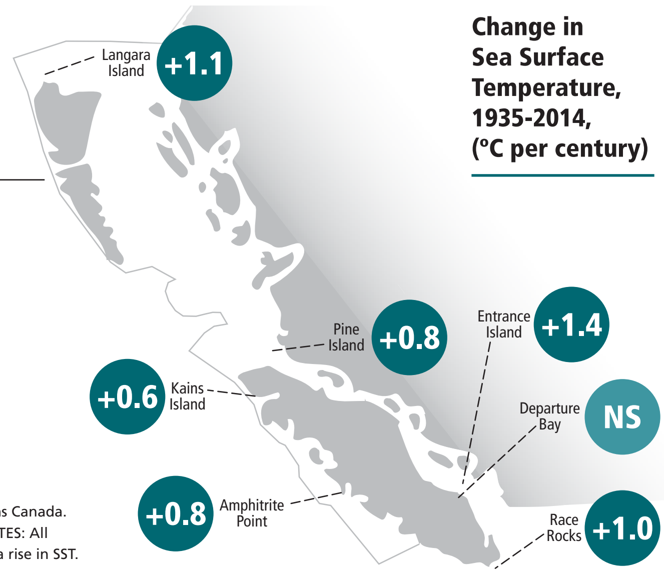
In most areas, climate change is expected to produce mean and extreme water levels higher than any yet recorded. Where relative sea level is projected to rise, extreme high water levels are expected to occur with increasing frequency.

Sea level is expected to continue to rise, even if greenhouse gas concentrations in the atmosphere stabilize. The deep ocean responds slowly to climate change, and thermal expansion of the ocean is likely to continue for hundreds of years. As well, ice masses (glaciers, ice caps, and ice sheets) are expected to continue to shrink with the melted ice increasing the volume of water in the ocean.

Revised 2016

Indicators: SEA SURFACE TEMPERATURE

Sea surface temperature in BC's coastal waters increased during the 20th century. Higher temperatures are associated with reduced ocean productivity and potential adverse impacts on marine resources and the human communities that depend on them.



SOURCE: Data from Department of Fisheries and Oceans Canada. Analysis by PCIC for Ministry of Environment, 2016. NOTES: All statistically significant trends are positive and indicate a rise in SST.

ABOUT THE INDICATORS

Sea surface temperature is measured manually at light stations along the BC coastline. Measurements are taken at the first daily high tide using a collection bucket and thermometers. Of the 19 stations with sea surface temperature records, only seven have a sufficient record for long-term analysis. Trends were calculated on data from the years 1935 through 2014 on a seasonal and annual basis.

SEA SURFACE TRENDS IN BRITISH COLUMBIA

Annual average sea surface temperatures have warmed significantly between 1935 and 2014 at all stations examined. Seasonal sea surface temperatures have warmed significantly at some stations and seasons and not significantly for others. For fall and winter, only three of the seven stations report a statistically significant trend (Entrance Island near Nanaimo, Langara Island off the NW coast of Haida Gwaii, and Race Rocks in the Strait of Juan de Fuca west of Victoria). Warming trends increase in spring and are strongest in summer. In spring, four stations reported significant trends (Amphitrite Point on the west coast of Vancouver Island near Ucluelet, Entrance Island, Pine Island off the northeast coast of Vancouver Island, and Race Rocks south of Victoria). In summer, five stations show significant warming (Amphitrite Point, Entrance Island, Kains Island off the northwest coast of Vancouver Island, Pine Island, and Race Rocks). Only Entrance Island and Race Rocks stations show seasonal trends that are significant in all seasons.

The results show seasonal warming trends from a low of 0.7°C per century for Race Rocks' winter trend to a high of 2.2°C per century for Entrance Island's summer trend. Trends in annual average temperature vary substantially from a low of 0.6°C per century for Kains Island, to a high of 1.4°C per century for Entrance Island. The lack of trends for any season at Departure Bay contrasts with results from other stations that reveal a significant trend in at least one season of the year. Departure Bay is in a location of limited tidal mixing and strong influences from nearby freshwater outfalls. Other nearby stations, such as Entrance Island, are more exposed to the Strait of Georgia where substantial tidal mixing and exposure to Fraser River waters occurs that minimize other local effects. These results differ slightly from published period of record analysis of annual trends. This is discussed in the report's appendix.

The Intergovernmental Panel on Climate Change (IPCC) suggests that average global sea surface temperature has increased at a rate of 1.1°C per century between 1971 and 2010. The rate of warming along the west coast of Vancouver Island – the coastal area most exposed to trends in the Pacific Ocean – is similar to the global average.

WHY IS IT IMPORTANT?

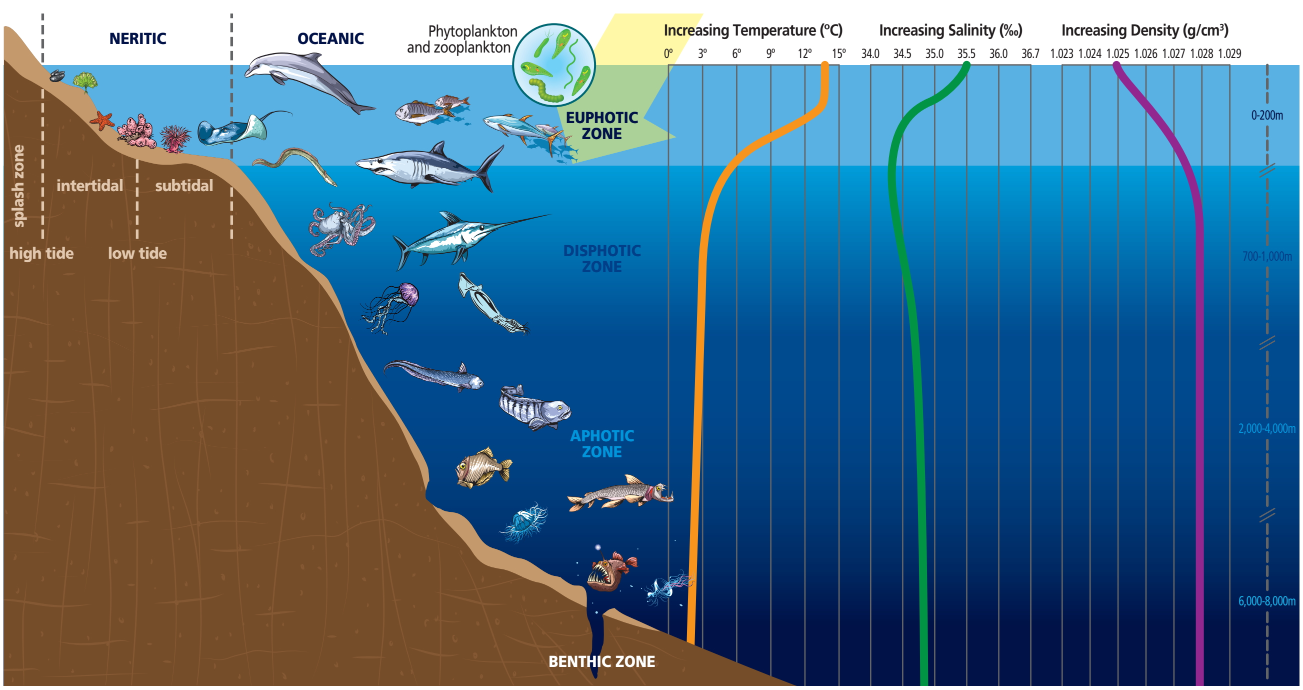
Ocean temperature, salinity, and density are important measures of marine ecosystem health and productivity. Long-term changes in one or more of these measures are likely to affect marine species and ecosystems and the human communities and resource industries that depend on the sea.

Higher sea surface temperatures are linked to changes in salmon distribution and migration patterns and subsequent potential declines in reproductive success (see “Salmon at Sea”). They are also associated with reduced availability of food for and declines in seabird populations (see “Seabird Survival”). In addition, sea temperature is important because it affects the stability of the water column, which in turn affects ocean productivity via nutrient supply.

The upper 100 metres or so is the most biologically productive part of the ocean. In this zone, sunlight drives photosynthesis, supporting the growth of microscopic plants. These phytoplankton become food for microscopic animals – or zooplankton – that in turn support fish and other marine animals.

In spring and summer, as phytoplankton populations grow, they use up nutrients in the upper layer of the ocean. These nutrients are typically replaced in the fall through mixing processes that bring mineral-rich water from the ocean depths to the surface. Such mixing is the result of waves, storms, tides, and prevailing winds. The deeper the mixing, the more nutrients rise to the surface, and the greater the productivity of the ocean the following year.

