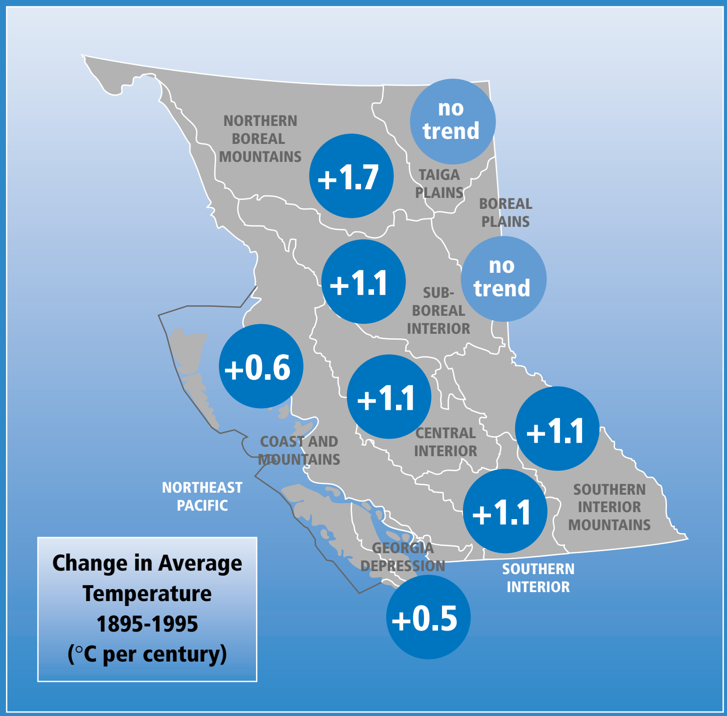

Indicators of Climate Change for British Columbia 2002

British Columbia
Ministry of Water, Land and Air Protection

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 1895 and 1995. Temperatures increased by 0.5°C to 0.6°C on the coast, 1.1°C in the interior, and 1.7°C in the north. 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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Technical papers that document methodologies and present the data behind the indicators are available on the Internet at **http://www.gov.bc.ca/wlap**.

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CONTENTS

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Indicators of Climate Change for British Columbia, 2002

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 50 years can be attributed to human activities that release greenhouse gases into the atmosphere. British Columbia, for example, produced almost 16 tonnes of greenhouse gases per person in 1999, most through the burning of fossil fuels for transportation and industrial activity.

Atmospheric warming affects other 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 changed during the 20th century and the rates at which these changes occurred. It outlines the potential impacts of these changes on freshwater, marine, and terrestrial ecosystems and on human communities. It describes how climate change is likely to affect the province during the 21st century.

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. Future impacts are based on the most up-to-date projections of climate researchers.

Past impacts

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

- Average annual temperature warmed by 0.6ºC on the coast, 1.1ºC in the interior, and 1.7ºC in northern BC.
- Night-time temperatures increased across most of BC in spring and summer.
- Precipitation increased in southern BC by 2 to 4 percent per decade.
- Lakes and rivers become free of ice earlier in the spring.
- Sea surface temperatures increased by 0.9ºC to 1.8ºC along the BC coast.
- Sea level rose by 4 to 12 centimetres along most of the BC coast.
- Two large BC glaciers retreated by more than a kilometre each.
- The Fraser River discharges more of its total annual flow earlier in the year.
- Water in the Fraser River is warmer in summer.
- More heat energy is available for plant and insect growth.

Future impacts

Climate models and scenarios suggest that the climate in British Columbia will continue to change during the 21st century. This will have ongoing impacts on ecosystems and communities.

- Average annual temperature in BC may increase by 1ºC to 4ºC.
- Average annual precipitation may increase by 10 to 20 percent.
- Sea level may rise by up to 88 centimetres along parts of the BC coast.
- Many small glaciers in southern BC may disappear.
- Some interior rivers may dry up during the summer and early fall.
- Salmon migration patterns and success in spawning are likely to change.
- The mountain pine beetle — an important pest — may expand its range.

The indicators presented in this report document some of the changes that have occurred during the past century. Many more potential indicators remain to be explored. For example, climate change may influence the frequency of extreme weather events, the extent of permafrost, ecosystem structures and processes, and species distribution and survival. It may 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.

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. In BC, for example, total emissions actually increased by more than 20 percent between 1990 to 1999 as the population of the province grew. Even if mitigation efforts are successful in reducing greenhouse gas emissions, they cannot prevent climate change. The greenhouse gases humans have already added to the atmosphere will likely continue to drive global climate change for centuries to come. British Columbia and other jurisdictions will therefore have to adapt.

The Kyoto Protocol commits its signatory parties to the development of national action programmes that include measures both to mitigate climate change and to facilitate adaptation to climate change. In Canada, the federal, provincial, and territorial governments are developing a national impacts and adaptation framework. Some municipal governments, including Vancouver, are starting to incorporate potential climate change impacts into long-term plans for drinking water supply, drainage, and storm-water infrastructure.

Through adaptation, we may be able to reduce some of the adverse impacts of climate change and enhance some of its potential benefits. Adaptation, however, will incur costs. It will probably be easier for human systems than for physical and biological systems to adapt to change. And countries and communities with access to technology, education, information, skills, and resources will be more able to adapt than those without such access.

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.

About the trends

The report documents changes during the 20th 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. Such changes are referred to as "trends."

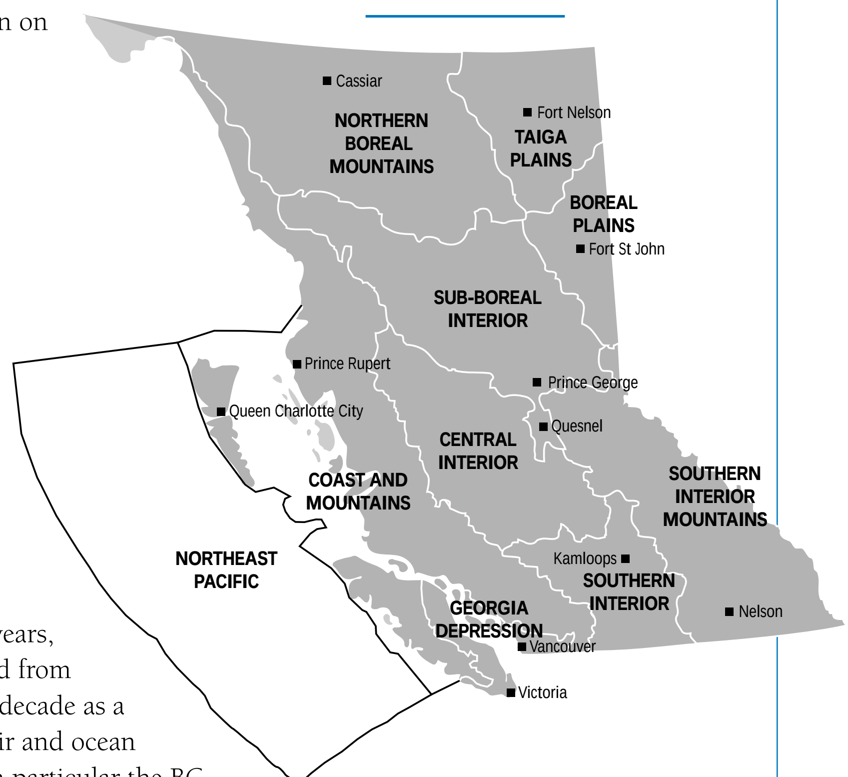
Where possible, the report identifies trends for each region of the province. The geographical unit used is the ecoprovince — an area delineated by similar climate, topography, and geological history. There are ten ecoprovinces in British Columbia — nine terrestrial and one marine.

Much of the information on past trends is based on a series of technical papers commissioned by the Ministry of Water, Land and Air and available on the Ministry website at http://www.gov.bc.ca/wlap/.

The information on future trends is based on the 2001 reports of the Intergovernmental Panel on Climate Change, available in summary form on the Internet at http://www.ipcc.ch/

During the past 1,000 years, the climate of BC has varied from year to year and decade to decade as a result of natural cycles in air and ocean currents (see Appendix). In particular the BC climate is strongly influenced by cyclical changes in the surface temperature of the Pacific Ocean. The Pacific Decadal Oscillation (PDO) has a warm and a cool phase. It tends to remain in each phase for 20 to 30 years, and a complete cycle from warm to cool and back again takes about 50 to 60 years. The PDO affects air temperature and other properties of climate across BC.

Ecoprovinces of British Columbia



One of the challenges in identifying climate trends for BC is to distinguish the influence of the PDO from the influence of atmospheric warming caused by the build-up of greenhouse gases in the atmosphere. In general, trends based on long historical records — about 100 years or longer — are most likely the result of climate change. Trends based on relatively short records — less than about 60 years — are most likely influenced by the PDO. As historical records for northern BC tend to be shorter, there are often not enough data to reveal trends associated with climate change for this part of the province.

Some of the trends presented in this document can be attributed to climate change, but others cannot. The ideal would have been to report only on those trends that can be attributed to climate change. This would mean trends that are both statistically significant and based on long historical records. The collection of climate data in British Columbia, however, dates back only to the late 19th century, and the collection of biological data is even more recent. For this reason, this document describes trends in values considered sensitive to temperature and other properties of climate, whether or not the record is long enough to link the trends definitively to climate change. Values that are sensitive to changes in temperature or precipitation, for example, are likely to be sensitive to climate change. As long as British Columbians continue to collect data about these values, in a few decades stronger climate change trends may emerge.

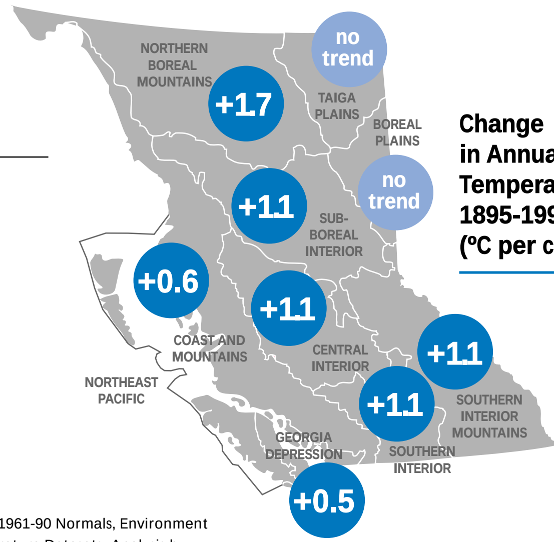
Even when the data are adequate, sorting out the influence of climate change from that of natural climate variability is a complex task. Analytical methods are still evolving. Smaller trends are more difficult to detect. For these and other reasons, some of the trends documented in this report may need to be adjusted in future. They are nevertheless instructive in providing information about some of the ways that climate change has affected BC.

INTERPRETING THE TREND INFORMATION

- The report presents only those results there were found to be significant at the 95 percent level through standard statistical tests. This means that the chance the trend arose randomly is less than 5 percent.
- Some of the trends are based on long records and almost certainly reflect climate change. Other trends are based on shorter records and likely reflect climate variability. These differences are documented in the text.
- Where the data record is relatively long — more than about 60 years — but fails to reveal a trend that is statistically significant at the 95 percent level, the report presents this as “no trend.”
- Where the data record is relatively short — less than about 60 years — and fails to reveal a trend that is statistically significant at the 95 percent level, the report presents no result.

