Climate Change

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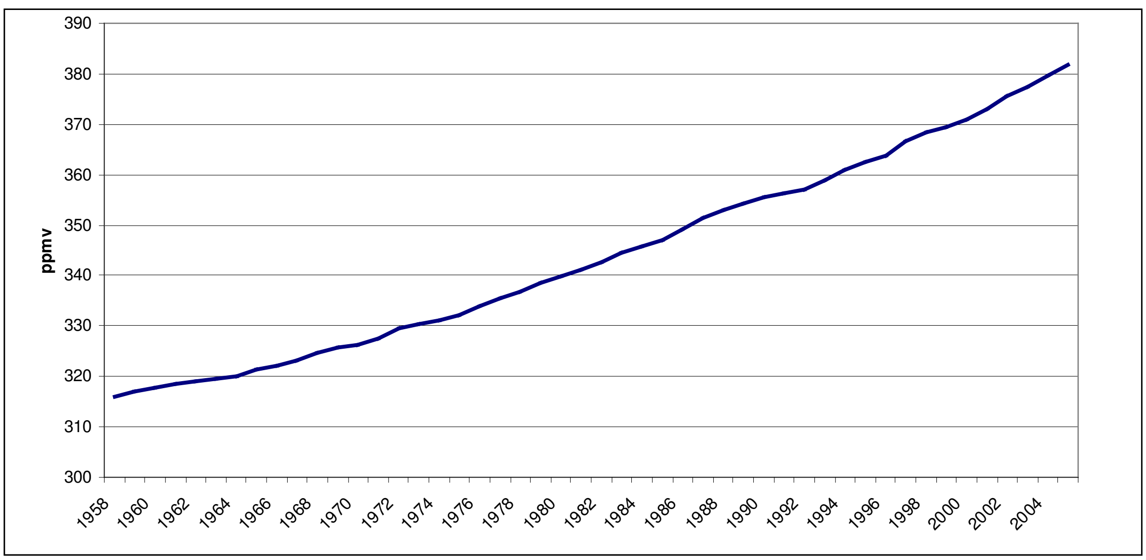
BACKGROUND

The most recent assessment of global climate change from the International Panel on Climate Change (IPCC) concludes with a high degree of certainty that Earth's atmosphere is warming and that the main cause is the build-up of greenhouse gases in the atmosphere from human activity. The IPCC is the authoritative international body set up by the United Nations in 1988 to review scientific information on climate change. It involves over 2,000 of the world's climate experts, who survey the worldwide technical and scientific literature and periodically publish assessment reports. The fourth, and most recent assessment, was released in 2007.

Greenhouse gases include atmospheric gases such as carbon dioxide (CO_2), methane, and nitrous oxide, and some human-created compounds. These gases are released into the atmosphere by fossil fuel combustion, deforestation, agriculture, and industrial activity, as well as through naturally occurring processes. The gases trap solar energy, which warms the atmosphere and the surface of the Earth. As the levels of these gases build up in the atmosphere, they trap more heat energy. As the atmosphere warms, the temperature of air, land, and water also warms, which in turn affects patterns of precipitation, evaporation, wind, and storms, as well as ocean temperature and currents.

Figure 1. Carbon dioxide concentrations in Earth's atmosphere recorded at Mauna Loa, Hawaii (1958–2006) (in parts per million by volume, ppmv).



Sources: Data through 2004 from *http://cdiac.ornl.gov/ftp/trends/co2/maunaloa.co2*; data for 2005, 2006 from *www.cmdl.noaa.gov/projects/web/trends/co2_mm_mlo.dat*.

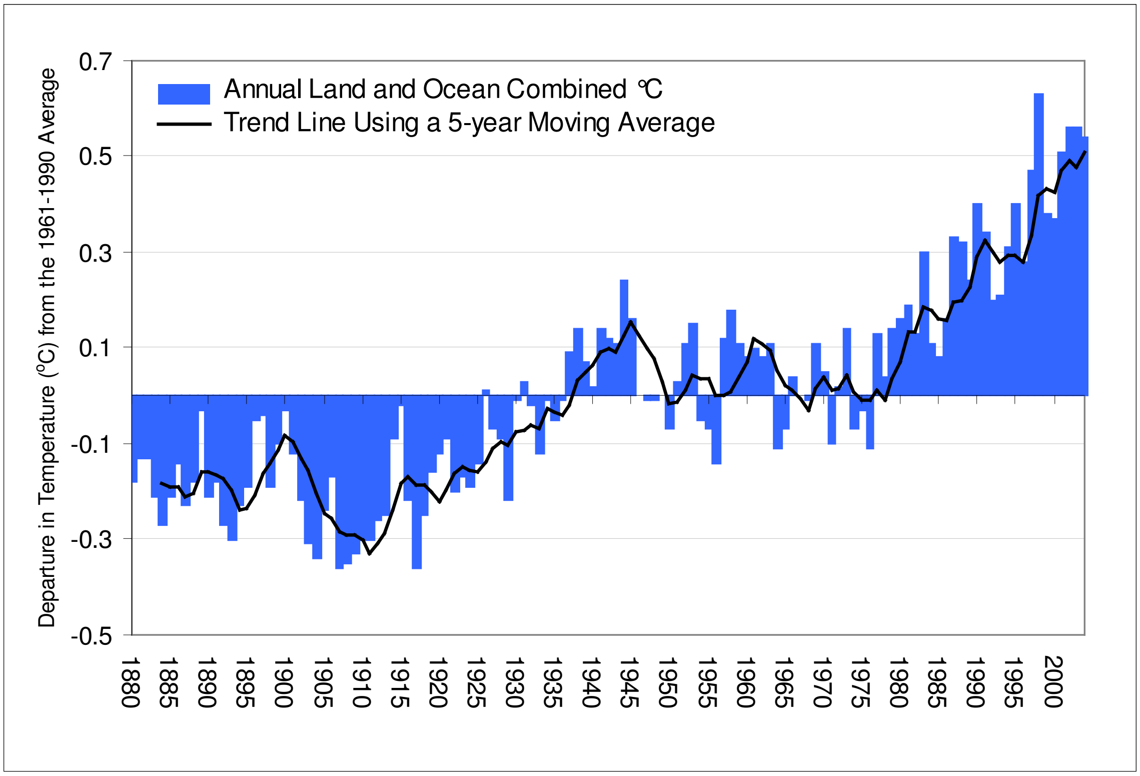
Since 1958 the observatory at Mauna Loa, in Hawaii, has been monitoring carbon dioxide concentration in the atmosphere. This is the longest continuous and accurate record of CO_2 in the world. Figure 1 shows that the average level of carbon dioxide, an important greenhouse gas, has been steadily increasing. In 2006 it reached 382 parts per million by volume (ppmv). Studies on air trapped in dated ice cores have shown that the concentration of CO_2 before the industrial era was about 280 ppmv. This means that the atmospheric CO_2 concentration has risen 42% over what it was about 260 years ago.