Temperature affects the stability of the water column and therefore the depth to which mixing can



Ocean light zones and generalized temperature, salinity, and density-depth profile for ocean water.
SOURCE: Adapted from Windows to the Universe, University Corporation for Atmospheric Research (UCAR), 2004.

occur. Temperature and salinity in the deep Pacific Ocean are stable on decade to century timescales. The sea surface is typically warmer, less saline, and less dense than the deeper water and therefore tends to "float" on top of the deeper, denser water. When the sea surface is warmer than usual, the difference in density between the surface and deeper water is greater, the surface sits more securely on top of the deeper water, and mixing becomes more difficult.

Natural cycles of climate variability are associated with cycles in ocean productivity. In an El Niño year, the sea surface near the BC coast is warmer than usual in summer, and the upper water column is more stable. Mixing may therefore occur to a depth of only 100 metres. In a La Niña year, the sea surface in summer is cooler than usual, and the water column is less stable. Mixing may occur down to 140 metres, which results in greater ocean productivity.

The trends towards warmer temperatures may lead to a more stable ocean near our coast, which would reduce nutrient supply and be of great concern.

WHY IS THE SEA SURFACE CHANGING?

The ocean is an integral and responsive component of the climate system. At its surface, it exchanges heat, water (through evaporation and precipitation), and carbon dioxide and other gases with the atmosphere. The 20th century trend towards higher sea surface temperatures is related to increasing atmospheric temperatures and is symptomatic of the warming ocean, including its interior. It is estimated that more than 90% of the increase in heat energy stored by the climate system as a result of increased GHGs is stored in the ocean.

Of BC's three regions of coastal waters, the west coast of Vancouver Island is the most exposed to the Pacific Ocean and the most likely to reflect oceanic trends. In the other two regions (Georgia Basin and Queen Charlotte Sound), local evaporation and precipitation rates and freshwater runoff from rivers and streams may affect temperature.

WHAT CAN WE EXPECT IN FUTURE?

Sea surface temperature will likely continue to vary from year to year and from decade to decade in response to natural cycles. Climate models project, however, that the Earth will continue to warm and that average global sea surface temperature will increase by 0.6°C to 2°C in the top 100m by the end of the 21st century. The ocean will warm more slowly than the land. Current models do not yet allow scientists to project with confidence the future frequency, amplitude, and spatial pattern of El Niño events.

2002 edition

SALMON AT SEA


S. Kirkvold

Natural variations in sea surface temperature are associated with changes in the distribution and survival of sockeye salmon. As a result, the effect of climate change on long-term increases in average ocean temperature is likely to have an impact on sockeye populations over time.

Salmon and other fish are cold-blooded, and the temperature of their environment regulates many of their physiological processes. Warmer water temperatures raise their metabolic rate and speed up movement and internal processes such as growth, oxygen consumption, and digestion.

Studies suggest that salmon prefer a temperature very close to the temperature that promotes optimal growth. When food is abundant, they can afford – from a biological perspective – to stay in warmer waters. The abundance of food makes up for the higher requirements needed to fuel a more active metabolism. When food is limited, however, fish move into cooler waters, where they need less food to grow and survive.

The temperature range that fish prefer is species-specific. In general, salmon like cold water, and sockeye prefer colder water than other salmon species. For this reason, sockeye may be the salmon species most sensitive to climate change. Fraser River sockeye stocks are of particular concern because they are already close to the southern boundary of the range for sockeye and are thus more likely than other sockeye stocks to be exposed to water temperatures outside their preferred range.

Most Fraser River sockeye stocks enter the ocean as smolts in the spring and spend a few weeks in the Strait of Georgia before migrating northwards along the coast of British Columbia to Alaska in early summer. During this migration, they stay on the continental shelf – a relatively shallow zone extending 20 to 30 kilometres offshore. In late autumn and winter, after reaching the Aleutian Islands, they move southwards into the open ocean. They spend one to three years at sea before they return as adults to the Fraser River in late summer and swim upstream to spawn and die.

HOW DOES SEA TEMPERATURE AFFECT SOCKEYE SALMON?

The sea surface is subject to natural cycles of warming and cooling and corresponding periods of lower and higher ocean productivity (see “Sea Surface Temperature”). These cycles are associated with year-to-year variability in sockeye production. Warmer sea surface temperatures are associated with increased juvenile sockeye mortality, changes in ocean distribution, changes in the timing of migrations, and smaller returning adult fish.

> For sockeye salmon, warm years are associated with increased juvenile mortality, reduced distribution, increased competition, and reduced spawning success.

During warm years, ocean productivity is relatively low and may result in slower growth in juvenile salmon, making them vulnerable to predation for a longer period of time. In addition, subtropical fish such as mackerel migrate northwards during warm years and can compete for food with, or prey upon, young salmon in coastal waters.

Some researchers have associated increasing sea surface temperatures with a decrease in the habitable area for sockeye in the North Pacific. During their years in the open ocean, sockeye undertake extensive migrations within a region bounded by the Bering Sea in the north and 40ºN latitude in the south. Within this region, the area used by sockeye varies by season and is closely associated with water temperature. The southern limit of their distribution varies from between the 6ºC and 7ºC isotherms in winter, to the 9ºC isotherm in spring and early summer, and the 13.5ºC isotherm in summer. In years when sea surface temperature is higher, the habitable area for sockeye is smaller.

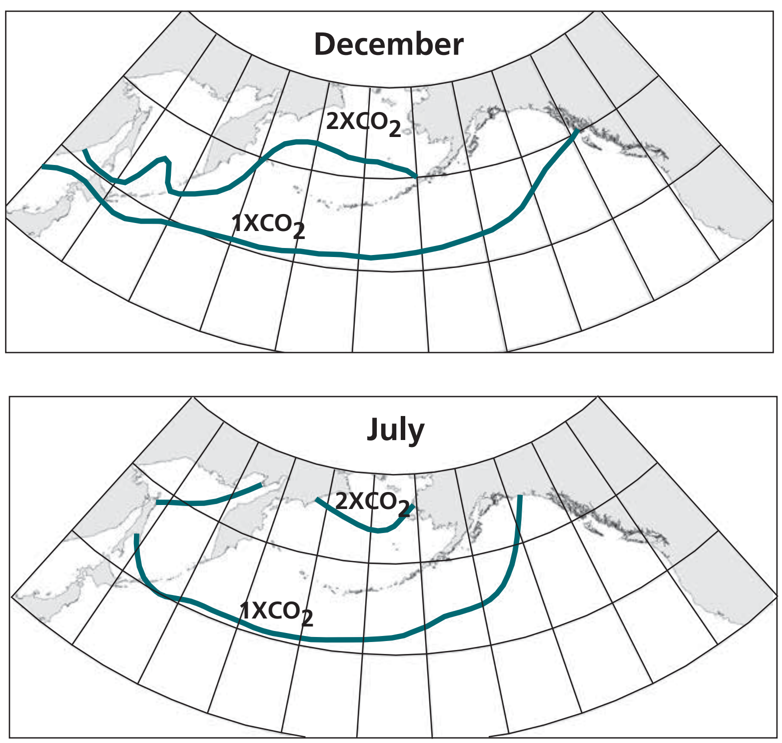
Ocean temperature appears to affect the timing of sockeye migrations from the ocean back to the Fraser River. Evidence suggests that in warm years, sockeye arrive later at the mouth of the river. Salmon that arrive later than normal at the mouth of the river may also arrive late at their spawning grounds. Late spawning can have a negative effect on the time when young salmon emerge the following spring and their subsequent survival.

Ocean temperature also appears to affect the size of the returning fish. In warmer years, if fish congregate within a smaller habitable area and compete for the same amount of food, individual growth may be slower, and returning fish may be smaller than normal. In addition, warmer years are associated with reduced ocean productivity and the potential for increased competition for food. In 1997 – a particularly warm year in the northeast Pacific Ocean – returning sockeye were much smaller than normal. Smaller fish may not be able to migrate upstream through the Fraser River system to their spawning grounds as effectively as larger fish.

WHAT CAN WE EXPECT IN FUTURE?

Coastal waters in BC have warmed during the past century, and climate models suggest that ocean warming associated with climate change will continue. While sea surface temperature will still vary from one year to the next, it will be "warm" during proportionally more years. For sockeye, warm years are associated with increased juvenile mortality, restricted distribution, increased competition for food, and reduced spawning success. An increase in the proportion of warm years can therefore reasonably be expected to have a profound long-term negative impact on Fraser River sockeye stocks.

Winter and Summer Distribution of Sockeye Salmon in the Pacific Ocean, Under Current (1XCO_2) and Future (2XCO_2) Concentrations of Atmospheric CO_2



SOURCE: Welch, D.W., Y. Ishida, and K. Nagasawa. 1998. Thermal Limits and Ocean Migrations of Sockeye Salmon (Oncorhynchus nerka): Long-Term Consequences of Global Warming. Can. J. Fish. Aquat. Sci. 55:937-948.
NOTES: 1XCO_2 refers to the current atmospheric concentration of CO_2. 2XCO_2 refers to the doubling of atmospheric CO_2 concentration from this baseline. Climate models predict that 2XCO_2 will occur during the 21st century. As CO_2 concentration increases, atmospheric and ocean temperature increase, and fish move northwards into cooler water.