AVERAGE TEMPERATURE

Average temperature increased over most of BC during the 20th century. Spring 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, 1895-1995 (°C per century)

SOURCE: Data from Archive of Monthly Climate Data and 1961-90 Normals, Environment Canada, and Canadian Historical and Homogenized Temperature Datasets. Analysis by Canadian Institute for Climate Studies, 1999 for BC Ministry of Water, Land and Air Protection. NOTES: A positive sign indicates a warming trend.

ABOUT THE INDICATORS

The indicators measure changes in average annual temperature and average temperature in each of the four seasons. Trends are based on available data from 1895 to 1995 for weather stations in each of the nine terrestrial ecoprovinces. Records for the Boreal Plains, Northern Boreal Mountains, and Taiga Plains are shorter. Seasonal trends are based on averages for spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

ANNUAL TEMPERATURE TRENDS

Coastal BC has warmed at a rate equivalent to 0.5°C to 0.6°C per century, or at roughly the same rate as the global average. The interior of BC warmed at a rate equivalent to 1.1°C per century, or at twice the global average. The records for these ecoprovinces are long (101 years) and the trends almost certainly reflect climate change.

Northwestern BC warmed at a rate equivalent to 1.7°C per century, or about three times the global average. The record for this region — the Northern Boreal Mountains ecoprovince — is relatively short (52 years) and the trend is likely influenced by climate variability as well as by climate change.

Although the records are relatively long for the Taiga Plains (59 years) and the Boreal Plains (65 years), the the data fail to reveal trends in average annual temperature for northeastern BC.

Average global temperature increased by 0.6°C during the 20th century. Most of this warming occurred from 1910 to 1945 and from 1976 to 2000. The 1990s were the warmest decade in the last 1,000 years. Globally, the greatest warming occurred in the higher latitudes of the Northern Hemisphere. The trend towards greater warming in northern BC is consistent with this global trend.

SEASONAL TEMPERATURE TRENDS

Spring across most of British Columbia is now warmer, on average, than it was a century ago.

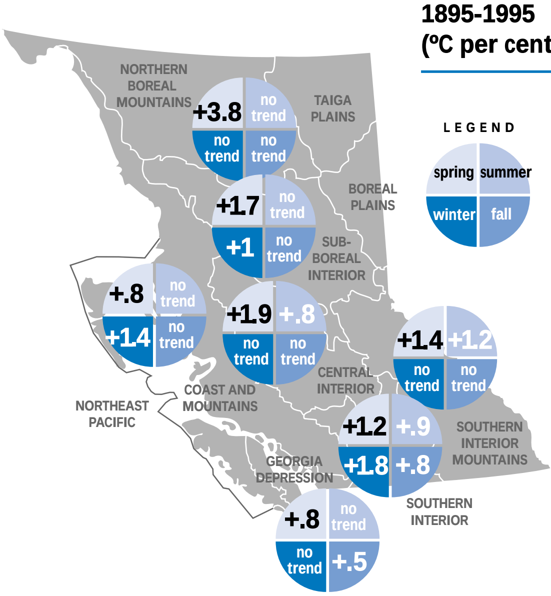
On the coast, spring temperatures have increased by 0.8°C. In southeastern BC they have increased by 1.2°C to 1.4°C. In the interior they have increased by 1.7°C to 1.9°C. All of these trends are based on long records (101 years) and almost certainly reflect climate change.

In the Northern Boreal Mountains ecoprovince, spring has warmed by 3.8°C. This trend is based on a relatively short data record (52 years) and likely reflects natural climate variability. The records are relatively long for the Taiga Plains (59 years) and the Boreal Plains (65 years), but the data fail to reveal seasonal trends.

Trends are less consistent across other seasons. Most of the interior of BC warmed during the summer at rates of 0.8°C to 1.2°C per century. The Coast and Mountains ecoprovince warmed during the winter by 1.4°C. The Georgia Depression warmed during the fall by 0.5°C. The Southern Interior warmed during all four seasons. All of these trends are based on long data records and almost certainly reflect climate change.

On the ground, the date that 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 to alpine areas. The seasonal trends described in this document are based on calendar dates, and as such may not reflect reality on the ground for some parts of BC.

Change in Seasonal Temperature, 1895-1995 (ºC per century)



SOURCE: Data from Archive of Monthly Climate Data and 1961-90 Normals, Environment Canada, and Canadian Historical and Homogenized Temperature Datasets. Analysis by Canadian Institute for Climate Studies, 2001 for BC Ministry of Water, Land and Air Protection. NOTES: All trends are positive and indicate warming.

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. They may mean a longer season for warm-weather outdoor recreation activities.

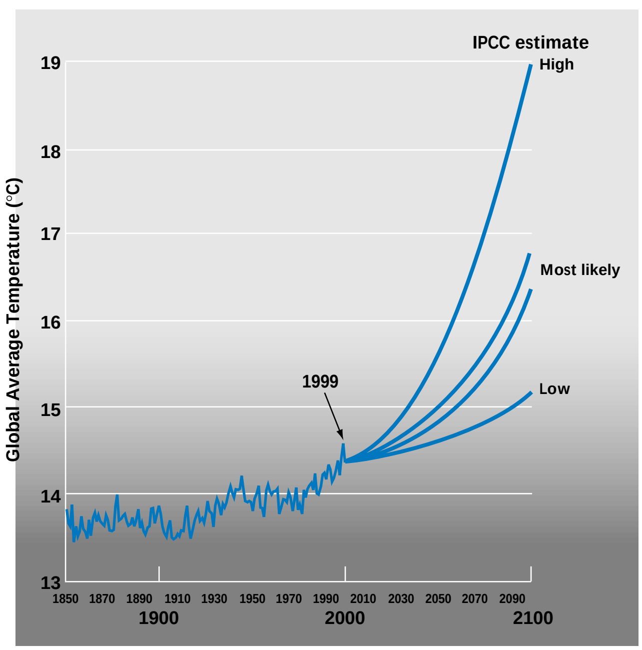
Warmer summers may increase rates of evaporation and plant transpiration. Reduced moisture may contribute to dust storms and soil erosion, increased demand for irrigation, loss of wetlands, slower vegetation growth, forest fires, and the conversion of forest to grasslands. It may contribute to declines 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 two natural cycles in air and ocean currents (see Appendix), which cause year-to-year and decade-to-decade variability in climate across the province. The warming trends observed during the 20th century are above and beyond such natural variability, and almost certainly reflect long-term climate change. The rate of warming is accelerated in more northerly regions, likely through a positive feedback mechanism. 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.

Global Temperatures, 1856-1999 and Projected Change to 2100



SOURCE: Temperatures 1856-1999: Climatic Research Unit, University at East Anglia, Norwich UK. Projections: IPCC, 1995.

The Intergovernmental Panel on Climate Change (IPCC) has concluded that most of the observed global atmospheric warming of the last 50 years is probably due to increases in greenhouse gas concentrations. Greenhouse gas emissions result from a variety of human activities, including the burning of fossil fuels and the clearing of land for agriculture and urban development.

The IPCC suggests that greater warming in some seasons may be the result of large-scale changes in atmospheric circulation, or of feedback mechanisms involving the melting of snow and ice.

WHAT CAN WE EXPECT IN FUTURE?

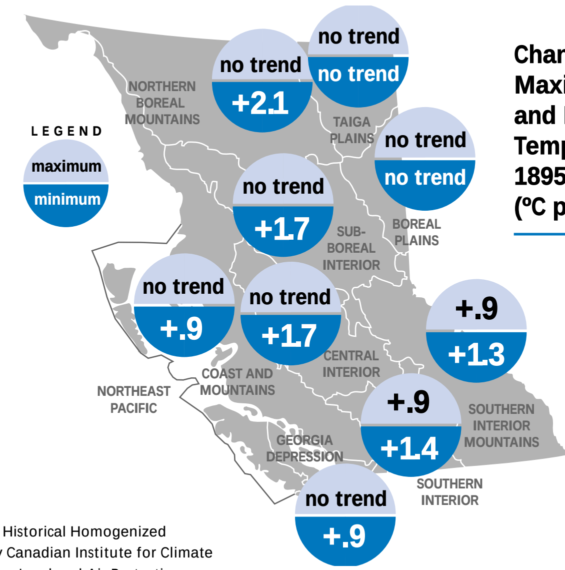
Average annual temperature across BC will continue to vary from year to year in response to natural cycles in air and ocean currents. Relatively warm years, however, will almost certainly increase in frequency.

Climate models project further warming in BC at the rate of 1°C to 4°C per century. 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.

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 5°C about 10,000 years ago was enough to melt the vast ice sheets that once covered much of North America.

MAXIMUM AND MINIMUM TEMPERATURE

Night-time minimum temperatures in most regions of BC are warmer on average than they were a century ago, particularly in spring and summer. Higher minimum temperatures in spring may increase the length of the frost-free season. In summer they may prevent buildings from cooling down during the night.



Change in Maximum and Minimum Temperature, 1895-1995 (ºC per century)

SOURCE: Data from the Canadian Historical Homogenized Temperature Datasets. Analysis by Canadian Institute for Climate Studies, 2001, for Ministry of Water, Land and Air Protection.
NOTES: All trends are positive and indicate warming.

ABOUT THE INDICATORS

The indicators measure change in the average annual day-time maximum temperature and the average annual 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 1895 to 1995. Records for the Boreal Plains, Northern Boreal Mountains, and Taiga Plains are shorter. Seasonal trends are based on averages for spring (March-May), summer (June- August), fall (September-November), and winter (December-February).

TRENDS IN MAXIMUM TEMPERATURE

Annual day-time maximum temperatures increased by 0.9ºC in the Southern Interior and the Southern Interior Mountains ecoprovinces. These trends are based on 101 years of data and almost certainly reflect climate change. In four other ecoprovinces (Georgia Depression, Coast and Mountains, Central Interior, Sub-Boreal Interior) the records are long (101 years), but the data fail to reveal trends in annual maximum temperature. In the three northern ecoprovinces the records are relatively short and the data fail to reveal trends.

Seasonal data indicate that maximum spring temperatures increased across much of BC. They fail to reveal trends in maximum temperature in the fall anywhere in BC.

In the interior of British Columbia, daytime maximum spring temperatures increased by 1.2ºC to 1.7ºC. The records for these ecoprovinces are relatively long (101 years) and the trends almost certainly reflect climate change.

In coastal British Columbia, daytime maximum summer temperatures decreased. Daytime maximum winter temperatures in the Coast and Mountains ecoprovince increased by 1.9ºC. The records for these ecoprovinces are relatively long (101 years) and the trends almost certainly reflect climate change.

Daytime maximum spring temperatures increased by 3.6ºC in the Northern Boreal Mountains and by 2.8ºC in the Taiga Plains. The records for these ecoprovinces are relatively short (55 and 47 years) and these trends are likely influenced by climate variability.

Daytime maximum summer temperatures in the Boreal Plains decreased by 1.9ºC. The record for this ecoprovince is relatively long (65) years and the trend likely reflects climate change.