Concentrations of other greenhouse gases have been rising as well, notably methane and nitrous oxide. All greenhouse gases added together have the warming equivalent of about 430 ppm CO_2 (CO_2 equivalent or CO_2e is used to make comparisons between gases). The most recent IPCC report states that the increase in CO_2 has been due primarily to fossil fuel use with a smaller input from land-use change, whereas the increases in methane and nitrous oxide have been caused primarily by agriculture (IPCC 2007a).

As greenhouse gas concentrations in the atmosphere increase, global temperatures also rise as more of the incoming energy (solar radiation) from the sun is trapped by the atmosphere. Records show that global temperatures, averaged world-wide over the land and sea, rose 0.74 ± 0.18ºC in the 100 years between 1906 and 2005 (IPCC 2007a) (see Figure 2). The average global air temperature increased almost twice as fast in the last 50 years as it did in the last hundred years, showing that the rate of change is increasing (IPCC 2007a). Globally, 11 of the 12 warmest years since 1850 occurred between 1995 and 2006. Cold days, cold nights, and frost have become less frequent, while hot days and nights and heat waves have become more common (Solomon et al. 2007).

The Earth is not warming evenly, however, and some parts, particularly northern latitudes, have been warming more rapidly than equatorial regions. As remote as they are, the polar regions have been most obviously affected so far by climate change. The average temperature in the Arctic is increasing twice as quickly as the global average (IPCC 2007a). The extent of sea ice, which was relatively stable until the 1960s, has been shrinking at the rate of 7.8% per decade since then (Stroeve et al. 2007). Arctic sea ice coverage in April 2007 was the lowest for that month since satellite imagery of the northern ocean began in 1979. The US National Center for Atmospheric Research projects that the Arctic Ocean will be almost free of ice in the late summer by 2040 (Holland et al. 2006). Farther south, the ground is thawing at sites near the southern margin of permafrost in northern Manitoba. The thawed ground no longer provides a good support for trees, which are being replaced by floating mats of sedge and moss (Camill 2005). A preliminary model showed that 60% of Canada's permafrost could be gone by 2100 (Lawrence and Slater 2005).

Figure 2. Annual global land temperature and ocean temperature (°C) relative to the average temperatures for 1961–1990.



Source: National Oceanic and Atmosphere Administration (NOAA)
http://lwf.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html#anomalies.

Impacts of Climate Change

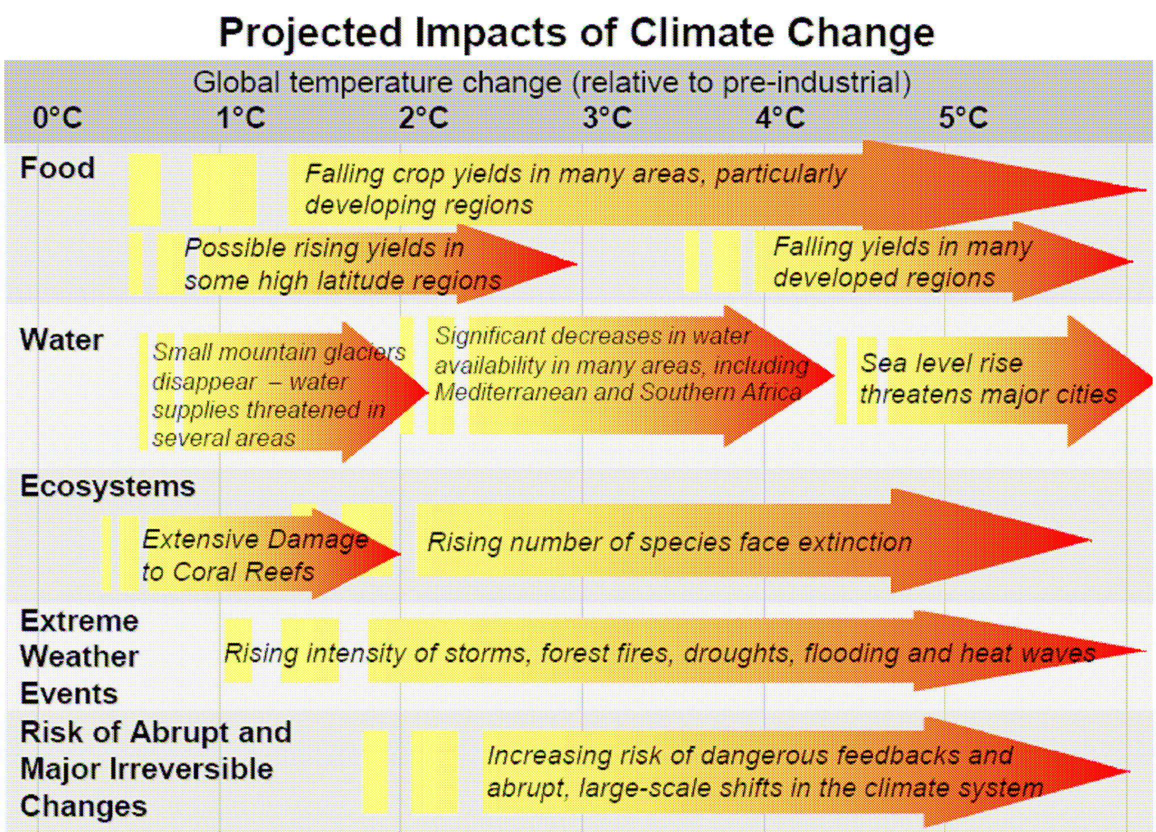
The global links between atmospheric temperatures, ocean circulation, sea level, and weather and storm patterns mean that changes to the climate from global warming will affect everyone. Because climate is the major factor controlling the global pattern of ecosystems, this is expected to result in changes to the ecosystems that people depend on for food, water, clean air, and economic activities. Also, built infrastructure (e.g., cities, ports, dams), agricultural systems, and other human activities will be affected because they have been based on past sea level and climate patterns. Figure 3 is from a recent British study (Stern 2006) showing the types of impacts that may be expected with each degree rise in average global temperature.

Some of the projected and observed changes include:

- **Physical impacts**, such as increasing frequency and severity of extreme weather (heat waves, drought, and high-intensity rainfall), changes in river flow, increased flood risk, increased wildfire risk, shrinking glaciers and snowpacks at most locations, rising sea level, and alteration of ocean temperature, salinity, and density.