2002 edition

SEABIRD SURVIVAL

SOURCE: BC Parks

The reproductive success of the Cassin's auklet *(Ptychoramphus aleuticus)* is sensitive to ocean temperature. Increases in sea surface temperature associated with climate change may therefore threaten the long-term survival of this seabird.

The auklet breeds in a few large colonies along the western coast of North America. Triangle Island, an ecological reserve off the northern tip of Vancouver Island, is home to the world's largest colony, consisting of 1.1 million breeding birds.

Some populations of Cassin's auklet have declined in recent years. A colony on the Farallon Islands in California experienced a 65 percent decline between 1972 and 1997. The Triangle Island population declined between 1989 and 1999, and in several years, breeding success was poor. However, a third population that breeds on Frederick Island off the coast of northern British Columbia showed no signs of population decline during the 1990s and has had consistently good breeding success.

Higher ocean temperatures will affect the long-term survival of Cassin's auklet populations in BC because warmer surface water decreases the food supply for developing chicks.

WHY ARE POPULATIONS DECLINING?

The evidence suggests that population declines are linked to a long-term reduction in the availability of zooplankton – a major food source for Cassin's auklet chicks – in the marine ecosystem that extends from California northwards as far as northern Vancouver Island. Research has documented a relationship between warmer spring ocean temperatures, reduced availability of zooplankton, and decreased growth rates and survival of seabird chicks.

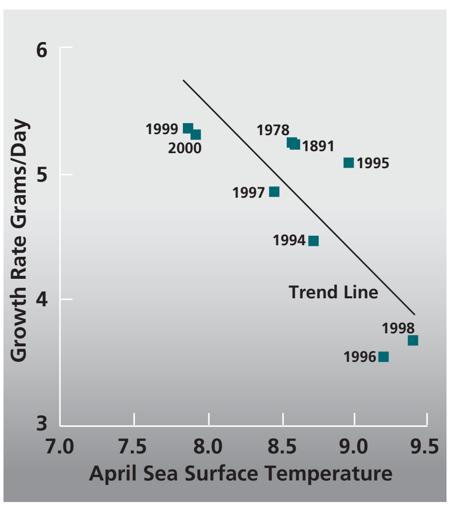
Cassin's auklets attempt to raise a single chick per year, and the survival of each chick is therefore important to the long-term survival of the entire population. Cassin's auklet parents care for their chick for 40 to 60 days after it hatches, feeding it zooplankton – primarily small shrimp-like organisms called copepods. Both parents use their wings to "fly" underwater in search of food for their chick, transporting the food within a throat pouch and regurgitating it for the chick when they get back to the burrow. The growth and survival of Cassin's auklet chicks depend on the availability of copepods in the top 30 metres of the ocean – the depth to which the auklet parents are able to dive.

Copepods inhabit the sea surface for only a brief period during the spring. Their metabolic rate, growth, and development are synchronized with temperature. As surface temperatures warm up, copepod larvae migrate from deep ocean waters to the surface, where they feed on phytoplankton and grow to adult size before returning to the deeper waters of the ocean. When spring surface waters warm earlier in the season, the copepods develop more quickly, become adults faster, and migrate back to deeper waters sooner than they do in years when spring surface waters are cool.

In warm years, the times when seabirds breed and when food is most available are poorly matched. By the time the Cassin's auklet chicks hatch, the copepods are already returning to deeper water, and there is a diminishing food supply for the chicks. As a result, the chicks grow slowly and often starve to death later in the season.

In contrast, when spring surface-water temperatures are cool, the copepods persist longer in the surface waters, so that food is available for chicks throughout the development period, from hatching to the time when they are ready to leave the burrow. The location of Frederick Island explains the health of its Cassin's auklet population. Because the island is so far north, the sea surface temperature during the period when chicks are growing and developing remains cool enough – even in warmer years – to ensure that they have enough food.

Average Growth Rate (grams/day) of Cassin's Auklet Chicks and Sea Surface Temperature near Triangle Island



SOURCE: Original data and analysis from Doug Bertram, Simon Fraser University, Centre for Wildlife Ecology and Canadian Wildlife Service, 2001 for Ministry of Water, Land and Air Protection. NOTES: Average growth rate (grams/day) of Cassin's Auklet chicks is based on weight change between 5 and 25 days from date of hatching. Cassin's Auklet chick growth rates and survival decline as ocean temperature increases (April SST > 7.5ºC). The slope of the line is statistically significant ($F_{1,7}$=12.5; P=0.009).

Climate change is linked to an increase in average sea surface temperature in waters off the coast of BC. In the 1990s, these temperatures were some of the highest ever observed in the 20th century. In years such as 1996 and 1998, when spring was early and sea surface temperatures were warmer than usual, the growth rates of Cassin's auklet chicks on Triangle Island were much lower than in cooler years such as 1999.

WHAT CAN WE EXPECT IN FUTURE?

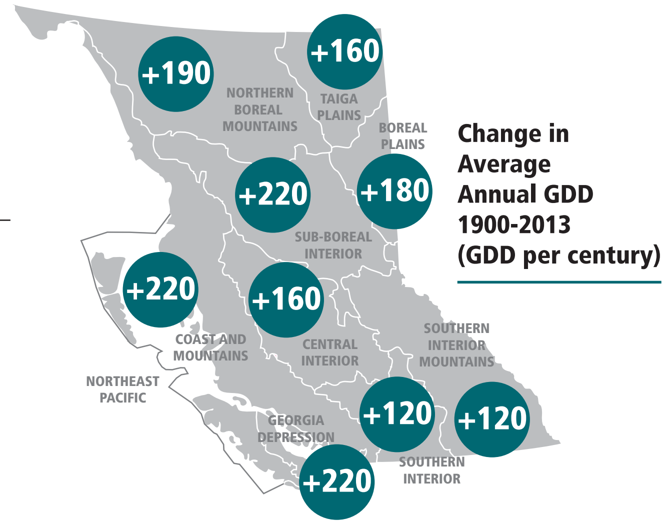
Average global sea surface temperature has increased by 0.4ºC to 0.8ºC since the late 19th century and is expected to continue to rise during the next century. Populations of Cassin's auklet on Triangle Island are therefore likely to continue to grow slowly, and chick mortality is likely to continue to increase. If the adult birds cannot replace themselves, the population will continue to decline.

The story of the Cassin's auklet is one example of how climate change may affect the distribution and survival of individual species in BC. Many other species – marine, freshwater, and terrestrial – may be similarly affected during the decades to come.

Revised 2015

Indicator: GROWING DEGREE DAYS

The average heat energy available for plant growth and development has increased over the past century, particularly in Coastal BC.



SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat. NOTES: A positive sign indicates an increase in GDD.

ABOUT THE INDICATOR

This indicator measures changes in the amount of heat energy available for plant growth, expressed in units called Growing Degree Days (GDD).

Assessment of annual GDD is based on available temperature records from 1900 to 2013.

GDD TRENDS IN BRITISH COLUMBIA

Annual Growing Degree Days increased from 1900 to 2013 across the province. On average there are 190 more GDD in BC than at the beginning of the 20th century. These trends are consistent with trends over the past century toward higher average annual temperatures across British Columbia.

The greatest increase in GDD has occurred on the coast. The Coast and Mountains and Georgia Depression ecoprovinces have both experienced an increase in energy available for plant growth of 220 GDD per century. Heat energy has increased in the Sub-Boreal Interior ecoprovince by 220 GDD per century as well. The annual trend in both the Southern Interior and Southern Interior Mountains ecoprovinces is an increase of 120 GDD per century. In the north of BC (Boreal Plains, Taiga Plains, and Northern Boreal Mountains) annual average heat energy has increased by 160 to 190 GDD per century.

WHY IS IT IMPORTANT?

Plants and invertebrates require a certain amount of heat to develop from one stage in their life cycle to another. The measure of accumulated heat is known as “physiological time” and is measured in units called “degree days.” All individuals of the same species require the same number of degree days to develop from one life stage to another. When temperatures are warmer, they develop faster.

Each plant species – and each insect species – has its own minimum temperature requirement for growth. For example, spinach can grow when average daily temperatures are as low as 2.2ºC, while corn requires temperatures of at least 10ºC.

Because of these differences, agrologists sometimes refer to an average minimum temperature of 5ºC when they talk about the heat requirements of agricultural plants as a group. For the typical agricultural plant, GDD for one day is calculated as the difference between the average temperature and 5ºC. For example, a day when the average temperature is 12ºC contributes 7 GDD to the

Heat requirements of Agricultural Crop and Pest Species

Species	Minimum Threshold	Degree Day Requirements (over threshold temperature)
Sweet corn	10C	855
Thompson grape	10C	1600-1800
Codling moth	11C	590
Pea aphid	5.5C	118

annual total number of GDDs for that location. GDD is calculated for only those days when the average temperature is higher than 5ºC.