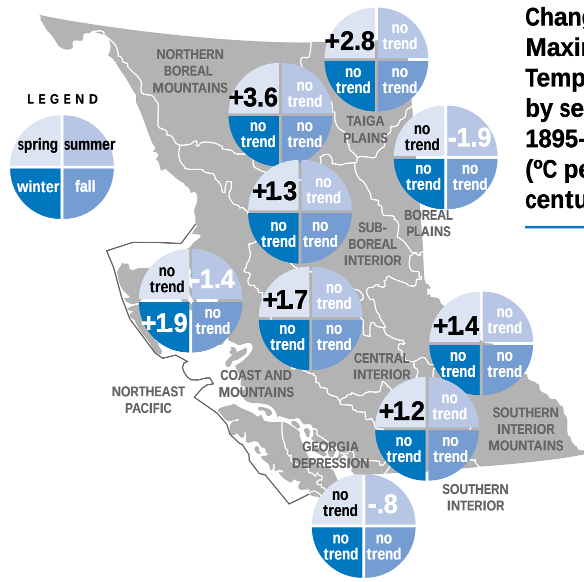
TRENDS IN MINIMUM TEMPERATURE

Annual night-time minimum temperatures increased by 0.9°C per century on the coast and by 1.3°C to 1.7°C per century in parts of the interior. These trends are based on 101 years of data and almost certainly reflect climate change. The greatest increase in minimum temperature has been in the Northern Boreal Mountains ecoprovince, where minimum temperatures increased at a rate equivalent to 2.1°C per century. In this ecoprovince, the record is relatively short (52 years) and likely reflects climate variability. In the two other northern ecoprovinces the records are relatively short and the data fail to reveal trends.

Seasonal data indicate that night-time minimum spring and summer temperatures increased across much of BC. They increased across all seasons in southern BC and in the Georgia Depression ecoprovince.

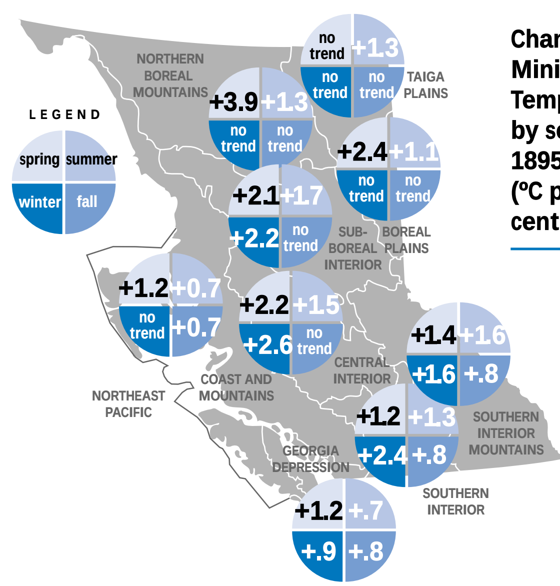
In the interior, minimum temperatures increased in spring by up to 2.2°C, in summer by up to 1.7°C, in fall by 0.8°C, and in winter by up to 2.6°C. On the coast, minimum temperatures increased in spring by 1.2°C, in summer by 0.7°C, and in fall by up to 0.8°C. They increased in winter by 0.9°C in the Georgia Depression. The records for the coast and interior are long (101 years) and the trends almost certainly reflect climate change.

Minimum temperatures increased in summer in the Taiga Plains, and in spring and summer in the Northern Boreal Mountains. The records for these ecoprovinces are short (47 and 55 years), and the trends likely reflect climate variability. In the Boreal Plains, minimum temperatures increased in spring by 2.4°C and in summer by 1.1°C. The record for this ecoprovince is relatively long (65 years) and the trends likely reflect climate change.



Change in Maximum Temperature, by season, 1895-1995 (°C per century)

SOURCE: Data from the Canadian Homogenized Temperature Datasets. Analysis by Canadian Institute for Climate Studies, 2002, for Ministry of Water, Land and Air Protection. NOTES: A positive trend indicates warming, and a negative trend indicates cooling.



Change in Minimum Temperature, by season, 1895-1995 (°C per century)

SOURCE: Data from the Canadian Homogenized Temperature Datasets. Analysis by Canadian Institute for Climate Studies, 2002, for Ministry of Water, Land and Air Protection. NOTES: A positive trend indicates warming, and a negative trend indicates cooling.

WHY IS IT IMPORTANT?

The overall pattern suggests that most regions of BC are warming because night-time minimum temperatures are increasing, not because day-time maximum temperatures are increasing. One could say that BC has actually become "less cold" rather than "hotter." The strong, increasing trends in minimum temperature, especially during the spring and summer, 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. National trends indicate minimum temperatures rose twice as fast as maximum temperatures from 1895 to 1991. Global trends indicate minimum temperatures increased twice as fast as maximum temperatures between 1950 and 1993. 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. 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.

WHY HAVE MAXIMUM AND MINIMUM TEMPERATURES CHANGED AT DIFFERENT RATES?

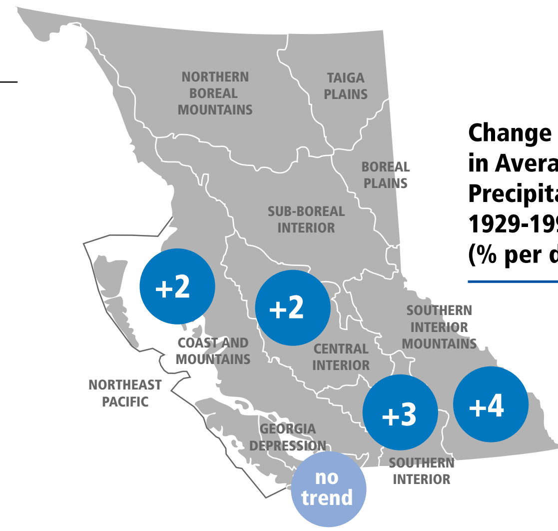
The reason for greater warming at night than in the daytime is not yet fully understood. During the early part of the 20th century, however, cloud cover increased over the mid-latitudes of Canada. Climate change may increase atmospheric moisture and cloud cover, both of which can act as a blanket to keep more of the heat that builds up on the ground during the daytime from radiating back into the atmosphere during the night. Increased cloud cover in summer over coastal BC may contribute to the cooling trend in summer.

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.

PRECIPITATION

Average precipitation increased over most of southern BC during the 20th century. 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, 1929-1998 (% per decade)

SOURCE: Data from Climate Research Branch, Meteorological Service of Canada. Analysis by the Canadian Institute for Climate Studies, 2001 for the Ministry of Water, Land and Air Protection.
NOTES: A positive sign indicates increasing precipitation.

ABOUT THE INDICATORS

The indicators measure changes in average annual precipitation at weather stations in five ecoprovinces in southern BC. They also measure changes in average precipitation in each of the four seasons. Trends are based on available data from 1929 to 1998. Seasonal trends are based on averages for spring (March-May), summer (June-August), fall (September-November), and winter (December-February). Records for the four northern eco-provinces are not sufficient to generate meaningful precipitation trends.

ANNUAL PRECIPITATION TRENDS

Average annual precipitation increased by 3 percent per decade in the Southern Interior and by 4 percent per decade in the Southern Interior Mountains ecoprovinces. The rates of increase in southeastern BC have been relatively steady during the record period, and it is very likely that precipitation will continue to increase in this region.

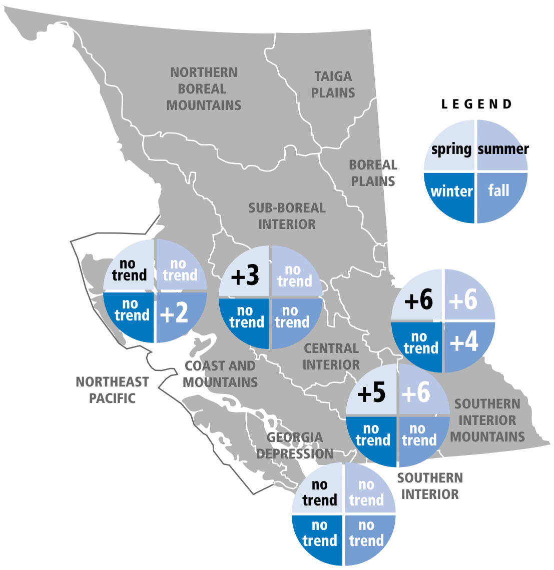
Precipitation in the Central Interior increased by 2 percent per decade. Precipitation increased in the Coast and Mountains ecoprovince by 2 percent per decade. The data fail to indicate a trend for the Georgia Depression.

The precipitation trends are based on 70 years of data and likely reflect the influence of climate change. All trends represent simple, rather than compound, averages.

Not enough data are available for northern BC to determine whether or not precipitation in this region has changed. The Intergovernmental Panel on Climate Change (IPCC), however, has concluded that regions of northwestern Canada experienced a gradual increase in annual precipitation of more than 20 percent from 1901 to 1995, or an increase of almost 2 percent per decade.

The IPCC has concluded that precipitation is very likely to have increased by 0.5 percent to 1.0 percent per decade over most mid-latitudes (30ºN to 60ºN) of the continental Northern Hemisphere during the 20th century. Precipitation trends in BC surpass this average.

Change in Seasonal Precipitation, 1929-1998 (% per decade)



SOURCE: Data from Climate Research Branch, Meteorological Service of Canada. Analysis by the Canadian Institute for Climate Studies, 2001 for the Ministry of Water, Land and Air Protection.
NOTES: A positive sign indicates increasing precipitation.

SEASONAL PRECIPITATION TRENDS

Trends in seasonal precipitation are inconsistent. In southwestern BC, precipitation has increased in both spring and summer, by 5 percent to 6 percent per decade. Precipitation has also increased in fall, by 4 percent per decade, in the Southern Interior Mountains.

Precipitation has increased in spring in the Sub-Boreal Interior ecoprovince, and in fall in the Coast and Mountains ecoprovince. The data fail to indicate trends in winter precipitation, or any seasonal trends in the Georgia Depression.

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 reality on the ground 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. El Niño years bring warmer, drier winters, while La Niña years bring cooler, wetter weather.

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, or more extreme precipitation events. Such long-term changes in the amount, form, and timing of precipitation will almost certainly have significant impacts on freshwater and terrestrial ecosystems. They will have both positive and negative impacts 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 will be 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 hydro-electric 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 infra-structure. 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 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 acci-dents. 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.
- More precipitation in spring — already a season of high stream flow in many parts of BC — may create faster, fuller rivers. In some areas, soils may become saturated with water, increasing the chance of landslides and debris torrents. Low-lying areas may flood more often. Flooding may have adverse impacts on some freshwater and riparian ecosystems.
- Precipitation increases in summer may help offset the potential loss of water in soil and river systems as a result of higher temperatures and higher rates of evaporation and plant transpiration.
- More precipitation in fall — typically a season of lower stream flow in many parts of BC — may mean higher water levels and better conditions for salmon spawning and egg-to-fry survival.

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.

Particularly in southern BC, summer may be characterized by increasing precipitation only because the same water is cycling more frequently from surface to air and back again. Under such circumstances, moisture availability and runoff may not be increasing at all, and may actually be decreasing.

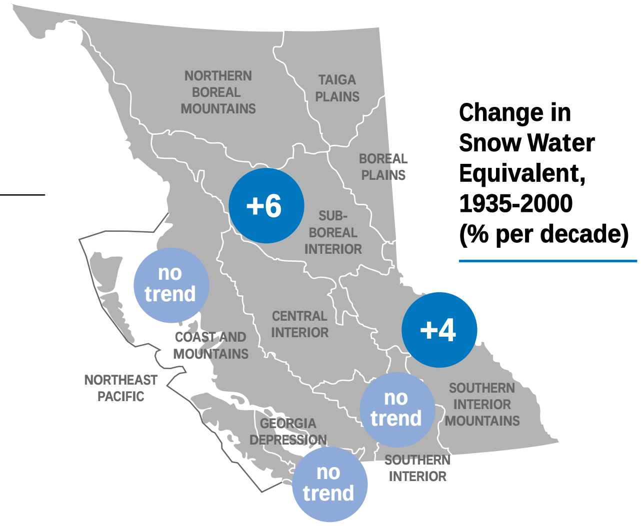
WHAT CAN WE EXPECT IN FUTURE?