- **Biological impacts** on ecosystems, such as changes to vegetation, species composition and distribution, ecosystem function (productivity, nutrient and water cycling), and distribution of ecosystems in the landscape. Timing of biological events, such as flowering, migration, growth, and reproduction, and interactions between species, will be affected. Patterns of natural disturbance (fires, pest infestations) and the impacts of alien species will also change.
- **Socio-economic effects**, including the economic cost of dealing with the impacts listed above. In particular, there will be costs due to extreme weather, flooding, and sea level rise, as well as costs of investing in conservation measures, developing alternative water supplies, building or replacing infrastructure, and possibly moving people to other locations. Ecosystem-based economic activities, such as agriculture, forestry, salmon fisheries, and tourism, will also be affected.
- **Health effects** will include increasing range of certain diseases (such as malaria) and increased risk of heat-related illnesses such as heat stroke.

Figure 3. Projected impacts of climate change with each degree increase in average global temperature.



Source: Stern Review on the Economics of Climate Change, 2006, reproduced with permission.

NATURAL SOURCES OF CLIMATE VARIATION IN BRITISH COLUMBIA

It is important to note that for B.C., the impacts on the climate from global climate change will interact, possibly unpredictably, with two major sources of natural short-term variation in the regional climate:

- The Pacific Decadal Oscillation (PDO) is a little-understood natural cycling of warm and cool phases in the sea surface temperatures of the Pacific Ocean. It appears to affect the B.C. climate over a 50- to 60-year cycle, spending roughly 20 to 30 years in each phase. In British Columbia, the warm phase of the PDO is generally associated with above-average air and ocean surface temperatures and below-average springtime snowpack. Some researchers feel that the cycle may now be beginning to shift toward a cool phase.
- The El Niño/Southern Oscillation (ENSO) phenomenon is related to shifts in tropical air pressure and ocean temperature that change temperature and precipitation patterns along the West Coast every few years. For British Columbia, an El Niño event generally means a warmer winter with below-average precipitation, and a La Niña event means a cooler winter with above-average precipitation.

The naturally large variability in air temperature, ocean temperature, and precipitation caused by these cycles and their interactions means that it takes a long series of observations to detect underlying long-term trends. Neither phenomenon is well understood and they may be changing as a result of changing climate in ways that may be both complex and unpredictable.

This paper presents indicators of climate change and trends in greenhouse gas emissions for British Columbia. It includes information on past trends as well as projected conditions for later in this century.

INDICATORS

1. Key Indicator: Long-term trends in air temperature in B.C.

This is a status indicator. It addresses the questions: Has the air temperature changed in British Columbia? What are the long-term trends in air temperature? How will it change in the future?

This indicator updates results reported in 2006 (BCMOE 2006) showing temperature trends in British Columbia taken from records over the past 50 years. Supplementary information follows that shows the projected increases in temperature by the middle of the century according to climate modelling.

Methodology and Data

This indicator uses Adjusted Historical Canadian Climate Data (AHCCD), available on the Environment Canada website (*www.cccma.bc.ec.gc.ca/hccd/*). Data were downloaded July, 2007. The AHCCD dataset has been adjusted to correct for non-climate related changes, such as a change in station location or instrument changes (Vincent and Gullet 1997; Mekis and Hogg 1999).

Records from 15 stations were used for the calculations shown in Table 1. Fourteen stations had continuous records from before 1950 extending through 2006, but Quesnel Airport records were to 2005 only. The stations represent three of the four climatic zones in British Columbia because updated data were not available for the North BC Mountains climatic zone.

Trends for the period 1950-2006 were calculated using the Microsoft Excel template MAKESENS (Salmi et al. 2002; available at *www.fmi.fi/organization/contacts_25.html*). The MAKESENS software uses the nonparametric Sen's linear estimate for the slope of the trend line and the nonparametric Mann-Kendall test to evaluate whether that slope is statistically different from zero (no trend). Before trend calculations, the data were checked for possible serial correlation using the Durbin-Watson statistic. The station data were adjusted for serial correlation (autocorrelation) using the prewhitening method of Wang and Swail (2001). This is a statistical procedure applied to climate data so that the subsequent analysis avoids overestimating the significance of a trend. Table 1 shows trends in the annually averaged daily minimum, mean, and maximum temperatures. Statistically significant increases are designated with asterisks.

Table 1. Trends in the average daily minimum (Tmin), mean (Tavg), and maximum (Tmax) temperatures per decade. Calculations are based on records from 1950 through 2006†.

			Change per decade (in °C)				
Station name	Climate Zone	Element	Annual	Winter	Spring	Summer	Autumn
Abbotsford Airport	Pacific	Tmin (°C)	0.40	0.88	0.48	0.32	0.13
		Tavg (°C)	0.33*	0.29*	0.38*	0.41*	0.15*
		Tmax (°C)	0.11	0.63	-0.23	0.67	-0.42
Comox Airport	Pacific	Tmin (°C)	0.32*	0.22*	0.44*	0.36*	0.21*
		Tavg (°C)	0.23*	0.22*	0.28*	0.25*	0.12*
		Tmax (°C)	0.13*	0.17*	0.13	0.15	0.06
Port Hardy Airport	Pacific	Tmin (°C)	0.21*	0.24*	0.28*	0.25*	0.02
		Tavg (°C)	0.19*	0.27*	0.20	0.17	0.04
		Tmax (°C)	0.15*	0.29*	0.23*	0.08	0.03
Victoria Airport	Pacific	Tmin (°C)	0.22*	0.20*	0.35*	0.25*	0.11*
		Tavg (°C)	0.25*	0.22*	0.32*	0.29*	0.12*
		Tmax (°C)	0.24*	0.29*	0.24*	0.27*	0.10
Fort St. John	Northwestern forest	Tmin (°C)	0.41*	1.06*	0.49*	0.18*	0.15
		Tavg (°C)	0.31*	0.98*	0.46*	0.11	0.05
		Tmax (°C)	0.35*	0.92*	0.43	0.05	0.00