A significant increase in available heat energy could allow farmers to introduce new varieties of crops that were previously marginal or not viable in their regions. If adequate soil moisture, soil fertility and light are also available, this could allow agriculture to expand to new regions and sites within the province.

Some of the other impacts of climate change could have negative impacts on agriculture. Changes in hydrological systems combined with warmer temperatures and greater evapotranspiration, for example, may mean less available soil moisture in some regions. And warmer temperatures may also mean that new insect pest species are able to move into a region. Further, warmer temperatures may threaten crops that are not tolerant of extreme warm temperatures above certain fixed thresholds that reflect the crop's physiology.

WHY IS GDD INCREASING?

From 1900 to 2013 average annual temperatures warmed in BC at a rate of 1.4ºC per century. Because GDD is related to average daily temperature, it is not surprising that the amount of energy available for plant growth and development has also increased.

WHAT CAN WE EXPECT IN FUTURE?

Climate models indicate that temperatures will continue to rise in BC by 1.7ºC to 4.5ºC by the 2080s. The higher rate of warming is projected to occur over the interior of the province. Annual GDD should continue to increase as the climate continues to warm.

The United Nations Intergovernmental Panel on Climate Change (IPCC) suggests, however, that increases in average annual temperature of more than a few degrees centigrade will result in a general reduction, with some variation, in potential crop yields in mid-latitudes.

2002 edition

MOUNTAIN PINE BEETLE RANGE

SOURCE: Canadian Forest Service

The mountain pine beetle is a native insect with an important role in maintaining many pine ecosystems. It is also the most important forest pest in western Canada and has killed an estimated 300 million trees in British Columbia over the last 20 years and damaged timber worth an estimated six billion dollars.

While mountain pine beetle will attack most western pines, its primary host throughout most of its range is lodgepole pine. Mountain pine beetles burrow into the bark of the host tree and lay their eggs there in summer. The eggs hatch inside the tree and larvae remain there over the winter. During the following spring, larvae complete their development. Burrowing and feeding activities of the larvae create networks of channels known as galleries beneath the bark, causing the death of the tree.

Adult beetles emerge from their host tree in mid- to late summer and disperse in search of new trees to colonize. Dispersal may be within the same stand or over distances of 100 kilometres or more. Once the beetles find a new host tree, mated females bore through the bark to lay their eggs, starting a new cycle.

Endemic populations of mountain pine beetle are common throughout lodgepole pine forests. They tend to inhabit individual trees dispersed throughout a stand that are weaker and less resistant to invasion. In these endemic populations, births and deaths are in balance. Predators, disease, and competition for food and space control population size. The capacity of most healthy trees to resist a normal beetle attack also helps control the beetle population.

Mountain pine beetle populations increase from time to time within a stand when conditions allow – for example, when trees are stressed by crowding, flooding, or root disease. Such stand-level infestations can quickly become a full-scale outbreak under ideal conditions, with beetles invading – and ultimately killing – many trees across the forest landscape. Periodic mountain pine beetle outbreaks like this created ideal conditions for fire, which has historically played a vital role in maintaining native pine ecosystems by eliminating competing vegetation, preparing the seedbed, and releasing seeds from cones, which require heat to open.

HOW DOES TEMPERATURE AFFECT MOUNTAIN PINE BEETLES?

Temperature is one of the primary sources of mortality for mountain pine beetles.

When temperatures in the summer and fall are warm enough, larvae hatch and grow adequately before the onset of winter. When they are at the late larval stage, mountain pine beetles are resistant to cold and can withstand temperatures close to -40ºC for long periods of time.

When temperatures in the summer and fall are relatively cool, however, the larvae grow more slowly and may not reach the ideal life stage before winter. As a result, many will die. For this reason, the mountain pine beetle cannot establish populations at high elevations or at northern latitudes. Its distribution is bounded by the -40ºC isotherm, which joins sites where the

> Temperature limits the range and size of mountain pine beetle populations. Warmer temperatures may allow the beetles to move northwards into new regions and upwards into new ecosystems.

average of the lowest temperature recorded each year (1921-1950) is -40ºC.

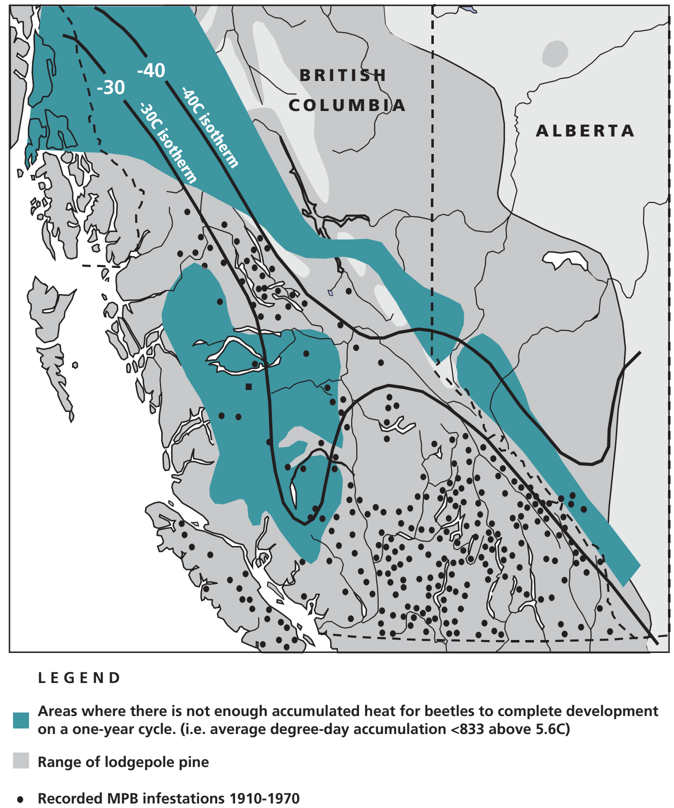
Lodgepole pine ecosystems – the preferred forest of the mountain pine beetle – extend north into the Yukon and the Northwest Territories and east into Alberta. Climate limitations currently prevent the mountain pine beetle from establishing itself in these regions. Warmer temperatures, in particular warmer winter temperatures associated with climate change, may allow the mountain pine beetle to extend its range northwards and eastwards into these ecosystems. With warming, regions that are currently too cold for the mountain pine beetle will become more suitable.

A 2.5ºC increase in temperature would likely shift the northern boundary of the region suitable for the mountain pine beetle a further 7 degrees of latitude north. A range expansion of this size would allow beetles potential access to formerly unoccupied lodgepole pine habitat. It would also give them the potential to invade jack pine forests, a major component of the boreal forest that is currently free of beetles.

Warmer winter temperatures may also allow the mountain pine beetle to extend its range upwards into high-elevation pine forests – for example, whitebark and limber pine forests in southeastern BC – that are not adapted to the beetle's impacts.

An additional concern is the possibility that climate change may allow mountain pine beetle infestations and outbreaks to occur more regularly and with greater severity within the beetle's current range. At present, mountain pine beetle outbreaks in BC are limited to the southern portion of the province. Outbreaks occur almost exclusively in regions where it is warm enough for mountain pine beetles to complete their development within a year. In such regions, when weather conditions are warmer than usual, a large number of larvae can survive the winter. Larger populations of adult beetles can more easily overcome the resistance of healthy trees, allowing the development of stand-level infestations and of outbreaks. Consequently, it is highly possible that an increase in winter temperatures associated with climate change could increase the potential for outbreaks.

Distribution of Mountain Pine Beetle Infestations, 1910-1970



SOURCE: A. Carroll, Pacific Forestry Centre, 2001. Adapted from Safranyik, L. 1990. Temperature and insect interactions in western North America. Proceedings of the Society of American Foresters National Convention. Washington DC. SAF Publication 90-02. pp. 166-170. Isotherms from Department of Mines and Technical Surveys. 1957. Atlas of Canada.

WHAT CAN WE EXPECT IN FUTURE?