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.

Climate models project that average annual precipitation in the mid-latitudes of the Northern Hemisphere will continue to increase. Precipitation will remain within 10 percent of present levels until 2050 and will increase by 10 to 20 percent by 2090. In addition, the majority of climate models project that there will be an increase of 5 to 20 percent in winter precipitation in western North America during the 21st century. As temperatures increase, more winter precipitation will fall as rain rather than snow.

SNOW

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



SOURCE: Data from BC Environment Historical Snow Survey. Analysis by Canadian Institute for Climate Studies, 2001 for Ministry of Water, Land and Air Protection. NOTES: A positive number indicates a trend towards increasing SWE.

ABOUT THE INDICATORS

These indicators measure changes in snow water equivalent (SWE), the weight of water in a column of snow, and snow depth. Together, the measures provide information about snow density. Trends are based on data collected at provincial snow survey stations in winter (February) and spring (March and April). Most stations are located between 1,000 and 2,000 metres above sea level. The periods of record range from 36 to 64 years, depending on data availability.

SNOW TRENDS IN BRITISH COLUMBIA

Overall, the BC trends in SWE and snow depth are considered weak because they are not consistent across all months sampled and between adjacent regions.

In the Southern Interior Mountains, SWE increased in February at a rate of 4 percent per decade. The record is relatively long (63 years) and the trend may reflect climate change. The data fail to indicate SWE trends for March and April or trends in snow depth.

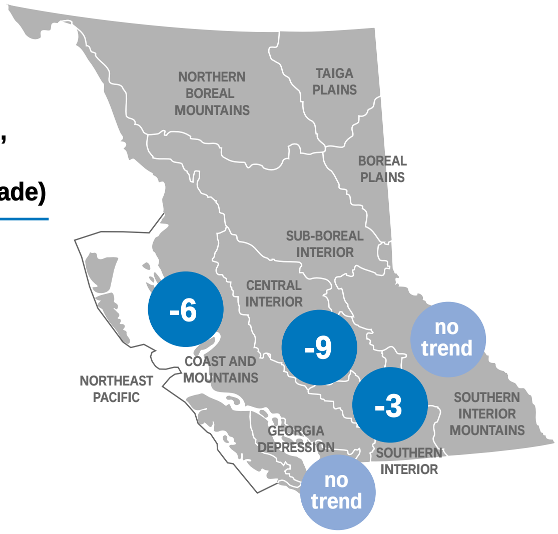
In the Sub-Boreal Interior, SWE increased in March and April at a rate of 6 percent per decade. The record is relatively short (41 years) and the trend likely reflects climate variability. The data fail to show a SWE trend for February or trends in snow depth.

In the Southern Interior, Coast and Mountains, and Georgia Depression ecoprovinces, the record is relatively long (51 to 66 years) but the data fail to show trends in SWE. Snow decreased in the Coast and Mountains ecoprovince in February by 6 percent per decade and in the Southern Interior in March by 3 percent per decade.

In the Boreal Plains, Central Interior, Northern Boreal Mountains, and Taiga Plains ecoprovinces, the data fail to show SWE trends. Snow depth in the Central Interior decreased by 9 percent per decade in March. The records for these ecoprovinces are short (36 to 44 years) and these trends likely reflect climate variability.

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 may have increased in five ecoprovinces, the two where SWE increased and depth remained the same and the three where SWE remained the same and depth decreased.

Change in Snow Depth, 1935-2000 (% per decade)



SOURCE: Data from BC Environment Historical Snow Survey. Analysis by Canadian Institute for Climate Studies, 2001 for Ministry of Water, Land and Air Protection.
NOTES: A negative number indicates a trend towards decreasing snow depth.

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 dominated, meaning they are characterized by a surge of water when snow melts in the spring and early summer. This freshet 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, 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. Particularly on the coast, when heavy rain falls on top of dense, wet snow, it can trigger rapid melting and flooding and damage to eco-systems and infrastructure. Denser snow is less suitable for skiing, but more suitable for some other forms of backcountry recreation.

The geographical extent of snow cover is as important as its physical characteristics. Satellite data show that in the Northern Hemisphere, the extent of snow cover has probably decreased by about 10 percent since the late 1960s. This has adverse implications for water supplies. 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.

SOURCE: Tourism BC

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.

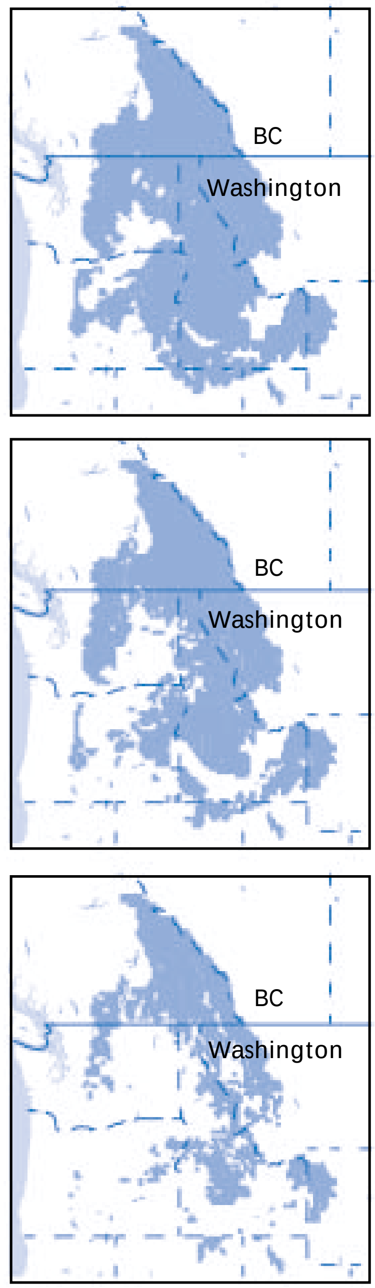
Projected Change in Extent of Snow Cover in the Columbia River Basin, 2000 – 2100

MARCH

2000

~2025

~2095

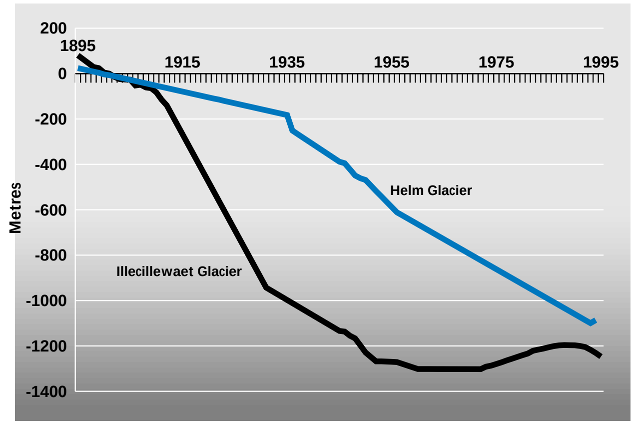


SOURCE: Adapted from snow cover map produced by Joint Institute for the Study of the Atmosphere and Ocean, University of Washington. NOTES: In areas still snow covered in 2095, models predict lower SWE.

GLACIERS

Glaciers in southern BC retreated during the 20th century. In the short term, retreating glaciers may add water to mountain-fed streams and rivers. In the long term, glacier retreat will probably mean less runoff, particularly in the summer months.

Change in Glacier Terminus Position, 1895-1995



SOURCE: Data from National Hydrological Research Institute. Analysis by A. Berger, 1999 for the Ministry of Water, Land and Air Protection.

ABOUT THIS INDICATOR

Glaciers advance and retreat in response to changes in local climate. This indicator measures changes in the length and position of the front edge, or "terminus," of two southern British Columbia glaciers between 1895 and 1995. Helm Glacier (49°58'N, 123°00'W) is in Garibaldi Provincial Park, and Illecillewaet Glacier (51°15'N, 117°30'W) is the north-extending tongue of the Illecillewaet Icefield in Glacier National Park.

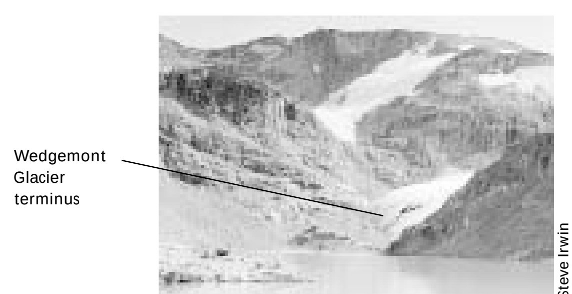
TRENDS IN GLACIER TERMINUS POSITION

The terminus positions of Helm Glacier in southwestern BC and Illecillewaet Glacier in southeastern BC both receded by more than 1,100 metres from 1895 to 1995. Most of the other glaciers and icefields that have been studied in Alberta and BC also lost significant ice volume in the 20th century. Some small glaciers in the Rocky Mountains may have lost as much as 75 percent of the ice volume they had 100 years ago. Wedgemont Glacier near Whistler, BC has retreated hundreds of metres in the past two decades alone.

Glacier melting in BC is consistent with the findings of the United Nations Intergovernmental Panel on Climate Change (IPCC), which identified a massive retreat of mountain glaciers in tropical and temperate zones during the 20th century. According to the World Resources Institute, the world's total glacier mass decreased by about 12 percent over the century.

Wedgemont Glacier, 1979-1998

1979



1998

There is some evidence that glaciers near coastal areas in northwestern BC — such as the Taku Glacier — and glaciers at high elevations have remained stable or advanced over the past century.

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 patterns, and possibly the 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?

Changes in the position of a glacier's terminus are indirect and delayed signals of changes in local climate. 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 in most glaciers, changes in temperature, rather than changes in precipitation, control the evolution of mass. Although winter precipitation fuels the growth of a glacier, a warm summer can melt large gains from more than one previous year. The IPCC believes that warmer temperatures associated with climate change are the cause of world-wide glacial melting.

While the dominant global trend is towards glacier retreat, some glaciers have advanced over the last few decades, particularly in mountainous coastal regions and at high elevations. Higher than average levels of winter precipitation that may also be associated with climate change probably account for this advance.

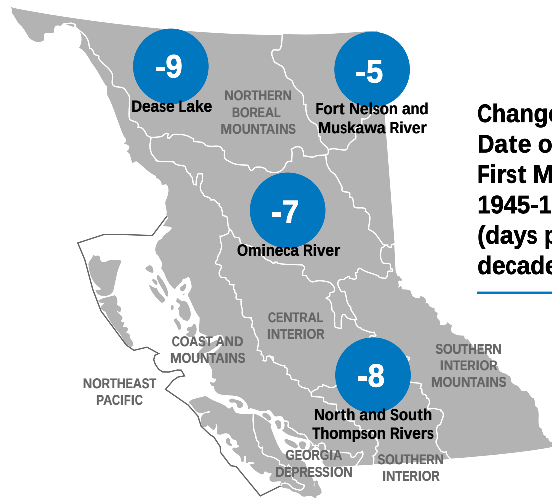
WHAT CAN WE EXPECT IN FUTURE?