Fort Nelson	Northwestern forest	Tmin (°C)	0.36*	0.83*	0.38*	0.12	0.15
		Tavg (°C)	0.36*	0.85*	0.48*	0.11	0.15
		Tmax (°C)	0.38*	0.82*	0.53*	0.10	0.10
Smithers	South BC mountains	Tmin (°C)	0.29*	0.65*	0.26*	0.17*	0.00
		Tavg (°C)	0.30*	0.56*	0.27*	0.14	0.02
		Tmax (°C)	0.25*	0.48*	0.29*	0.13	0.05
Burns Lake	South BC mountains	Tmin (°C)	0.16	0.55	0.21	0.14	-0.14
		Tavg (°C)	0.31*	0.60*	0.29*	0.19*	0.04
		Tmax (°C)	0.36*	0.62*	0.37*	0.29*	0.11
Quesnel Airport †	South BC mountains	Tmin (°C)	0.40*	0.80*	0.43*	0.17*	0.20
		Tavg (°C)	0.35*	0.64*	0.35*	0.17*	0.13
		Tmax (°C)	0.27*	0.44*	0.39*	0.13	0.03
Summerland	South BC mountains	Tmin (°C)	0.29*	0.33*	0.33*	0.36*	0.13
		Tavg (°C)	0.29*	0.29	0.32*	0.31*	0.14
		Tmax (°C)	0.27*	0.26	0.29*	0.27*	0.17
Cranbrook Airport	South BC mountains	Tmin (°C)	0.31*	0.42*	0.42*	0.28*	0.15
		Tavg (°C)	0.29*	0.32*	0.39*	0.23*	0.14
		Tmax (°C)	0.25*	0.27	0.39*	0.18	0.17
Kamloops Airport	South BC mountains	Tmin (°C)	0.43*	0.61*	0.39*	0.42*	0.21*
		Tavg (°C)	0.34*	0.52*	0.35*	0.24*	0.12
		Tmax (°C)	0.25*	0.44*	0.30*	0.06	0.04
Prince George Airport	South BC mountains	Tmin (°C)	0.40*	0.81*	0.47*	0.35*	0.10
		Tavg (°C)	0.38*	0.66*	0.43*	0.28*	0.11
		Tmax (°C)	0.35*	0.47*	0.44*	0.21	0.07
Revelstoke	South BC mountains	Tmin (°C)	0.33*	0.40*	0.38*	0.27*	0.17*
		Tavg (°C)	0.26*	0.43*	0.29*	0.13	0.13
		Tmax (°C)	0.18*	0.38*	0.23	0.00	0.10
Vernon	South BC mountains	Tmin (°C)	0.43*	0.56*	0.41*	0.34*	0.21*
		Tavg (°C)	0.37*	0.43*	0.40*	0.29*	0.18
		Tmax (°C)	0.29*	0.29	0.32*	0.25*	0.18

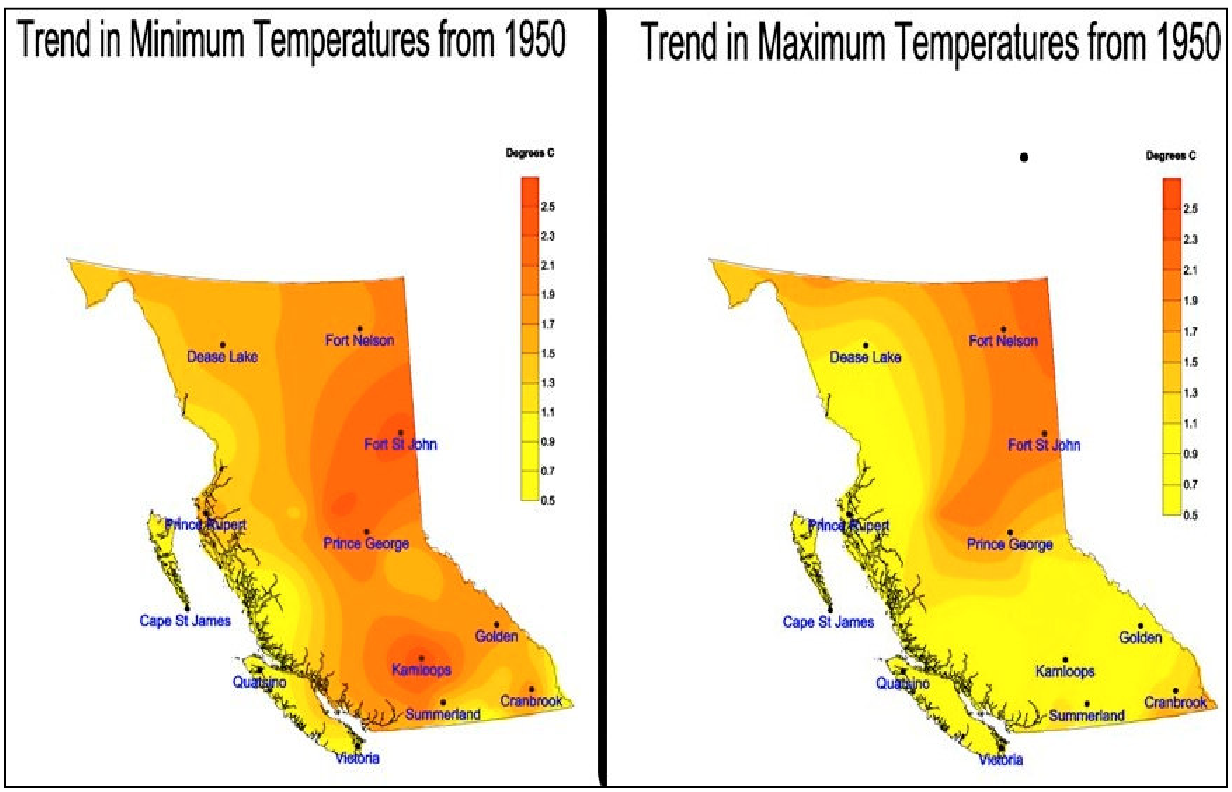
† Records for Quesnel Airport, 1950–2005.

Note: Asterisks indicate a statistically significant difference, meaning there is at least a 95% probability that the trend is not due to random chance.

Results show that there has been a statistically significant increase in the average temperatures (minimum, mean, and maximum) at most stations in the province. The addition of 5 new years to the data set (2002–2006) did not change the results much from trends reported previously for 1950-2001 (BCMOE 2006). Generally, the most recent calculations show slightly higher average increases per decade, reflecting the inclusion of five of the warmest years in the last 50 years. There was also an increase in the number of trends that were statistically significant, which increases confidence in the finding that British Columbia's climate has warmed significantly since the 1950s.

Figure 4 shows a graphical representation of temperature trends from 1950 to 2001, using records from 36 climate stations. For information on methods, data and locations of the stations used to calculate the trends shown in Figure 4, see the British Columbia Coastal Environment: 2006 report (BCMOE 2006).

Figure 4. Fifty-year trends in daily minimum and maximum temperatures shown as change (in °C), 1950–2001.



Source: Environment Canada: *www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_e.cfm*.

Note: The graphic shows generalized temperature changes for the region but is not meant to represent accurate temperature changes for specific areas or locations.

Interpretation

British Columbia is experiencing a pattern of warming consistent with what has been observed globally. All stations showed increasing temperatures from 1950 to 2006, with the greatest changes occurring in the northern and interior regions (i.e., the Northwestern Forest climate zone). There were seasonal differences in trends per decade, with the least change occurring in the autumn over most of the province (the southwest is an exception).