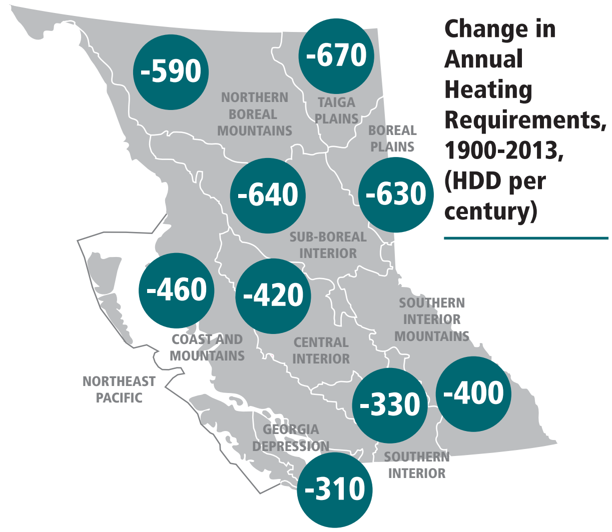
Monitoring indicates that average temperatures over most of British Columbia warmed during the past century, with the greatest increases occurring in the north. Climate models project that this warming trend will continue. Most importantly, the data show that minimum temperatures have warmed during this time period.

Because minimum temperatures delineate the northern range of the mountain pine beetle, this increase in minimum temperatures provides forest managers with reason for concern.

Revised 2015

Indicators: HEATING AND COOLING REQUIREMENTS

Throughout BC, but especially in the north, the amount of energy required for heating similarly constructed and insulated buildings decreased during the past century. The amount of energy required for cooling increased the most in southern BC.



Change in Annual Heating Requirements, 1900-2013, (HDD per century)

SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment. NOTES: A negative sign indicates a decrease in heating requirememts.

ABOUT THE INDICATORS

These indicators measure changes in the annual energy requirements for heating and cooling. The figures in this section show the average rate of change in annual Heating Degree Days and Cooling Degree Days over a century for all the ecoprovinces in BC. The trends are based on temperature records from 1900 to 2013 from weather observation stations throughout the province.

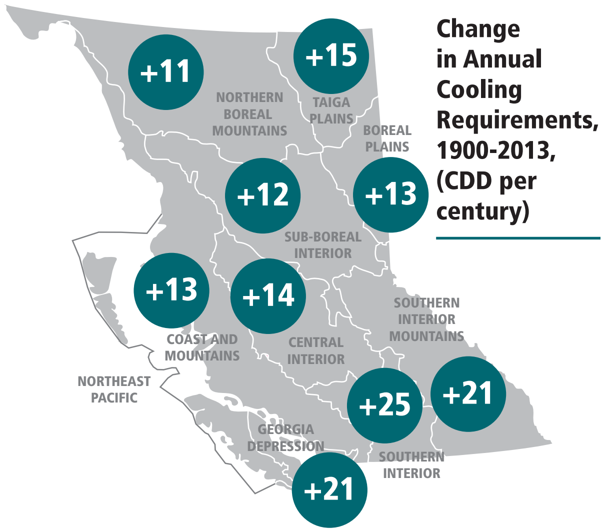
Heating requirements are measured in units called Heating Degree Days (HDD). HDD for one day is calculated as the difference between 18ºC and the average outdoor temperature for that day when the outdoor temperature is less than 18ºC. For example, a day with an average temperature of 8ºC has an HDD of 10. Over a month of similar days the monthly HDD would be about 300. The HDD calculation looks only at days when the average outdoor temperature is less than 18ºC. Annual HDD represents the sum of daily HDD for the year.

Energy requirements for cooling are measured in units called Cooling Degree Days (CDD). CDD for one day is calculated as the difference between the average outdoor temperature for that day and 18ºC when the outdoor temperature is warmer than 18ºC. For example, a day with an average temperature of 21ºC has a CDD of 3. A month of similar days would have a monthly CDD of about 90. The CDD calculation looks only at days when the average temperature is more than 18ºC and cooling is required. Annual CDD represents the sum of daily CDD for the year.

HEATING AND COOLING TRENDS

There is a province-wide trend towards lower annual heating requirements. The annual Heating Degree Days (HDD) in the province as a whole have decreased by 600 HDD per century with the greatest reduction in energy requirements for heating in the northern parts of BC. In the Taiga Plains ecoprovince, the annual HDD have decreased by 670 HDD per century from 1900 to 2013. The Boreal Plains and Sub-Boreal Interior ecoprovinces experienced a decrease in HDD of 630 to 640 HDD per century. In the Georgia Depression ecoprovince the heating energy requirements have decreased by 310 HDD per century.

Cooling energy requirements have increased modestly throughout the province by an average of 13 Cooling Degree Days (CDD) per century. The greatest increase in energy required for cooling has occurred in the southern part of the province. The Southern Interior ecoprovince has experienced the greatest increase in annual CDD, at a rate of 25 CDD per century. The two ecoprovinces that experience the second highest rates of increasing cooling energy requirements are the Georgia Depression



SOURCE: Data from Ministry of Environment Climate Related Monitoring Program and Environment Canada. Trend Analysis for 1900 through 2013 conducted by PCIC, 2014 for the Ministry of Environment Climate Action Secretariat. NOTES: A positive sign indicates an increase in cooling requirememts.

and the Southern Interior Mountains. Both of these regions have experienced an increase in annual cooling requirements at a rate of 21 CDD per century. The Northern Boreal Mountains have experienced an increase in cooling energy requirements at 11 CDD per century. The Taiga plains are experiencing an average annual CDD increase at 15 CDD per century.

WHY IS IT IMPORTANT?

Building managers, owners, and residents often begin interior heating when the outdoor temperature is below 18ºC (although this threshold may be lower for homes constructed more recently). As outdoor temperature goes down, the amount of energy required for heating goes up.

The energy supply industry uses annual HDD figures extensively to measure and project heating requirements. Annual HDD figures help the energy industry estimate demand for residential and other heating and maximum demand on energy supply systems during extremely cold periods. All else being equal, when annual HDD decreases, there is less demand for energy for heating.

With respect to cooling, residents of warmer climates often turn on their air conditioners when the average daily outdoor air temperature, averaged over a 24-hour period, exceeds 18ºC.

CDD affects energy demand because most air conditioning and refrigeration systems use electricity to operate fans and pumps. In most of BC, however, cooling places minor demands on the energy system, and CDD is not a significant factor in energy management and planning decisions. However, CDD may become more of an issue for regional energy use planning in southern BC.

WHY ARE HEATING AND COOLING REQUIREMENTS CHANGING?

During the 20th century, average annual temperatures increased across most of BC. Because heating and cooling requirements are directly linked to temperature, it is not surprising that they too should have changed during the same period.

This rise in average annual temperature is only part of the story, however. Surface warming trends and trends in daily maximum and minimum temperature vary by season and from one region of BC to another (see "Average Temperature" and "Maximum and Minimum Temperature"), affecting heating and cooling requirements.

In winter, less energy is required to keep buildings warm when average daily temperatures increase, as they have throughout BC. The trends also suggest that heating requirements have gone down mainly because winter nights are not as chilly as they were in the past (see "Maximum and Minimum Temperature").

The summer temperature trends suggest that, in the Southern Interior, Georgian Depression and Southern Interior Mountains, slightly more energy may be required to keep buildings cool during the hot part of the day because summer nights are warmer now than in the past. Buildings therefore do not cool down as much during the night (see "Maximum and Minimum Temperature").

WHAT CAN WE EXPECT IN FUTURE?

Climate models indicate that temperatures will continue to rise over BC during the 21st century and that atmospheric warming will be more pronounced in winter and summer than in spring and fall. Consequently, winter heating requirements will likely continue to decrease, and summer cooling requirements to increase.

2002 edition

HUMAN HEALTH

Warmer temperatures, and changes in precipitation and other aspects of the climate system have the potential to adversely affect human health. Although at this time there are no data that directly link climate change and health in British Columbia, studies from other regions suggest that such links may exist.

HOW CAN CLIMATE CHANGE AFFECT HUMAN HEALTH?

Climate change may increase the frequency of heat-related and respiratory illness, water contamination and water-borne diseases, vector-borne diseases, and some weather-related accidents.

Heat-related Illness: Climate models predict that over the next century summer heat waves will occur more frequently, particularly in urban areas, where buildings and pavement absorb and retain heat. Between 1951 and 1980 in Victoria, an average of three days per year were warmer than 30°C. In the 21st century, hot days are expected to more than quadruple, to 13 days per year. Hot days will be even more frequent in the Lower Mainland and the interior of BC. As a result, heat-related health impacts – including heat stroke, dehydration, and cardiovascular and respiratory illness – are expected to increase.

Respiratory Illness: Heavy emissions from motor vehicles and industrial activities can contribute to the development of smog. This is particularly a problem in Vancouver and the Fraser Valley. A component of smog – ground level ozone – is linked to respiratory irritation, affecting individuals with asthma and chronic lung disease. Even healthy individuals can experience chest pain, coughing, nausea, and lung congestion when exposed to low amounts of this ozone.

On hot days, the reactions that produce smog and ground level ozone occur more quickly. The rise in average temperature associated with climate change will likely increase the incidence of smog. The Intergovernmental Panel on Climate Change (IPCC) has therefore concluded that ongoing climate change could exacerbate respiratory disorders associated with reduced air quality in urban and rural areas.