The IPCC believes that glaciers and ice caps will continue their widespread retreat during 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, whether glaciers advance, remain stable, or retreat will depend on their geographic location and elevation. Most glaciers in southern BC are likely to continue to retreat. Glaciers with a high proportion of their surface area at high elevations are likely to remain stable. In northwestern BC, increases in precipitation associated with climate change may offset higher temperatures and contribute to the ongoing advance of glaciers.

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.

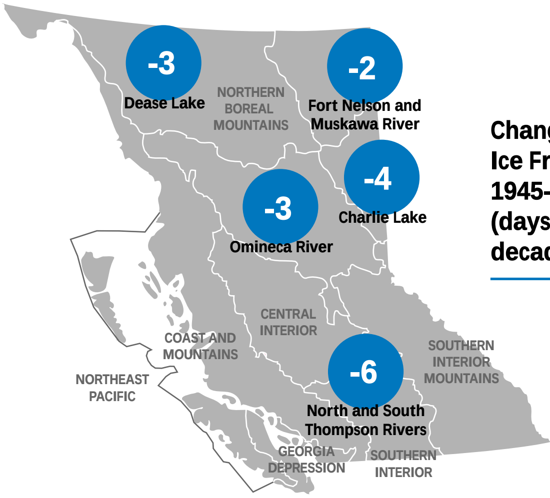
Lakes and rivers also become free of ice earlier, on average, than they did several decades ago. The ice free date has become earlier by 6 days per decade in the Thompson River region, 3 days per decade in Omineca River, 4 days per decade at Charlie Lake, north of Fort St. John, 3 days per decade at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

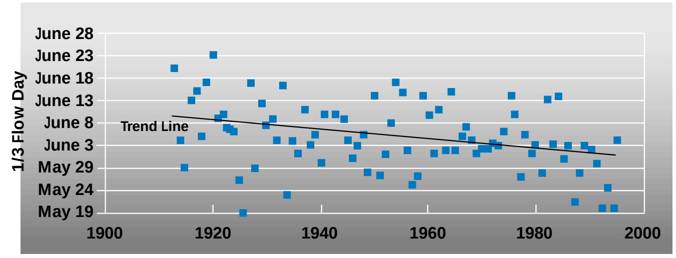
WHAT CAN WE EXPECT IN FUTURE?

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.

TIMING AND VOLUME OF RIVER FLOW

Seasonal changes in the timing and volume of the Fraser River flow are occurring earlier in the year on average. This is likely to cause water shortages and negative impacts on salmon and other aquatic organisms.

Change in Timing of One-third of Fraser River Annual Flow, 1912-1998



SOURCE: Data from the Water Survey of Canada, Environment Canada. Analysis by John Morrison, Institute of Ocean Sciences, 2001, for Ministry of Water, Land and Air Protection. NOTES: All values are statistically significant. (R^2 = 0.1216, p = 0.001).

ABOUT THE INDICATORS

The indicators measure changes in the dates by which one-third and then one-half of the total annual volume of the Fraser River pass the town of Hope. They are based on flow data collected at Hope for the years 1912 to 1998.

TRENDS IN CUMULATIVE FLOW

Milestones in the annual cumulative volume of the Fraser River's flow are occurring earlier in the year.

- The date by which one-third of the annual cumulative flow occurs has advanced at a rate equivalent to 11 days per century.
- The date by which one-half of the annual cumulative flow occurs has advanced at a rate equivalent to nine days per century.
- There was no significant trend in the date or the height of peak flow from 1912 to 1998.

The Fraser River's flow is subject to regular season-to-season fluctuations. Average daily discharge at Hope ranges from a peak of about 7,000 cubic metres of water per second in late June (after the annual spring snow melt) to a low of about 1,000 cubic metres per second in the winter.

Flow is also subject to year-to-year changes that are linked to natural climate variability. The highest peak flow ever recorded, for example, was 15,000 cubic metres per second. In general, river flow is greater after a La Niña winter, typically associated with higher-than-average precipitation and heavier snowfall. Peak flow arrives earlier in the year after an El Niño event, which is associated with warmer spring conditions and earlier melting of the snowpack. Flow is lower than average the summer following the drier winter conditions associated with an El Niño event. These are all examples of shorter-term natural variations in climate. The trends in cumulative flow stand out from such natural cycles and are probably the result of longer-term climate change. They are consistent with other trends observed in British Columbia, including warmer springs, earlier spring thaws, and melting glaciers.

WHY IS IT IMPORTANT?

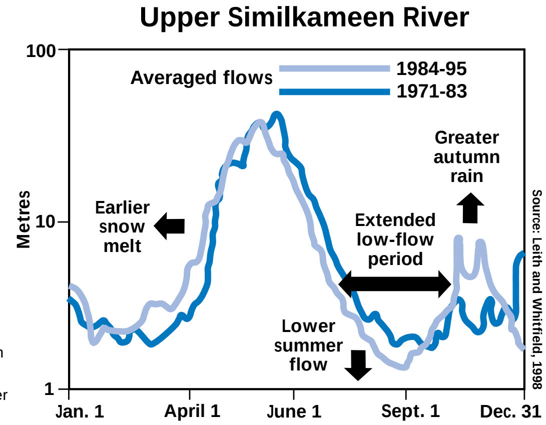
The Fraser River drains approximately 230,000 square kilometres — more than one-quarter of the land area of BC. Outside of the lower mainland, the river and its tributaries are in a relatively natural state, with few dams or control structures. Changes in the timing of its flow can affect both natural ecosystems and human communities.

When a greater proportion of the total flow moves through the river system earlier in the season, higher-than-usual water volume and velocity may increase river turbulence and scouring, with potential negative impacts on aquatic ecosystems, habitats, and organisms. Extreme flows, specifically changes in the height of peak flow, can affect water supplies, fisheries, and power generation and pose a flood risk to communities, roads, and railways.

Corresponding 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 summer rainfall coincides with below-average summer flows.

Lower flows are also associated with warmer water temperatures (see "River Temperature") and declining water quality, both of which threaten the health of aquatic ecosystems and of salmon and other aquatic species (see "Salmon in the River").

Flow and Timing Variability in a Southern Snowmelt-Dominated River



SOURCE: Leith R. and P. Whitfield. 1998. Evidence of climate change effects on the hydrology of streams in south-central BC. Cdn. Water Resources J. 23:219-230.

WHY IS RIVER FLOW CHANGING?

Most of the streams and rivers that contribute to the Fraser system are snowmelt dominated. In such watersheds, very little runoff occurs during the winter. Instead, the winter snowpack melts and feeds the river system during the following spring and early summer.

In snowmelt-dominated river systems, the characteristics of the snowpack and spring climate conditions determine the timing of the spring flow or "freshet," which can vary significantly from year to year. The trends toward warmer spring temperatures across BC, an increase in the water content of snow in parts of the interior, and earlier dates of spring thaw are all compatible with an earlier spring freshet.

When spring temperatures are higher, snow and ice melt and feed into streams and rivers earlier in the year. Lower summer flows occur because snow and ice sources have already been depleted by that time, and because higher summer temperatures increase evapotranspiration.

Not all river systems respond in the same way to a warming climate. Warming may cause rivers that are mixed snow-and-rain dominated to release a greater portion of their flow, and occasionally flood, in winter. Rainfall-dominated rivers may have greater flows in seasons with increased precipitation. And rivers that are highly managed (for example, the Columbia River) may show different or no significant trends.

WHAT CAN WE EXPECT IN FUTURE?

The timing and volume of river flow will always vary from one year to the next.

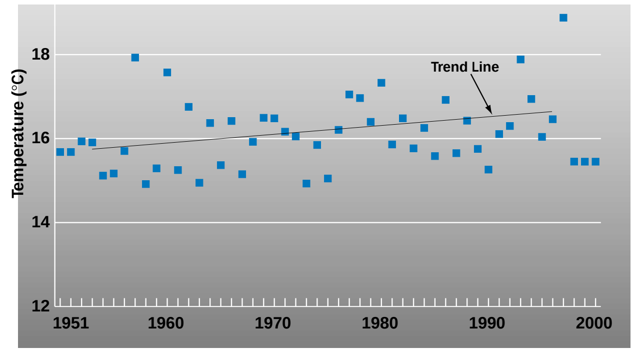
The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that in regions where seasonal snowmelt is an important aspect of the annual hydrologic regime — such as the basins of the Fraser, Columbia, and Peace rivers — warmer temperatures are likely to result in a seasonal shift in runoff, with a larger proportion of total runoff occurring in winter, together with possible reductions in summer flows. Some snowmelt-dominated river basins could shift towards a mixed snow-and-rain regime, with increased runoff during the winter months.

According to the IPCC, late summer stream discharge could decrease suddenly within only a few years in some regions.

Change in Average Fraser River Temperature, 1953-1998

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.



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 4°C 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 dominated. 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 at rates of 1°C to 4°C per century. 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.

SALMON IN THE RIVER

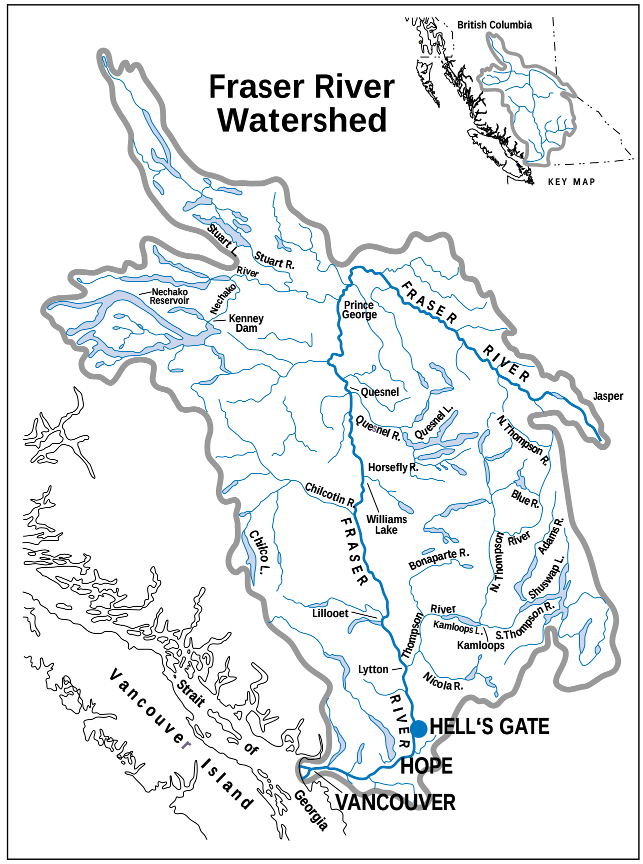
Tom Hall

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 24.5°C but prefer temperatures from 12°C to 15°C. Because sockeye prefer colder temperatures than other salmon species, sockeye may be the species that is most sensitive to climate change. Temperatures above 15°C 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 18°C can impair their swimming ability. They can die from several days' exposure to temperatures between 22°C and 24°C or from brief exposure to temperatures above 24°C.

> 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 have profound negative impacts on some salmon stocks.