The IPCC's Fourth Assessment reported that the average global warming trend over the last 50 years was 0.13 ± 0.03ºC per decade, for a total increase of 0.65 ± 0.15ºC for the 50-year period (Solomon et al. 2007). In British Columbia, both the average annual increase in mean temperature of 0.30 ± 0.04ºC per decade and the total increase of 1.5ºC during the last 50 years are higher than the global average. This is consistent with IPCC reporting, which shows that warming at higher latitudes has been greater than the global average (Solomon et al. 2007).

Within the province, the Northwestern Forest climatic zone had the largest increase in temperature, with winters warming faster than the other seasons. In the 1950 to 2006 period, the winter overnight low at Fort St. John increased by 5.3 ± 2.8ºC, while the daily average winter temperature increased 4.9 ± 2.7ºC. The South B.C. Mountains climatic zone also showed the greatest warming trend in the winter. The winter overnight low at Prince George has increased by 4.0 ± 3.0ºC. The warming pattern in the Pacific climatic zone differed from the other regions, showing temperatures warming fastest in the spring. The springtime overnight low at Comox Airport increased 2.2 ± 1.5ºC since 1950.

Overall, the overnight minimum air temperatures in the province have been increasing faster than the daytime maximums. This is creating a climate with a narrower daily temperature range and a longer growing season. Previous reporting also showed that there are also fewer days of frost each year (BCMOE 2006).

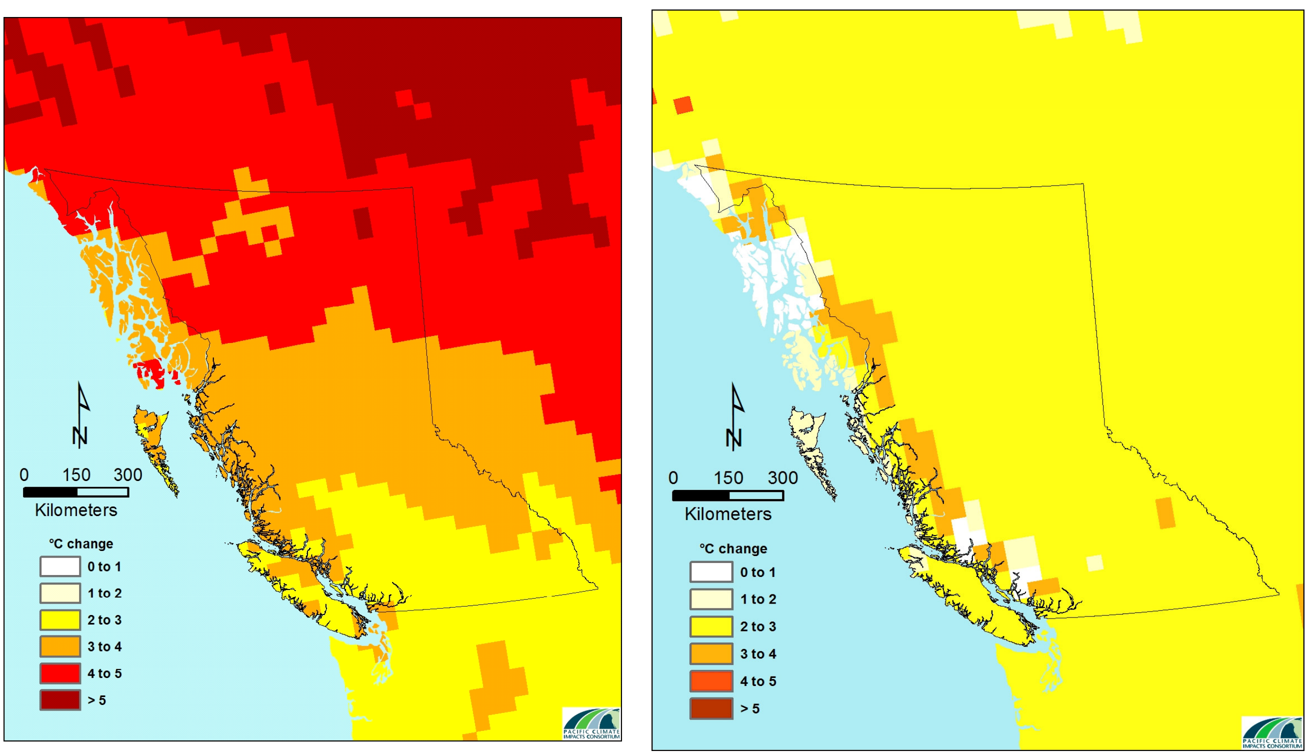
Supplementary Information: Temperature changes by mid-century in B.C.

The most recent IPCC assessment projects that globally averaged temperature will increase by at least 1.8 ± 0.7ºC over this century (IPCC 2007a). Increases may be as high as 4.0 ± 2.4ºC, depending on the extent to which society reduces the consumption of fossil fuels and controls greenhouse gas emissions by the end of the century. These projections were made using Global Circulation Models (GCMs), which have been developed and tested extensively since the 1980s. Such climate models balance calculations of incoming solar radiation against the outgoing planetary radiation and take into account the degree to which future greenhouse gas emissions will affect that balance. The models incorporate a series of specific emissions scenarios, which vary in their assumptions about future fossil fuel use and the actions that society may take to curb greenhouse gas emissions. The climate models are run using the range of greenhouse gas emissions under the different scenarios to produce a set of plausible outcomes.

Because global climate models operate on grids of 250 to 600 km across, they are not precise enough to characterize the smaller scale processes that influence temperature and precipitation at a provincial level. To develop regional projections for Canada, a team of researchers at the Consortium Ouranos developed the Canadian Regional Climate Model (CRCM) in collaboration with the Canadian Centre for Climate Modelling and Analysis. The CRCM runs on a 45-km grid and thus is designed to shows a finer, more regional scale of climate projection.

In April 2007, using the most recent version of this model (CRCM4.1.1) the Pacific Climate Impacts Consortium prepared projections of winter and summer temperatures for British Columbia. Figure 5 shows the projected temperature increases for a period in the middle of the 21st century (2041–2070) compared to the period 1961 to 1990, under the A2 emissions scenario. The model projects that winters will continue to warm faster than summers, reducing the contrast between seasons. Under this scenario much of the province would experience summers 2–3°C warmer by mid-century than occurred in the period 1961 to 1990. The northern half of the province would experience winters warmer by 3–5°C. These trends are projected to continue so that the province may be even warmer by the end of the century. Table 2 compares these climate model projections with regional average temperature increases accumulated in B.C. to date.

Figure 5. Temperature change projected for the middle of the 21st century (°C), compared to the 1961-1990 average. Left: Average winter conditions (December, January, February). Right: Average summer conditions (June, July, August).