Water Contamination: Water quality deteriorated between 1985 and 1995 at 11 percent of provincial water sampling stations. Past discharges from mining operations, non-point source pollution, and high waterfowl concentrations have made water in some communities unfit for recreation or drinking. Climate change poses additional threats. Sea level rise may inundate water systems in some low-lying coastal areas with saltwater, chemicals, and disease organisms. Extreme precipitation events may strain municipal drainage and sewage systems and increase the risk of contamination. Summer water shortages may exacerbate water quality problems in some areas by increasing the concentration of contaminants.

Water-borne Disease: Increased precipitation, runoff, and flooding associated with climate change may increase the transmission of parasites from other animals to humans through the water system. In 1995 Victoria experienced an outbreak of toxoplasmosis, a disease that causes symptoms ranging from swollen lymph glands to lung complications, lesions on major organs, and disorders of the central nervous system. The outbreak was linked to extreme precipitation, causing high levels of runoff that picked up the parasite from animal feces and carried it into drinking water reservoirs. In recent years BC has also experienced outbreaks of cryptosporidiosis, another serious water-borne disease transmitted through animal feces.

Increases in marine and freshwater temperature associated with climate change may also contribute to the survival of pathogens. Red tide, a disease of shellfish, is caused by a toxic algae that grows in warm coastal waters during the summer. Shellfish concentrate the red tide toxins in their flesh, and humans who eat contaminated shellfish can become seriously ill. Ocean warming associated with climate change may increase the incidence of red tide along the BC coast. In fresh water, warmer temperatures may create ideal conditions for the pathogen responsible for giardiasis, which is transmitted from animals to humans through water.

Vector-borne Disease: Animals, birds, and insects that carry human diseases are known as disease “vectors.” Warmer temperatures associated with climate change may enable vectors – and the diseases they carry – to extend their ranges. The chance of humans contacting the disease may therefore increase. Vectors of concern in BC include rodents, ticks, and mosquitoes.

The deer mouse is the primary vector in Canada for hantavirus, and it transmits the virus to humans through its feces. When the feces dry, the virus is released into the air and can be inhaled by humans who are in the vicinity. Six cases of hantavirus in humans are known to have occurred in BC, two of them resulting in death.

Various species of ticks can carry Lyme disease and transmit it to humans. The most important vector in BC is the western black-legged tick, which is extremely common on the coast during the early spring and summer. The microorganism that causes Lyme disease has also been detected in adult ticks in the Fraser Valley.

Mosquitoes are the primary vector in North America for encephalitis. Viral transmission rates from mosquitoes can increase sharply as temperatures rise. Studies elsewhere show a correlation between temperature and the incidence of tick-borne encephalitis in humans. Swedish studies suggest that the relatively mild climate in the 1990s in Sweden contributed to increases in the density and geographic range of ticks. At high latitudes, warmer-than-usual winter temperatures were related to a northward shift in tick distribution. Further south, mild and extended autumn seasons were related to increases in tick density.

Weather-related Accidents: In general, climate change is associated with increased precipitation, flooding, landslides and extreme weather-related events. Such events may increase the incidence of accident-related injuries and deaths in BC. Other impacts of climate change – for example, reduced winter snowfall – may decrease the potential for accidents. The IPCC has concluded that in some temperate countries reduced winter deaths would outnumber increased summer deaths from climate-related factors.

WHAT CAN WE EXPECT IN FUTURE?

No cause-and-effect relationships have been established between climate change and provincial health impacts. More research is needed before we will be able to assess the degree of risk that climate change poses to the health of British Columbians. Little information is available about possible health benefits. The IPCC has also noted that potential adverse health impacts of climate change could be reduced through appropriate public health measures.

Appendix A: Climate Change
Past Trends and Future Projections

Climate reflects weather conditions for a specified area over a relatively long time period, usually decades or centuries, but sometimes even millennia. It is typically described in terms of averages and extremes in such properties as air temperature, precipitation, humidity, sunshine, and storm frequency.

Climate is characterised by:

- temperatures of the surface air, water, land, and ice
- wind and ocean currents, humidity, cloudiness and cloud water content, groundwater, lakes, and water content of snow and sea ice
- pressure and density of the atmosphere and ocean, salinity and density of the ocean, composition of dry air, and boundaries and physical constants

These properties are interconnected through physical processes such as precipitation, evaporation, infrared radiation emitted by the earth and the atmosphere, vertical and horizontal movements of the atmosphere and ocean, and turbulence.

Historically, the climate of the earth has varied continuously from year to year, decade to decade, century to century, and millennium to millennium. Such changes may be the result of climate variability, climate change, or both.

CLIMATE VARIABILITY

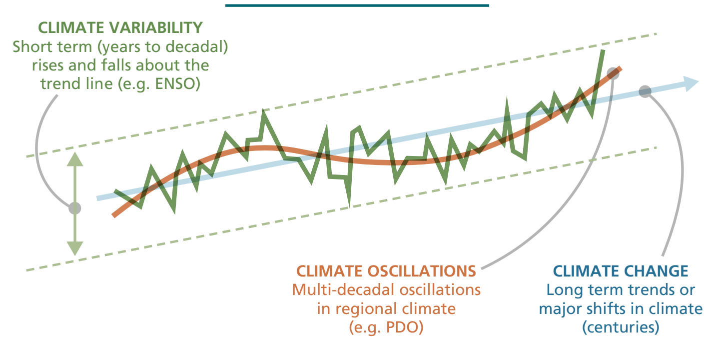
Much of the climate variability we experience involves relatively short-term changes and can occur as a result of natural alterations in some aspect of the climate system. For example, increases in the concentration of aerosols in the atmosphere as a result of volcanic eruptions can influence climate for a few years. Climate variability can also result from complex interactions between different components of the climate system: for example the ocean and the atmosphere.

The climate of British Columbia is strongly influenced by two natural patterns in the Pacific Ocean: the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

ENSO is a tropical Pacific phenomenon that influences weather around the world. El Niño, the so-called “warm phase” of ENSO, brings warmer winter temperatures and less winter precipitation to BC. La Niña, the “cool phase” of ENSO, is associated with cooler and wetter winters. During neutral years, ENSO is in neither a warm nor a cool phase and has little influence on global climate. ENSO tends to vary from the two extremes and the neutral state within two to seven years, usually staying in the same state for no longer than a year or two.

The PDO is a widespread pattern of sea surface temperature in the northern Pacific Ocean. Like ENSO, it has a warm and a cool phase. The PDO tends to remain in one phase for 20 to 30 years. It was in a cool phase from about 1900 to 1925 and from 1945 to 1977. It was in a warm phase from 1925 to 1945 and from 1977 onwards. A change from warm to cool appears to have occurred around the end of the 1990s.

Climate variability, oscillations and change



SOURCE: Adapted from original, courtesty of Pacific Climate Impacts Consortium.

The PDO is associated with cyclical changes in the sea surface temperature of the northern Pacific Ocean. Because prevailing winds blow from the North Pacific towards the BC coast and air temperature is affected by sea temperature, average air temperatures over coastal BC have also fluctuated in accordance with the phase of the PDO.

CLIMATE CHANGE

Climate change represents longer-term trends that occur over many decades or centuries.

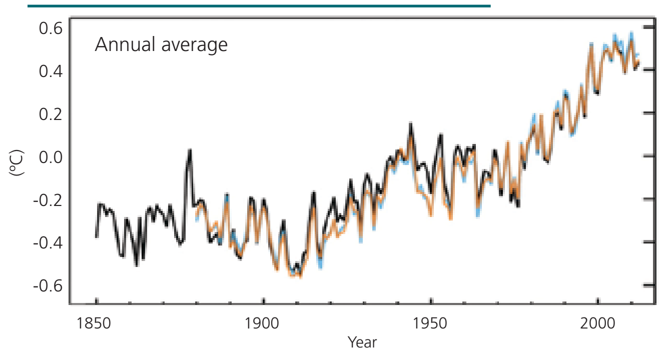
There is strong evidence that change is an ongoing feature of the global climate system. At present, however, it is occurring at an unprecedented rate. According to the AR5 report by the IPCC, global temperature, for example, has increased by 0.85ºC since the 19th century. The IPCC also notes that in the last three decades, each decade has been warmer than any preceeding decade since temperature started being recorded (1850). Also, the last 30 years in the Northern Hemisphere were likely the warmest 30-year period of the last 1,400 years. Weather observations also reveal significant changes in average global precipitation and atmospheric moisture, as well as changes in patterns of atmospheric and oceanic circulation and the frequency of extreme weather.

Climate change occurs simultaneously with, and also influences, natural climate variability. For example, El Niño events may have become more frequent in recent years, and four of the ten strongest El Niño events of the 20th century have occurred since 1980.