Fraser River Watershed

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

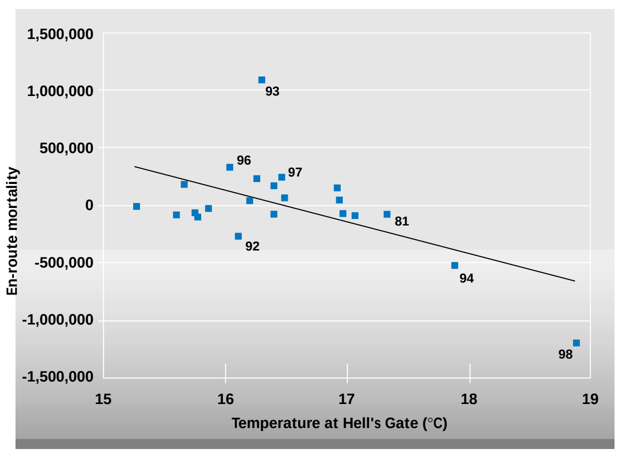
Each summer and fall, adult sockeye return from the ocean to spawn in more than 150 natal stream, river, and lake spawning areas in the Fraser River watershed. Different stocks start their long swim upriver at different times. The summer run group, including stocks that originate in the Quesnel and Chilko 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.

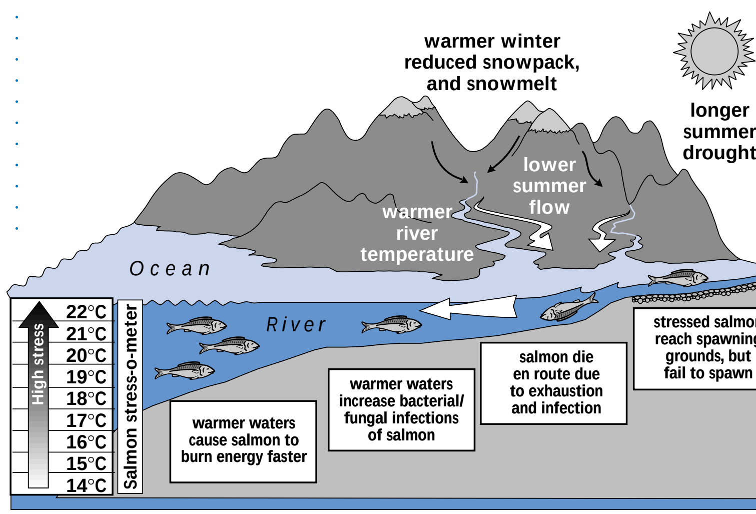
SOURCE: Data and analysis by S. Macdonald and J. Grout, Fisheries and Oceans Canada, 2001. NOTES: En route mortality is the difference between estimates of the number of fish entering the Fraser River, and the number reaching the spawning grounds. A negative number represents fish lost en route. A positive 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?

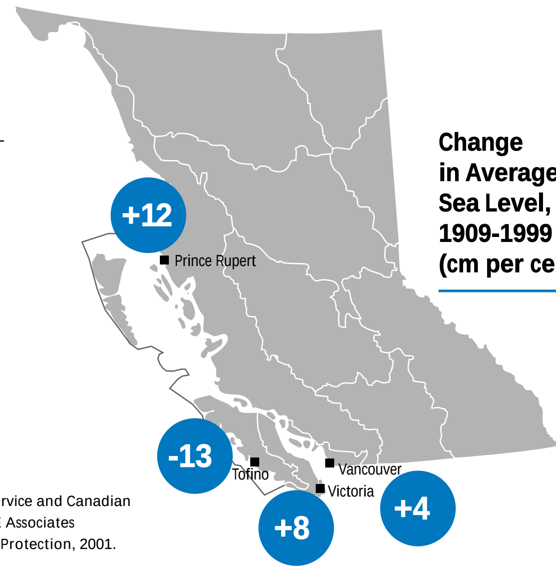
While river flow and temperature will still vary from one year to the next, summers with lower flow and warmer temperatures will likely occur more often in the future. This is expected to have profound negative impacts on Fraser River sockeye stocks over the long term. More research is needed to determine 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.

SEA LEVEL

Average sea level has risen along most of the BC coast over the past 95 years. Higher sea levels increase the risk of flooding of low-lying coastal areas and may damage coastal ecosystems and infrastructure.



Change in Average Sea Level, 1909-1999 (cm per century)

SOURCE: Data from Marine Environmental Data Service and Canadian Hydrographic Service. Analysis by J. F. Garrett, 2WE Associates Consulting Ltd. for Ministry of Water, Land and Air Protection, 2001.
NOTES: A positive trend indicates rising sea level.

ABOUT THE INDICATOR

This indicator measures changes in the average level of the sea relative to the adjacent land and trends in the height of unusually high and low water. It is based on records from 1909-1999 (with some gaps) from four monitoring stations along the British Columbia coast.

The trends identified for coastal BC reflect the combined impacts of climate change and the vertical movements of coastal land masses as a result of geological processes. The coast of BC is still rebounding upwards at rates of 0 to 40 centimetres per century from the melting of the massive ice sheet that once covered much of the province. As a result of other geophysical processes, Vancouver Island is tilting. The southwest coast of the island is rising at a rate of up to 40 centimetres per century in addition to the rate of rebound. The rest of the island is sinking.

SEA LEVEL TRENDS

During the 20th century, average relative sea level rose 12 centimetres at Prince Rupert, 8 centimetres at Victoria, and 4 centimetres at Vancouver. These trends reflect the combined impacts of vertical movements of the shoreline and a rise in average global sea level. Relative sea level fell at Tofino at an average rate of 13 centimetres per century. This is because the southwest coast of Vancouver Island is rising faster than the sea.

Tide gauge data — which show relative sea level — suggest that global average sea level rose between 10 and 20 centimetres during the 20th century. This rate is about 10 times faster than the rate over the previous 3,000 years.

The height of extreme high water events has increased at a faster rate than the mean sea level has increased. It increased by 22 centimetres per century at Prince Rupert, 16 centimetres per century at Vancouver, and 34 centimetres per century at Point Atkinson, near Vancouver. The lack of a clear trend at Victoria may be the result of the relatively short record length (37 years) for this indicator. At Tofino, where average sea level has fallen, the height of extreme high water events showed little change.

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 some Aboriginal heritage sites. It may also strain drainage and sewage systems in some coastal communities. Salt water may intrude into

Coastal Regions at Risk

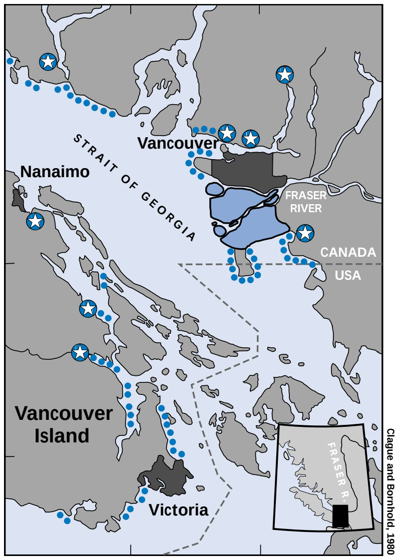
LEGEND

Shoreline vulnerable to erosion

Fraser River delta

Other low-lying areas

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



groundwater aquifers, making the water they contain unfit for household or agricultural use. Even before they are actually inundated, low-lying agricultural lands may become too saline for cultivation.

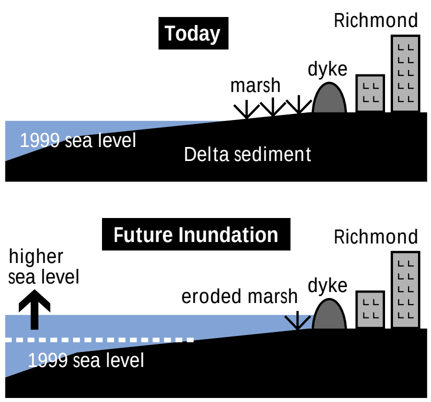
Higher mean sea level and more frequent extreme high water events will increase the likelihood that storms will damage waterfront homes, wharves, roads, and port facilities and contribute to coastal erosion.

Areas particularly at risk are the Fraser River delta, where 100 square kilometres of land are currently within 1 metre of sea level, and Prince Rupert, where extreme high water events are occurring three times more frequently than in other areas of the coast.

Changes in the height and direction of prevailing ocean waves, storm waves, and 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 believed to have been 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 mass of water in the ocean increases or decreases. As ice caps and glaciers melt, water previously stored on land as ice and snow is added to the ocean. Such processes are expected to contribute substantially to a rise in sea level over the next century.

Processes not related to climate change also influence sea level. These include vertical movements of the land and short-term natural changes in ocean temperature and circulation patterns. Long-term changes in climate patterns — for example, stronger onshore winds or more severe low pressure systems — may influence the frequency of extreme changes in sea level.

WHAT CAN WE EXPECT IN FUTURE?

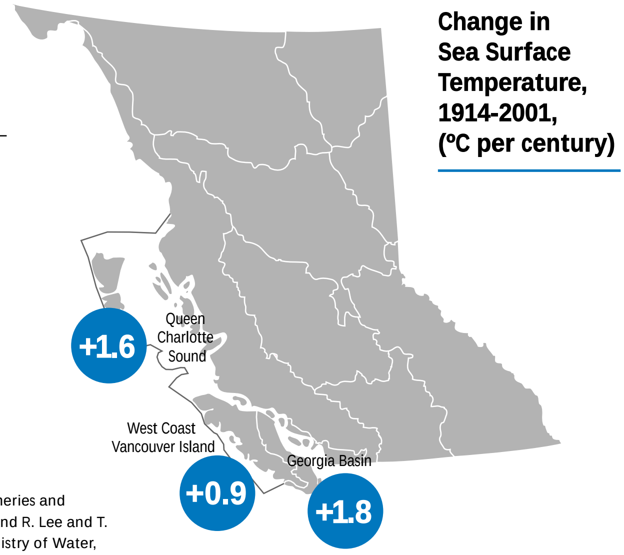
Climate models project a further rise in global mean sea level of 9 to 88 centimetres by 2100. The rate and magnitude of this rise in sea level will not be uniform over the globe. It will vary from one basin to another, reflecting variations in the amount of ocean warming and the way in which ocean currents redistribute heat and mass.

In most areas, climate change is expected to produce mean and extreme water levels higher than any yet recorded. 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. Ice caps are likely to continue to melt for thousands of years.

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 the Institute of Ocean Sciences (IOS), Fisheries and Oceans Canada. Analysis and discussion by H. Freeland, IOS, and R. Lee and T. Murdock, Canadian Institute of Climate Science, 2001 for Ministry of Water, Land and Air Protection. NOTES: A positive trend indicates a rise in SST.

ABOUT THE INDICATORS

There are two important sea surface indicators. The first measures temperature changes in the top 10 metres of the sea surface at lighthouses along the BC coastline. Trends are based on data from 1914 to 2001 in the Georgia Basin, from 1934 to 2001 on the west coast of Vancouver Island, and from 1937 to 2001 in Queen Charlotte Sound. The second indicator measures changes in salinity. Together, temperature and salinity provide information about the density of sea water.

SEA SURFACE TRENDS IN BRITISH COLUMBIA

During the 20th century, sea surface temperature (SST) increased at a rate equivalent to 0.9ºC per century along the west coast of Vancouver Island, 1.6ºC per century in Queen Charlotte Sound, and 1.8ºC per century in the Georgia Basin. The trends are based on relatively long records and likely reflect climate change.