Source: Pacific Climate Impacts Consortium, April 2007 (analysis). Consortium Ouranos and Canadian Centre for Climate Modelling and Analysis (data and modelling).

Notes: Initial boundary conditions for the Canadian Regional Climate Model that were used (CRCM4) were specified by output from the larger scale Canadian Global Climate Model CGCM3, using the IPCC SRES A2 emissions scenario. Resulting grids were mapped using ArcGIS software.

Table 2. Comparison of climate model projections with regional average temperature increases accumulated in B.C. to date.

Climatic zone	Season	Temperature increase 1976–2005	Model projection for increases to 2055 over 1976 baseline*
Pacific	Winter	0.7°C warmer	2–4°C warmer
	Summer	1.6°C warmer	2–3°C warmer
South BC Mountains	Winter	1.6°C warmer	2–4°C warmer
	Summer	0.7°C warmer	2–3°C warmer
Northwestern Forest	Winter	2.8°C warmer	3–4°C warmer
	Summer	No significant trend	2–3°C warmer

* Output from CRCM4, A2 scenario.

One of most obvious consequences of rising temperature is that people in British Columbia can expect more hot days. There is a 90% chance that heat waves will increase in frequency (IPCC 2007a). Hot extremes will become more common as the climate warms and cold extremes will become less frequent. For the region that includes British Columbia, this means that by the end of the century, 14 to 19 new annual temperature records may be set every 20 years (Ravilious 2007). Extreme events, such as record high temperatures, are of critical importance because human health and the distribution of living organisms can be affected by extreme conditions more than by changes in average conditions.

2. Secondary Indicator: Coastal sea surface temperature

This is a impact indicator. It addresses the question: What is the impact of climate change on ocean temperature along the B.C. coast? This indicator was reported in the British Columbia Coastal Environment: 2006 report and is summarized here. For more detailed information see the full report (BCMOE 2006, *www.env.gov.bc.ca/soe/bcce/03_climate_change/ocean_temp.html*).

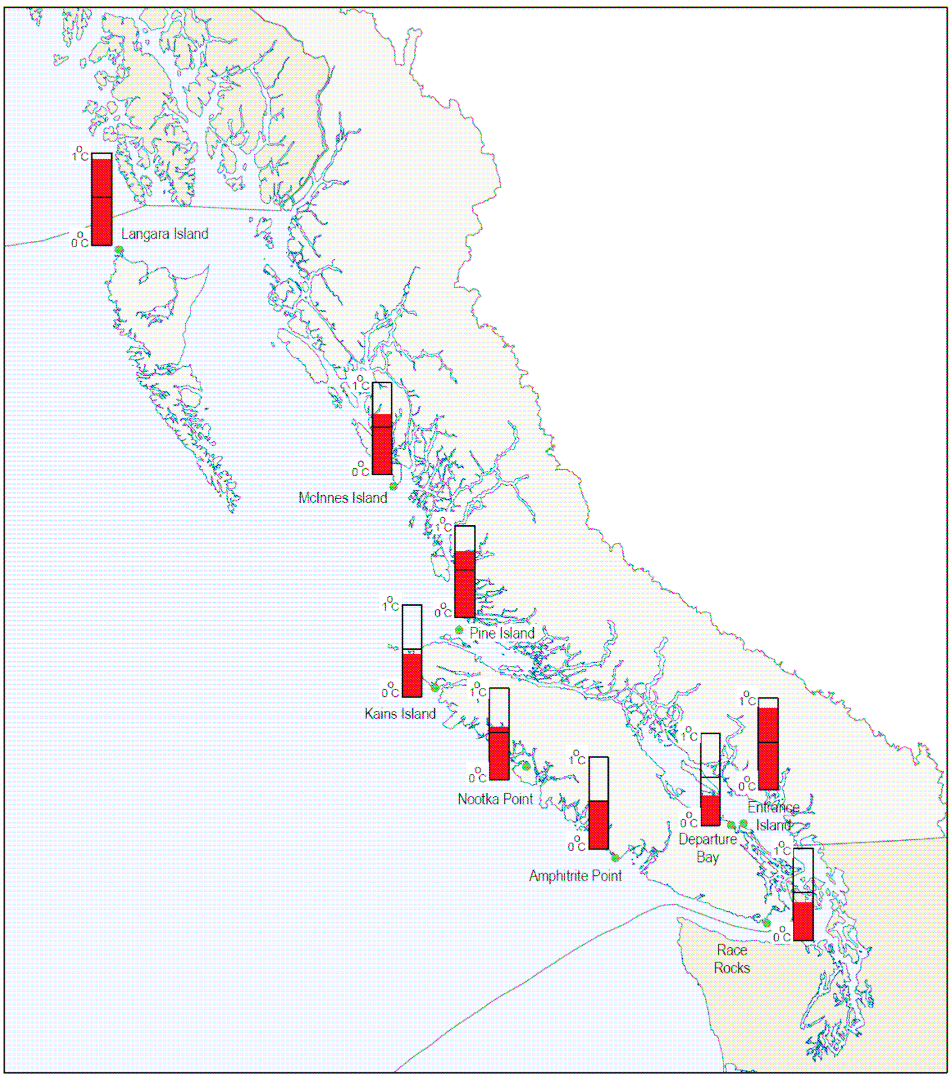
The temperature of the ocean affects coastal weather and climate. Along with salinity, ocean temperature affects the survival, growth, and reproductive success of marine life and the productivity and composition of marine ecosystems. The impacts of global climate change on the B.C. coast interacts with two major sources of natural variation in the ocean temperature: the Pacific Decadal Oscillation and the El Niño/Southern Oscillation phenomenon (see text box on natural sources of climate variation, above).

Methodology and Data

The longest water temperature series for the B.C. coast comes from daily surface observations taken at eight lighthouses and at the Pacific Biological Station in Departure Bay (Table 3) (available on Fisheries and Oceans Canada website *www-sci.pac.dfo-mpo.gc.ca/osap/data*). The annual mean temperatures reported here have been calculated from the monthly mean data for only those years where monthly mean values are available for all 12 months.

Trends were determined using the Microsoft Excel template MAKESENS and statistical analyses to remove any autocorrelation (using the pre-whitening procedure described in Wang and Swail 2001). Note that other methods for computing trends give slightly different results, both in terms of confidence intervals and the number of datasets showing significant positive trends. Regardless of the computational method, however, there is agreement in the overall finding that there are detectable and statistically significant increases in sea-surface temperature.

Figure 6. Rate of change in sea-surface temperature (ºC/50 years) at nine lighthouse stations on the B.C. coast.



Source: Fisheries and Oceans Canada *www.pac.dfo-mpo.gc.ca/sci/osap/data*.