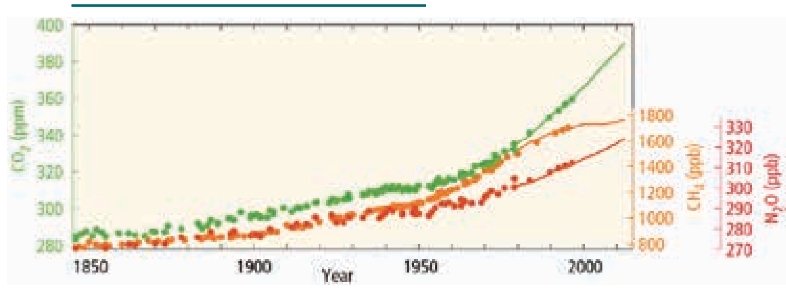
Some of the causes of climate change – including long-term changes in the amount of energy radiating from the sun and variations in the orbit of the earth around the sun – are entirely natural. Others are anthropogenic – of human origin. Some human activities – in particular the burning of fossil fuels and land-use changes – are associated with an increase in the concentration of carbon dioxide and other greenhouse gases in the atmosphere over the last century and a half. There is a strong connection between the concentration of these gases in the atmosphere and atmospheric temperature.

Anthropogenic climate change appears to be responsible for much of the atmospheric warming observed during the past century, and especially the last 60 years. The earth is currently exposed to the highest levels of CO_2 in the atmosphere in at least 800,000 years according to the IPCC's AR5 report. And some greenhouse gases, including CO_2, are persistent – they remain in the atmosphere for centuries. Climate models project that even if we stop burning fossil fuels tomorrow, the atmosphere will continue to warm for a few centuries.

Globally averaged combined land and ocean surface temperature anomaly



Globally averaged greenhouse gas concentrations



SOURCE: Adapted from IPCC, 2014, Climate Change 2014 Synthesis Report - Summary for Policy Makers, Figure SPM.1, p. 3.
OBSERVATIONS:
(left) Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets.
(right) Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange), and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines).

DISTINGUISHING PAST TRENDS

Even during a period of general global atmospheric warming, climate variability can result in cooler-than-average regional temperatures. To obtain long-term climate change trends from historical data records it is therefore necessary to identify the "signal" of climate change against the "background noise" of climate variability.

Climate variability in BC is characterized by decadal variability associated with the PDO. Short records may be too strongly influenced by this natural cycle to produce meaningful climate-change trends. Only data records that likely span one or more full cycles of the PDO, can be used to distinguish the effects of climate variability from the effects of climate change.

The majority of the climate-change and related trends described in this report were obtained through the analysis of historical data collected at weather and other monitoring stations across BC. Where trends have been identified the data show a clear "signal" of climate change.

MODELLING THE FUTURE

This report describes how the climate in BC may continue to change during the 21st century and the ongoing impacts climate change may have on marine, freshwater, and terrestrial ecosystems, and on human communities.

Most information about future projections is based on analysis by PCIC, data available on Plan2Adapt, and on AR5 reports published in 2014 by the Intergovernmental Panel on Climate Change (IPCC). The findings about future climate change are largely based on climate models – representations of the climate system that take into account relevant physical, geophysical, chemical, and biological processes. While the models have been tested to ensure that they can reasonably simulate past and current climates, they present a range of possible future climates rather than specific predictions.

Climate models incorporate scenarios of possible future states of the global climate. The most common scenarios are based on a range of socioeconomic assumptions (for example, future global population, gross domestic product) which drive the models. The IPCC Representative Concentration Pathways (RCPs) project global temperature increases ranging from 6.0ºC to 8.5ºC by the end of this century, accompanied by changes in precipitation and other aspects of the climate system.

In general, the ability of climate models to provide information about future changes in temperature, precipitation, and other climate variables at the regional level is improving. Mountainous regions such as BC – where valleys may have quite a different climate from adjacent mountainous terrain – present particular problems. In general, projections about temperature are more reliable than projections about precipitation or other weather elements.

Finally, information about how natural and human systems respond to shorter-term climate variability provides insights into how the same systems might respond to climate change.

ADDITIONAL RESOURCES

For more information about what climate change is, and the science behind it please refer to the Climate Insights (http://pics.uvic.ca/education/climate-insights-101) materials provided by the Pacific Institute for Climate Solutions (PICS).

For more information about future climate projections in BC and potential impacts, please see Plan2Adapt (http://www.pacificclimate.org/analysis-tools/plan2adapt), an interactive online tool provided by the Pacific Climate Impacts Consortium (PCIC).

For more information about global trends and projections please refer to the Intergovernmental Panel on Climate Change (IPCC) publications, available on their website (http://www.ipcc.ch).

Appendix B: Data and Methods
Long-Term Trends In Temperature, Derived Temperature Variables, Precipitation, and Glacier Change

DATA

Temperature, Derived Temperature Variables, and Precipitation Trends

Data was sourced from the Pacific Climate Impacts Consortium (PCIC) Data Portal (http://www.pacificclimate.org/data). The PCIC Data Portal was established by PCIC through a negotiated agreement with the Ministry of Environment's Climate Related Monitoring Program (CRMP). The result is a single portal that stores and delivers data collected by the BC Natural Resource Sector Ministries, BC Hydro and RioTinto AlCan (http://www.env.gov.bc.ca/epd/wamr/crmp.htm). The data set also includes data from Environment Canada and de-activated historical networks. This project used temperature and precipitation measurements from the station observational dataset.

This analysis requires stations with relatively long records. The early part of the analysis (early 1900's) are based on a sparse network of stations, so any understanding of the detailed climate at that time is less certain than for more recent years when there are more stations distributed broadly across the province. This issue is most critical for precipitation because its distribution across the landscape is highly complex and anomalies compared against climate normals have more detailed spatial structure than temperature does. This is especially true considering the diversity of topography in BC. This analysis reports trends for the full period for precipitation, while acknowledging that the statistical uncertainty in the trends may not fully capture the uncertainty that arises from changes in the observational network over time. However, the trends reported here are broadly consistent with other analyses carried out at a coarser spatial resolution and at individual stations.

Trends in Glacier Volume and Area Change

Glacier area change was assessed by comparing the mapped extents of glaciers from the BC Terrain Resource Information Management (TRIM) data set which are based on arial photos from the mid-1980s through the late 1990s. Glacier volume change was assessed by differencing the topography measured during the TRIM campaign from the topography measured during the shuttle radar tomography mission (SRTM) which was flown aboard the space shuttle during February 2000 (Jarvis et al., 2008).

ANALYSES

Temperature, Derived Temperature Variables, and Precipitation Trends

The general methodological approach:

1. Calculate monthly anomalies for the period of record for every station that has a climate normal associated with it. Here the climate normals were derived from the PRISM project (Anslow et al., in prep.) and are for the 1971-2000 climate normal period.
2. Compute seasonal (defined as DJF, MAM, JJA and SON) and annual anomalies for each station where monthly coverage is sufficient. This requires all three months for a seasonal anomaly and all 12 months for an annual anomaly. Anomalies are weighted appropriately based on the number of days in a given month when computing the seasonal or annual mean. For the degree day variables, number of degree days were summed on a seasonal basis for stations with sufficient data as determined through the computation of the seasonal and annual means of the temp. and precip. variables. A threshold of 5 degrees was used for growing degree days and 18 degrees was used to delineate between heating and cooling degree days.

3. For each season and complete year in all years from 1900 to 2013, interpolate the available anomalies onto a 1/2 degree grid. Then, using shape files defining the province of BC and the ecoprovinces, calculate the mean anomaly over the region of interest for each year of interest.
4. Calculate trends based on the mean anomaly for the domains of interest. Trends were calculated using the "Robust Linear Model" in R (i.e. Huber and Ronchetti, 2009). This choice was made to allow the uncertainty in the splined anomalies as well as the station density to provide weights for each year's mean anomaly. The probability of the trend being significant is provided and values greater than or equal to 0.95 may be deemed significantly different from the null hypothesis of no trend.

Trends in Glacier Volume and Area Change

The changes to glaciers that have occurred in the past several decades and which are projected to occur with climate change was intensively studied through the Western Canadian Cryospheric Network. For this report, we rely on two separate studies; the first looked at the change in volume of the glaciers in British Columbia from roughly 1985 until winter 1999-2000. The second investigated the changes in glacier area from the period 1985 through 2005. Both resultant datasets cover all glaciers in British Columbia and thus provide an excellent snapshot of both the state of glaciers in the early 2000s as well as the changes those ice masses underwent during a very warm climatological period. Glacier area change was assessed by comparing the mapped extents of glaciers from the BC Terrain Resource Information Management (TRIM) data set which are based on arial photos from the mid-1980s through the late 1990s. Glacier volume change was assessed by differencing the topography measured during the TRIM campaign from the topography measured during the shuttle radar tomography mission (SRTM) which was flown aboard the space shuttle during February 2000 (Jarvis et al., 2008). Changes in volume were computed by subtracting the earlier surface from the later surface using control points of fixed topography to assess error. The glacier analysis was done by Bolch et al. (2010) for glacier area and Schiefer et al. (2007) for glacier volume change at UNBC.