Sea salinity decreased along the west coast of Vancouver Island during the record period. Sea density in this area also decreased. Density reflects a complex relationship between temperature and salinity; in general, as temperature increases and salinity decreases, density decreases. Although the records for the Georgia Basin and Queen Charlotte Sound are relatively long (87 and 67 years), the data fail to reveal trends in sea salinity and density in these areas.

The Intergovernmental Panel on Climate Change (IPCC) suggests that average global sea surface temperature has increased by 0.4ºC to 0.8ºC since the late 19th century. 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?

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 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.

The upper 100 metres or so is the most biologically productive part of the ocean. In this zone, sunlight drives photosynthesis, supporting 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 occur. Temperature and salinity in the deep ocean are stable. The sea surface is typically warmer, less saline, and less dense than the deeper water and therefore tends to "float" on top of it. 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 are associated with cycles in ocean productivity. In an El Niño year, the sea surface in summer is warmer than usual, 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.

Scientists have a high degree of confidence that if warm, El Niño-like events increase in frequency, the biomass of plankton and fish larvae will decline, and this will have a negative impact on fish, marine mammals, seabirds, and ocean biodiversity. The trends towards warmer temperatures, reduced salinity, and reduced density observed in surface waters off the BC coast are therefore 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. The trend towards decreasing salinity may be the result of higher sea surface temperatures because warmer water is typically less saline than cold water. It may also be influenced by increased precipitation over the ocean or increased freshwater runoff from the adjacent land.

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 and salinity.

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 1ºC to 6ºC 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.

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.

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

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.

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 40°N 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 6°C and 7°C isotherms in winter, to the 9°C isotherm in spring and early summer, and the 13.5°C isotherm in summer. In years when sea surface temperature is higher, the habitable area for sockeye is smaller.

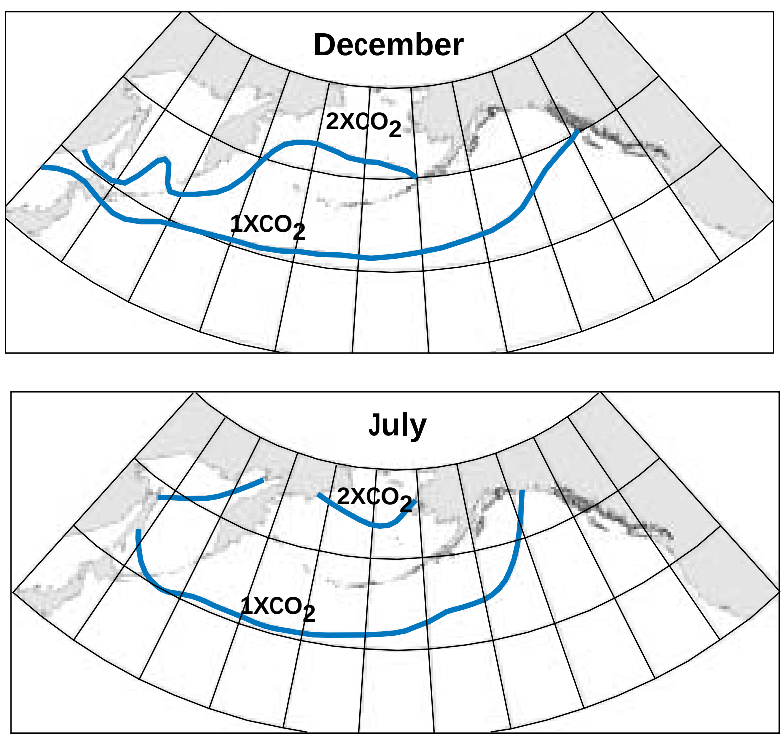
Ocean temperature appears to affect the timing of sockeye migrations from the ocean back to the Fraser River. Evidence suggests that in warm years, sockeye arrive later at the mouth of the river. Salmon that arrive later than normal at the mouth of the river may also arrive late at their spawning grounds. 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.

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.

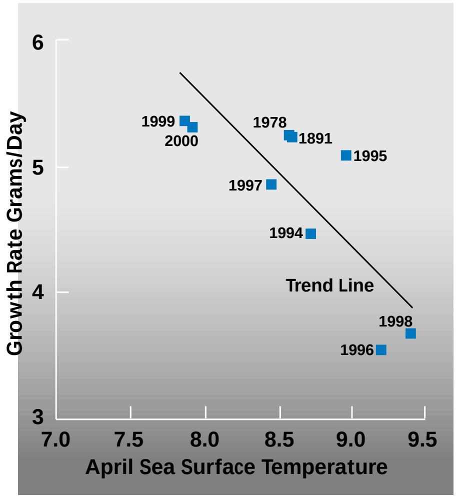
Copepods inhabit the sea surface for only a brief period during the spring. Their metabolic rate, growth, and development are synchronized with temperature. As surface temperatures warm up, copepod larvae migrate from deep ocean waters to the surface, where they feed on phytoplankton and grow to adult 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.

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.

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 ($F_{1,7}=12.5$; $P=0.009$). Editor's Note: "1891," above, should read "1981."

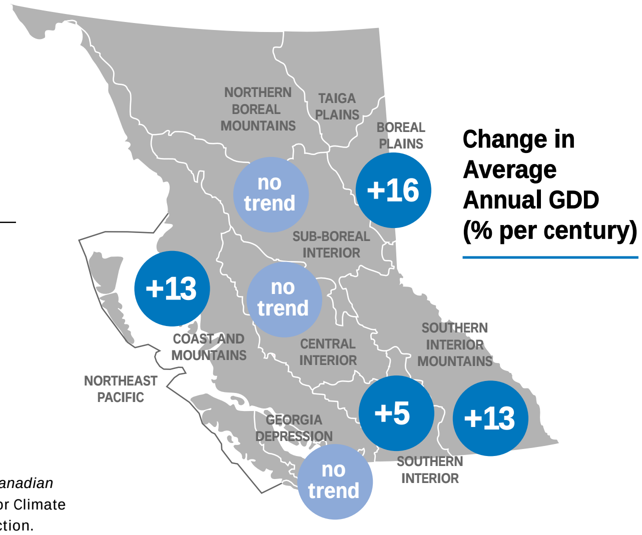
WHAT CAN WE EXPECT IN FUTURE?

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.

GROWING DEGREE DAYS

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



SOURCE: Data from Environment Canada, *Archive of Canadian Monthly Climate Data.* Analysis by Canadian Institute for Climate Studies, 2001 for Ministry of Water, Land and Air Protection.
NOTES: A positive trend 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 1888 to 1992 from low-elevation weather observation stations in each of the nine terrestrial ecoprovinces.

GDD TRENDS IN BRITISH COLUMBIA

Annual GDD increased during the 20th century at rates of 16 percent per century in the Boreal Plains ecoprovince, 13 percent per century in the Coast and Mountains, 5 percent per century in the Southern Interior, and 13 percent per century in the Southern Interior Mountains. These trends are consistent with trends over the past century toward higher average annual temperatures across British Columbia.

The trends for three ecoprovinces (Coast and Mountains, Southern Interior, and Southern Interior Mountains) are based on long records (94 to 102 years) and probably reflect the effects of climate change. The record for the Boreal Plains is relatively short (58 years) and is therefore more likely to have been influenced by natural climate variability.

The records for the Georgia Depression, the Central Interior, and the Sub-Boreal Interior ecoprovinces are relatively long (93 to 105 years) but the data fail to reveal trends in GDD. The records for the Northern Boreal Mountains and Taiga Plains ecoprovinces are relatively short (55 and 47 years) and are insufficient to determine whether or not trends exist.

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 2.2°C, while corn requires temperatures of at least 10°C.

Because of these differences, agrologists some-times refer to an average minimum temperature of

Heat requirements of Agricultural Crop and Pest Species

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

5°C 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 average daily temperature and 5°C. So on a day when the average temperature is 12°C, the GDD is 7. GDD is calculated for only those days when the average temperature is higher than 5°C. Annual GDD is calculated as the sum of GDD for the year.

A significant increase in available heat energy could allow farmers to succeed in introducing new varieties of crops that were previously marginal or not viable in their region. 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.

WHY IS GDD INCREASING?

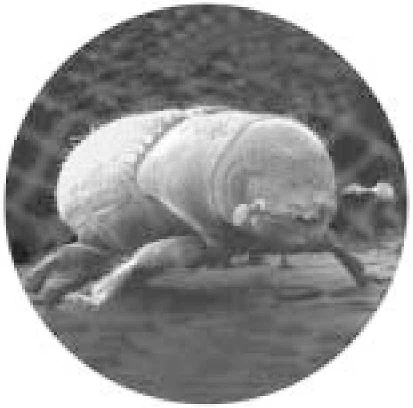
During the 20th century, average annual temperatures warmed in much of BC at rates of 0.6°C to 1°C per century. Because GDD is related to average daily temperature, it is not surprising that the amount of energy available for plant growth and development has also increased.

WHAT CAN WE EXPECT IN FUTURE?

Climate models indicate that temperatures will continue to rise in BC by 1°C to 4°C during the next 100 years. 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.

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.

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.

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

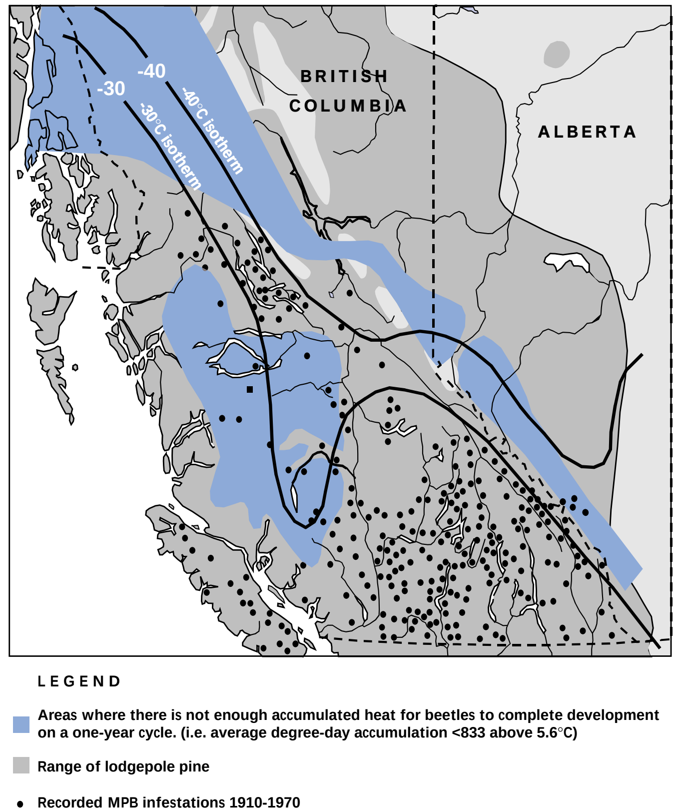
Lodgepole pine ecosystems — the preferred forest of the mountain pine beetle — extend north into the Yukon and the Northwest Territories and east into Alberta. Climate limitations currently prevent the mountain pine beetle from establishing itself in these regions. Warmer temperatures, in particular 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.