Note: Red bars indicate values that are statistically significant at <0.5%, meaning there is at least a 95% chance that the trend is real.

Table 3. Mean annual sea-surface temperature at nine stations on the B.C. coast.

Station	Area	First year	Latest year	Years used in analysis	Annual mean (°C)	Standard deviation (°C)	Trend (°C/50 yrs)
Langara Island	North coast	1941	2003	61	8.8	0.52	0.94*
McInnes Island	Central coast	1955	2003	46	9.6	0.48	0.65
Pine Island	Central coast	1937	2003	65	8.7	0.51	0.71*
Kains Island	West coast Vanc. Is.	1935	2003	68	10.2	0.55	0.43
Nootka Point	West coast Vanc. Is.	1935	2003	32	10.9	0.51	0.55
Amphitrite Point	West coast Vanc. Is.	1935	2003	68	10.4	0.52	0.50*
Departure Bay	East coast Vanc. Is.	1915	2003	68	11.1	0.50	0.29
Entrance Island	Strait of Georgia	1937	2002	65	11.2	0.51	0.82*
Race Rocks	Juan de Fuca Strait	1922	2003	64	9.1	0.44	0.39*

Source: Fisheries and Oceans Canada, *www-sci.pac.dfo-mpo.gc.ca/osap/data*.

Note: Asterisks indicate statistical significance. Probability or chance that there is no trend (α): <5%.

Interpretation

Over the last 50 years, the ocean has become warmer all along the B.C. coast (Figure 6). Five of the nine stations showed statistically significant increases in mean annual sea-surface temperature (Table 3). The largest and most significant increase was a warming of 0.9°C in 50 years for Langara Island, at the northwest tip of the Queen Charlotte Islands. The second largest change, 0.8°C in 50 years, was for Entrance Island, in the central Strait of Georgia.

A more detailed analysis reported in BCMOE (2006) showed three of the nine stations had statistically significant increases in either the annual maximum or annual minimum temperature. The most statistically significant trend was an increase in annual maximum temperature at Entrance Island. There was an increase of 1.7°C in 50 years at this station, which may reflect the increased summer warming in the Strait of Georgia.

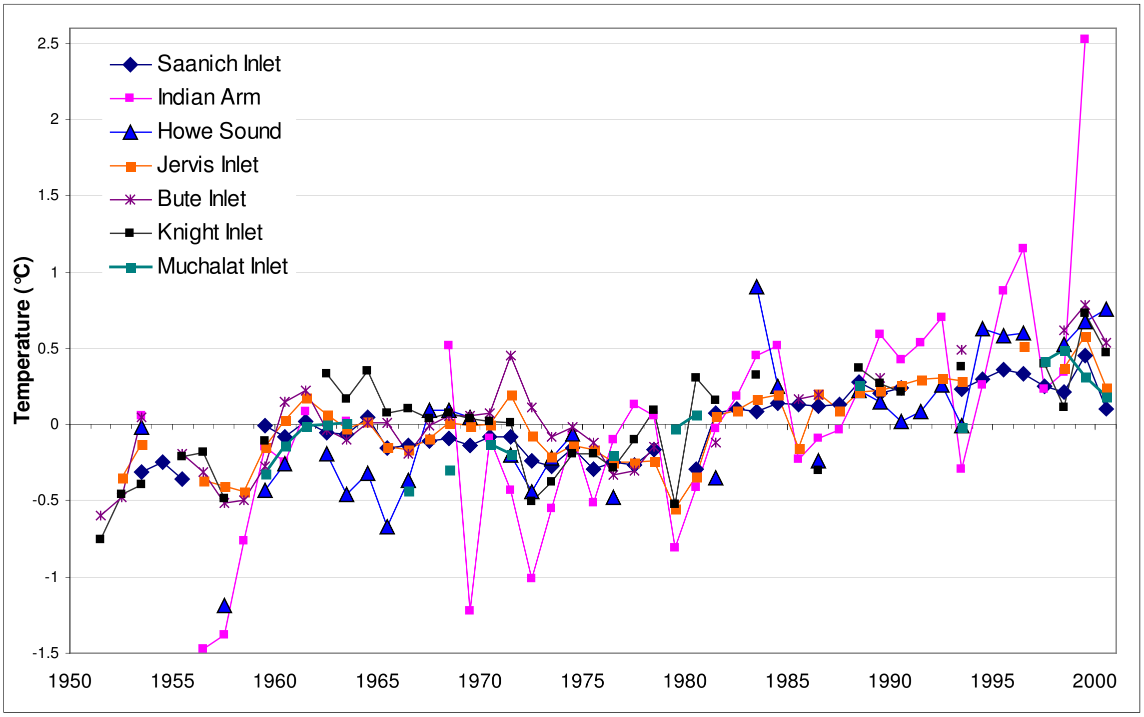
The water around Langara Island, at the extreme northwest point on the B.C. coast, is about 1.5°C colder than that around Amphitrite Point, on the southwest coast of Vancouver Island, for both annual mean and average annual extremes. At the present rate of increase, temperatures at Langara Island would resemble current conditions at Amphitrite Point in less than a hundred years.

Supplementary Information: Deep-water warming on the B.C. coast

A warming trend in the ocean along the southern B.C. coast also shows in the deeper waters of five inlets on the mainland coast and two on Vancouver Island. Consistent with the temperature trends shown in the sea-surface indicator, all seven inlets showed a warming of 0.5 to 1.0°C over the last 50 years.

Figure 7 shows temperature differences that depart from the average (set as 0°C) over the period for each time series. Bottom water temperatures in the inlets generally range from 6.5 to 8.5°C.

Figure 7. Deep-water temperature anomalies for inlets in southern B.C. The baseline of zero represents the average over the period for each time series.