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Appendix C: Data and Methods
Snow, Timing and Volume of River Flow, Sea Level, and Sea Surface Temperature

DATA

Snow Water Equivalent and Depth

Analysis of snow water equivalent and depth was done using manual snow survey data collected by the BC Ministry of Environment, provided to PCIC by the BC Ministry of Forests, Lands and Natural Resource Operations' River Forecast Centre. These data are collected in the field by taking repeat, direct measurements of snow depth and water content of the snowpack at numerous sites throughout the province. These measurements are made at monthly intervals starting January 1 and running through the latter part of the winter. These data were supplemented with April 1 snow water equivalent data from the automated snow pillow network. The automated snow pillow network operated by BC Ministry of Environment collects continuous data on snow water equivalent via its automated snow pillow network throughout BC at 71 historical locations with 51 currently operating. Data were gathered from River Forecast Centre website.

Water Survey of Canada Station ID	Water Survey of Canada Station Name
08HA001	Chemainus River near Westholme
08HA003	Koksilah River at Cowichan Station
08JB002	Stellako River at Glenannan
08JE001	Stuart River near Fort St. James
08LA001	Clearwater River near Clearwater Station
08LD001	Adams River near Squilax
08MF005	Fraser River at Hope
08MG005	Lillooet River near Pemberton
08NB005	Columbia River at Donald
08NF001	Kootenay River at Kootenay Crossing
09AE003	Swift River near Swift River

Timing and Volume of River Flow

Station information was downloaded using the Environment Canada Data Explorer – HYDAT Version 1.0 (Jan. 26, 2015). Ten stations were selected based on their association with the Reference Hydrometric Basin Network (Whitfield et al., 2012), record length, representation of major hydrologic regimes in BC and spatial location with respect to hydrologic modelling projections from the Pacific Climate Impacts Consortium at the University of Victoria (http://tools.pacificclimate.org/dataportal/hydro_stn/map/).

The Fraser River at Hope station (08MF005) was analyzed to maintain consistency with Fraser and Smith (2002) and also because it is a significant watershed in the province and provides an overview of climate-related changes to hydrology. Water extractions from the Fraser River basin through the Nechako Reservoir started in 1958. An adjusted time series was created to account for flows lost. The analyzed data are the combined 1912 to 2012 record downloaded from HYDAT and the adjusted data, which covers 1958 to 2007. This adjusted data was received from Alan Chapman in 2007 who was Lead of the River Forecast Centre at that time.

Sea Level

Relative sea level data is collected at tide gauges at numerous locations along the coast of Canada by the Canadian Hydrographic Service, part of the Department of Fisheries and Oceans. The analysis in the 2002 climate indicators report calculated trends at four long-term stations on the BC coast – Tofino, Prince Rupert, Victoria and Vancouver – and these same stations have been analyzed here. These all have data as early as 1910 but large gaps exist for some records in the 1920s and 1930s. For example, Tofino has a gap from 1920 through 1939. Prince Rupert has a similar length gap with a couple of annual observations from 1924 and 1927. Our choice of trend estimator accommodates such gaps so infilling was not attempted. Homogenization efforts were not applied to these data owing to no indication of inhomogeneity in the data upon visual inspection of plotted annual sea level. Although sea level does change systematically with season and with interannual variability principally due to weather and ocean climatic state, seasonal trends were not computed given the interest in identifying any large scale and long-term climate driven changes.

Sea Surface Temperature

Sea surface temperature data are gathered by the Department of Fisheries and Oceans Canada as part of routine monitoring programs. The sea surface temperature data analyzed here is measured manually once daily adjacent to light stations. Water is gathered within an hour of high tide and its temperature (and salinity) are measured with well-calibrated instruments. In locations where light stations are no longer manned, the work is carried out by contractors. The program comprises 38 stations that have operated at some point since the 1930s. For this project, data were gathered from the 19 stations that have current or recent observations. Only seven had sufficiently long records to compute long-term trends.

Efforts were made to apply automated data homogenization techniques to the sea surface temperature data to correct for any potential non-climatic but systematic changes in observation values arising from, e.g., transition to contract observers or changes in instruments in time. Although the DFO has made great efforts to control the observing conditions, such issues could crop up. It was found that most of the records were resistant to such analysis likely because of the very strong decadal variability in sea surface temperature data which, makes detecting unnatural transitions very difficult. Because of this, we left the data unchanged, however, note that several stations exhibit inhomogeneities in this analysis but we are not confident enough that they are non-climatic to warrant adjusting the data.

ANALYSES

Snow Water Equivalent and Depth

The measurement taken at or near April 1 is typically viewed as a standard indicator of snow accumulation for a given year. This analysis follows this convention by examining the April 1 measurements of snow throughout the province for all years with observational data. The manual snow survey program's earliest observation year is 1935 making this a long-term dataset. The methodology and instrumentation for collecting snow depth and water equivalent has changed very little since then, producing a data set that is methodologically homogeneous. However, snow depth observation sites are subject to changing land cover conditions as vegetation changes through time, introducing some inhomogeneity. Still, the data represent a high quality 82 year-long record of snow at specific locations in the province.

The target outcome of analyzing these data is a regional quantification of changes in snow depth and water equivalent of ecoprovinces for as long a time-scale as the observational network will support. The approach consists of three steps. First, annual anomalies were computed on the station data over the 1981 to 2010 30-year normal period. Second, the anomalies were interpolated into a gridded product using thin plate spline interpolation. Finally the regional average for each year and region was taken and trends were computed from the timeseries of those averages for each ecoprovince.

Timing and Volume of River Flow

Data was processed and analyzed using code written in R. Trends were computed using the 'zyp' R Package (Bronaugh and Werner, 2015). Streamflow trends were computed for Annual Date of 1/3 of Flow, Annual Date of ½ of Flow or Centre of Timing, Annual Mean, Annual Minimum, Annual Maximum, July-August-September Minimum, April-May-June Minimum, December-January-February Mean, March-April-May Mean, June-July-August Mean and September-October-November Mean. Trends were provided in trend per unit time, trend over the period, and relative trend as per the methods of the Climate Overview

(Rodenhuis et al., 2009), which followed that of Mote et al. (2005) and trend as a percentage of the mean flow for that metric (e.g., Annual Minimum). The centre of timing (CT) is the day of the year on which one-half of the total water flow for the year has occurred (Barnett et al., 2008), where year refers to calendar year. It is important to note that we do not look at "the water year, the day between 1 October and 30 September of the next year, on which 50% of the water year streamflow has passed," which is the definition used by Hidalgo et al.(2009), who followed Maurer et al. (2007).

Trends were computed for two time periods, 1958-2012 and 1912-2012. Some stations of interest did not have records stretching back to 1912, the start date for trend analysis in the Fraser River at Hope.

Relative Sea Level

For trend analysis, the relative sea level data were converted to anomalies using the 1981-2010 average sea level for each station. Trends were analyzed using Mann-Kendall non-parametric trend analysis and slopes were calculated using the Sen slopes method. These approaches are strongly resistant to outliers in data and are better able to handle data with temporal gaps in the record.

Sea Surface Temperature

Trends in the data were analyzed on anomalies in seasonal and annual mean values relative to a 30-year climatology. To maximize the number of stations that could be included in the analysis, a 30-year normal period was chosen in which the largest number of stations contained enough data to have a climate normal calculated (requiring 75% data coverage for the given month). This resulted in a somewhat unusual climate normal period of 1968 to 1997. Because the anomalies themselves are not presented, an arbitrary normal period is acceptable. Using this approach, 15 of 19 stations had sufficient data during the climate normal period to be further considered in this analysis. Seasonal and annual climatologies were based on the monthly values and were only calculated when complete seasons or years were available thus propagating the 75% data requirement. The averages of months to make seasonal or annual climatologies were weighted by the number of days in the given month to arrive at a correct average. Trends were analyzed using Mann-Kendall non-parametric trend analysis and slopes were calculated using the Sen slopes method. These approaches are strongly resistant to outliers in data and are better able to handle data with temporal gaps in the record.

The trend analysis performed here differs from that in two published analyses of the same data over earlier periods (Cummins and Masson, 2014; Freeland, 2013).This caused the numeric trend values in those studies to differ from those presented here. Those analyses relied on linear regression to compute trend and two different approaches to adjusting uncertainty estimates to account for autocorrelation in the data. The data in Cummins and Masson (2014) were gap-filled prior to computing trends on the monthly data. Despite this, the agreement between the methods is high and the approach used for this report allows the delivery of trends as they differ between seasons.

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