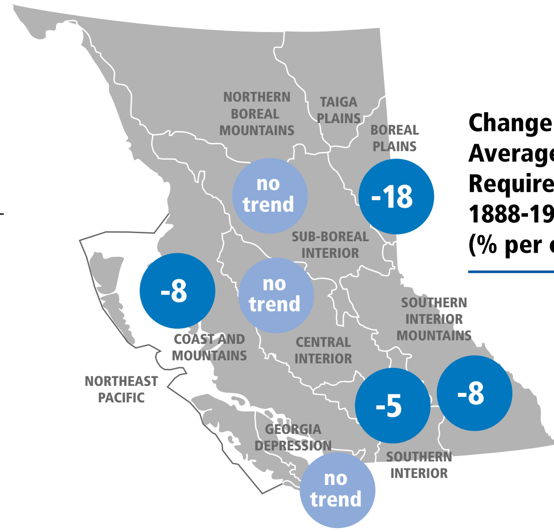
WHAT CAN WE EXPECT IN FUTURE?

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.

HEATING AND COOLING REQUIREMENTS

In coastal and southeastern BC, the amount of energy required for heating similarly constructed and insulated buildings decreased during the past century. In southern BC, the amount of energy required for cooling increased.



Change in Average Heating Requirements, 1888-1993, (% per century)

SOURCE: Data from Environment Canada. Analysis by Canadian Institute for Climate Studies, 2001 for Ministry of Water, Land and Air Protection. NOTES: A negative sign indicates a decrease in heating requirements.

ABOUT THE INDICATORS

These indicators measure changes in the annual energy requirements for heating and cooling. The trends are based on available temperature records from 1888 to 1993 from weather observation stations in populated valleys.

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 example, a day with an average temperature of 8ºC has an HDD of 10. 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.

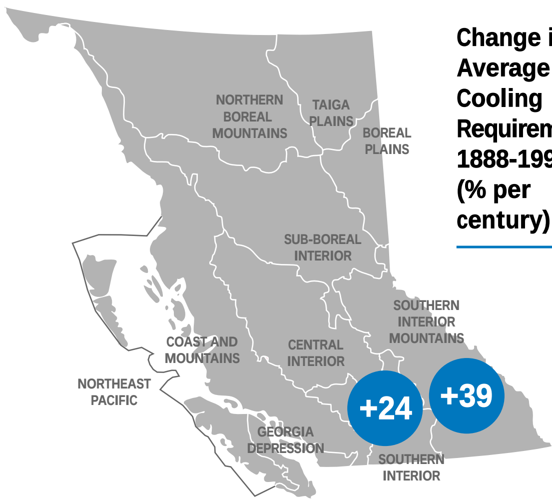
Energy requirements for cooling are measured in units called Cooling Degree Days (CDD). CDD for one day is calculated as the difference between the average outdoor temperature and 18ºC. For example, a day with an average temperature of 21ºC has a CDD of 3. The CDD calculation looks only at days when 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

Four ecoprovinces show trends towards lower annual heating requirements. The trends for three ecoprovinces (Coast and Mountains, Southern Interior, and Southern Interior Mountains) are based on relatively long records (94 to 102 years) and almost certainly reflect climate change. The trend for the Boreal Plains is based on a shorter record period (58 years) and may be influenced by climate variability as well as by climate change.

The records for the Georgia Depression, the Central Interior, and the Sub-Boreal Interior ecoprovinces are relatively long (93 to 105 years) but the data fail to reveal trends in HDD. The records for the Northern Boreal Mountains and Taiga Plains ecoprovinces are relatively short (55 and 47 years) and are insufficient to determine whether or not trends exist.

Cooling requirements have increased by 24 percent in the Southern Interior ecoprovince and by 39 percent in the Southern Interior Mountains over the last century. Both trends are based on relatively long record periods (102 and 94 years) and almost certainly reflect climate change. In the seven other ecoprovinces, days with significant cooling requirements are infrequent. Thus the data are insufficient to assess whether or not there are trends.



Change in Average Cooling Requirements, 1888-1993, (% per century)

SOURCE: Data from Environment Canada. Analysis by Canadian Institute for Climate Studies, 2001 for Ministry of Water, Land and Air Protection. NOTES: A positive sign indicates an increase in cooling requirements.

WHY IS IT IMPORTANT?

Building managers, owners, and residents typically try to maintain buildings at a comfortable interior temperature of 18°C. They tend to begin interior heating when the outdoor temperature is below 18°C (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 tend to turn on their air conditioners when the average daily outdoor air temperature exceeds a comfortable 18°C and when there are several hours of uncomfortable heat during the day.

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 an important factor in energy management and planning decisions.

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 in the Coast and Mountains and Southern Interior ecoprovinces. The trends also suggest that in the Southern Interior and Southern Interior Mountains, 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 and Southern Interior Mountains, more energy is 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 spring than in summer and fall. Consequently, winter heating requirements will likely continue to decrease, and summer cooling requirements to increase.

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 30ºC. 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.

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 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

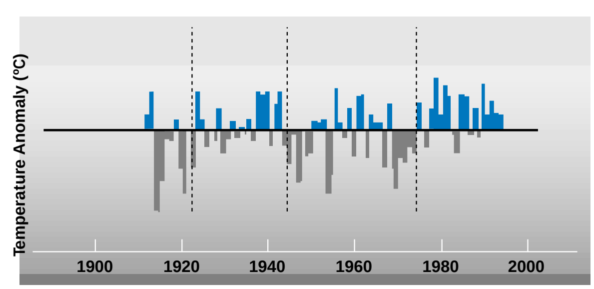
Climate variability involves relatively short-term changes and can occur as a result of natural alterations in some aspect of the climate system. For example, increases in the concentration of aerosols in the atmosphere as a result of volcanic eruptions can influence climate for a few years. Climate 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 cycles in the Pacific Ocean: the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Both ocean patterns have an influence on patterns of atmospheric circulation and both affect western North America.

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. There is evidence that ENSO is a permanent feature of the climate system and that El Niños have occurred for millennia.

The PDO is a widespread oscillation 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

British Columbia Coastal Sea Surface Temperature 1900-1995



SOURCE: University of Washington, Department of Atmospheric Sciences.
NOTES: SST along the BC coast reflects the influence of the PDO. Dotted vertical lines indicate the years in which the PDO has switched from warm to cool or vice versa.The graph shows values above (in blue) and below (in grey) average sea surface temperatures.

1925 to 1945 and from 1977 onwards. A change from warm to cool may have occurred in the mid-1990s.

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 BC have also fluctuated over a 50- to 60-year cycle.

CLIMATE CHANGE

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

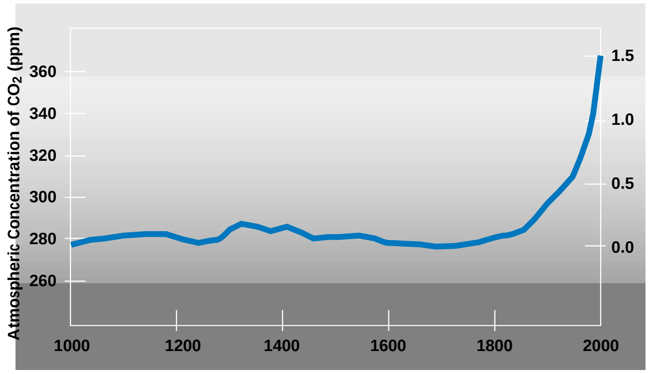
There is strong evidence that change is an ongoing feature of the global climate system. At present, however, it is occurring at an unprecedented rate. Global temperature, for example, has increased by 0.4ºC to 0.8ºC since the 19th century. The rate of warming is probably faster than at any other time during the past 1,000 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 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 proportion of carbon dioxide and other greenhouse gases in the atmosphere over the last century and a half. There is a strong connection between the proportion of these gases in the atmosphere and atmospheric temperature.

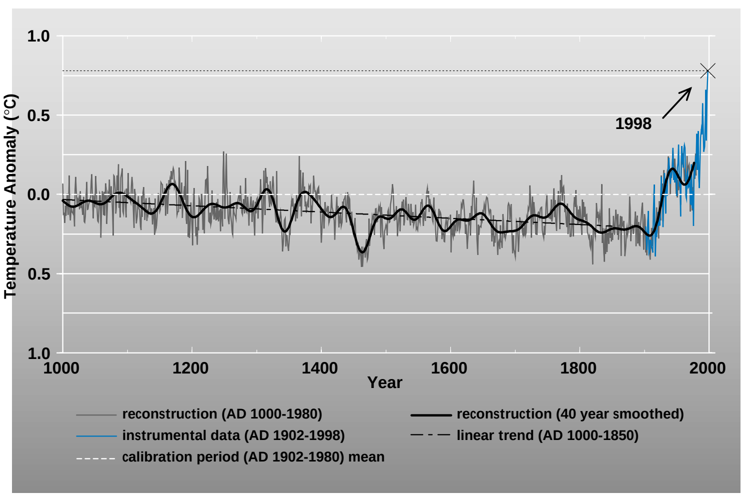
Anthropogenic climate change appears to be responsible for much of the atmospheric warming observed during the past century, and especially the last 50 years. The earth is currently exposed to the

Atmospheric CO2 Concentrations, 1000–2000 AD



SOURCE: IPCC, 2001

Northern Hemisphere Temperatures, 1000-2000 AD



SOURCE: Mann et al. 1999. Northern Hemisphere temperatures during the past millennium: inferences, uncertainties, and limitations. Geophysical Research Letters, 26:759-762. NOTES: The average temperature for the calibration period (1902-1980) is roughly 15ºC. For most of the period from 1000 to 1850 AD, average temperatures in the Northern Hemisphere were decreasing. Since the late 1800s, average temperatures have been increasing. Temperatures from 1000 to 1850 AD are based on tree ring, ice core, geological, coral and other proxy data.

highest levels of CO_2 in the atmosphere — and the warmest surface air temperatures — in at least 1,000 years. And some greenhouse gases 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.

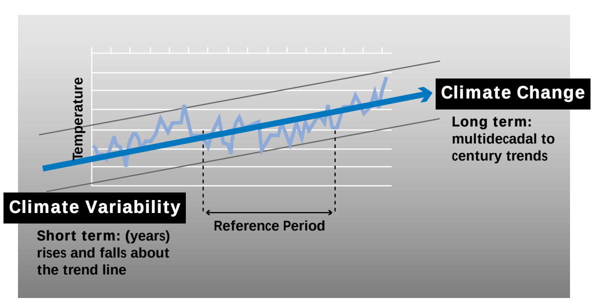
DISTINGUISHING PAST TRENDS

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 the 50-to 60-year cycle of the PDO. Data records that span 40 to 60 years or less may be too strongly influenced by this natural cycle to produce meaningful climate-change trends. Only data records that span one or more full cycles of the PDO, or that begin and end at roughly the same point in the cycle, 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. Particularly in northern BC, the available data is sometimes insufficient. It may come from too few monitoring stations within an ecoprovince, or the data records may be too short. As a result, it is not always possible to identify a long-term climate-change trend for every indicator and for every ecoprovince.

Relationship between Climate Variability and Climate Change



SOURCE: Canadian Institute for Climate Studies. NOTES: The Reference Period corresponds to one cycle of the PDO. The graph shows a long term climate change trend above and beyond natural climate variability, and for a period of time longer than one PDO cycle.

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 trends is based on reports published in 2001 by the Intergovernmental Panel on Climate Change (IPCC). The findings of the IPCC about future climate change are largely based on climate models — simplified 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 models project global temperature increases ranging from 1.4°C to 5.8°C by 2100, 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 limited, but improving. Mountainous regions such as BC — where valleys may have quite a different climate from adjacent mountainous terrain —- present particular problems. Models do not yet include the level of detail required to make projections at the local level. 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.