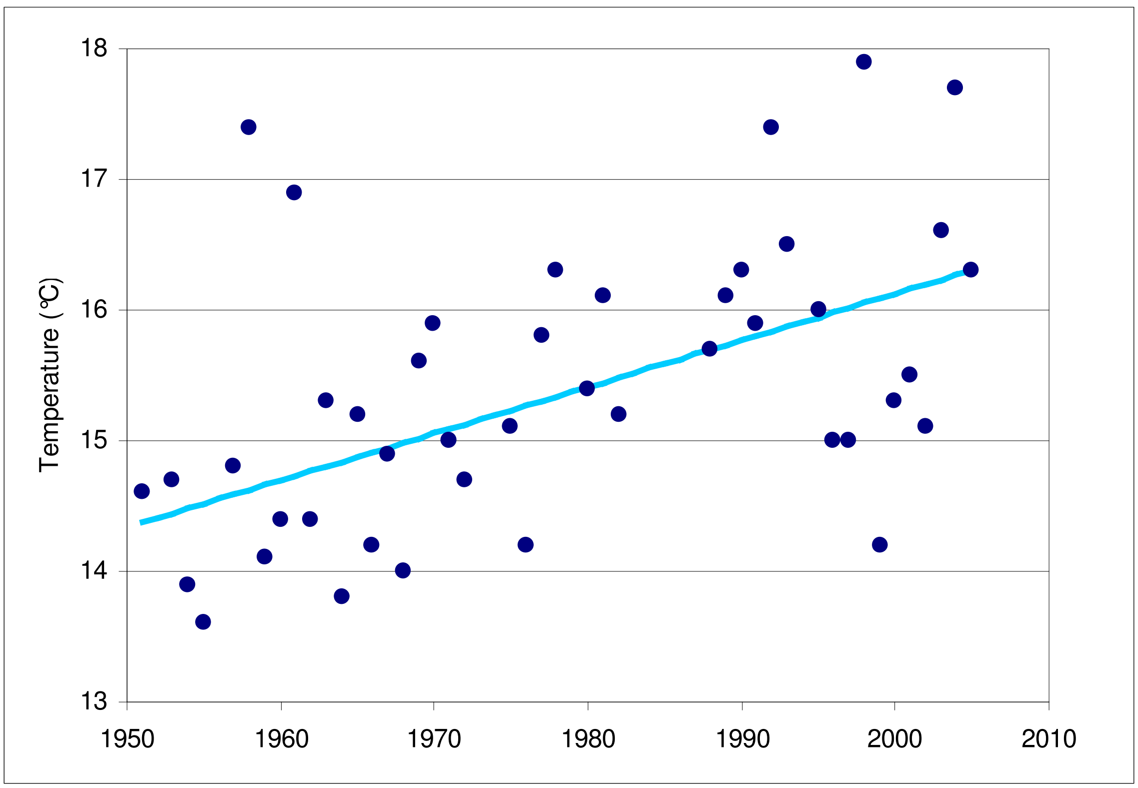


Source: Ocean Science and Productivity Group, Institute of Ocean Sciences, Fisheries and Oceans Canada, *www-sci.pac.dfo-mpo.gc.ca/osap/projects/bcinlets/intro_e.htm*.

Supplementary Information: Trends in stream and river temperatures in B.C.

Few long-term temperature datasets for rivers and streams are available, but the Pacific Salmon Commission and Fisheries and Oceans Canada have been measuring temperature in the lower Fraser River, at Hell's Gate. Interruptions in the data prevent an analysis for the years before 1950. Figure 8 shows that the average summer temperature in the river has been rising since 1950, at the rate of 0.3 ± 0.1ºC per decade.

Figure 8. Average summer (June, July, August) temperature of the lower Fraser River at Hell's Gate.



Source: Pacific Salmon Commission and Institute of Ocean Sciences, Fisheries and Oceans Canada.

Water temperature increases with increasing air temperature and decreasing flow in the catchment basin above Hell's gate. Model projections suggest that the average water temperature at Hell's Gate will increase 1.5ºC by the middle of the century and 1.9ºC by the end of this century (Morrison et al. 2002). Projections also suggest that the average summer temperature in the Thompson River at Spences Bridge may reach 19.1ºC by the end of the century.

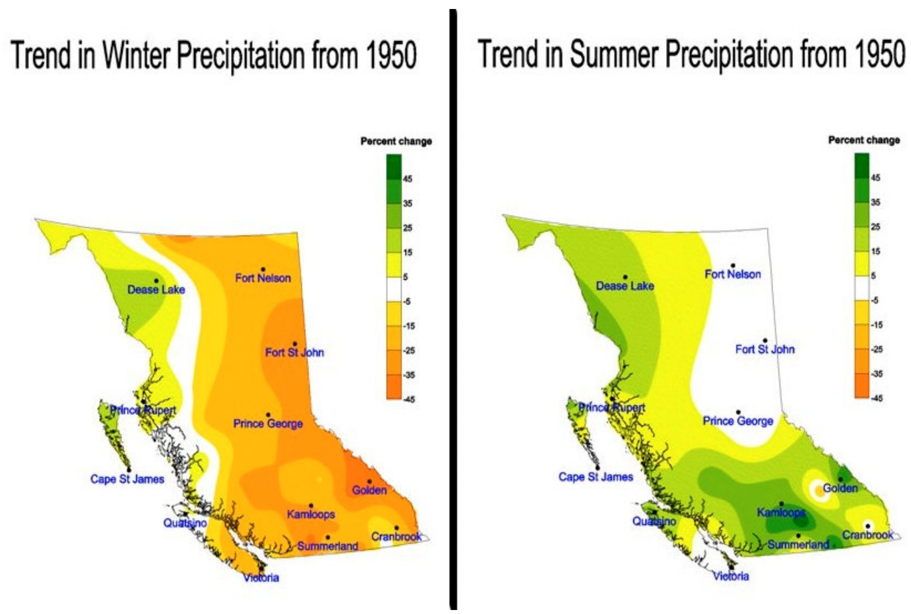
This is of vital importance to salmon, which are sensitive to high water temperature during their migration up-river to spawn. The Hell's Gate records show that before 1990, no daily temperature was above 20ºC, but in 2004 there were 16 days above 20ºC. Pre-spawn mortalities of sockeye of more than 90% have already occurred due to warmer water in some years (Lapointe et al. 2003; English et al. 2005). This raises concerns for the survival of many Fraser River salmon stocks later in this century as the temperature continues to rise.

3. Secondary Indicator: Precipitation changes in B.C.

This is a status indicator. It addresses the questions: How have precipitation patterns in British Columbia changed? How might climate change affect precipitation patterns in the future?

Precipitation (along with temperature) is one of the most important physical variables affecting terrestrial and coastal ecosystems. Trends in precipitation in the province over 50 years (1950–2001) were reported previously in BCMOE (2006) and are shown in an approximate graphical representation in Figure 9.

Figure 9. Fifty-year trends in winter and summer precipitation, shown as percentage change, 1950–2001.



Source: Environment Canada *www.ecoinfo.ec.gc.ca/env_ind/region/climate/climate_e.cfm*. For detailed information on methods, data and locations of the 36 stations used to calculate the trends shown see British Columbia Coastal Environment: 2006 (*www.gov.bc.ca\soe\bcce*).

Note: The graphic shows generalized precipitation changes for the region; it does not represent accurate changes for specific areas or locations.

The analysis showed that total annual precipitation (1950–2001) has increased in several regions of British Columbia. The Okanagan and North Coast regions show the largest increases. Eastern British Columbia has been receiving less precipitation on an annual basis. Winters throughout most of the province have been drier, whereas spring and summer seasons have been wetter.

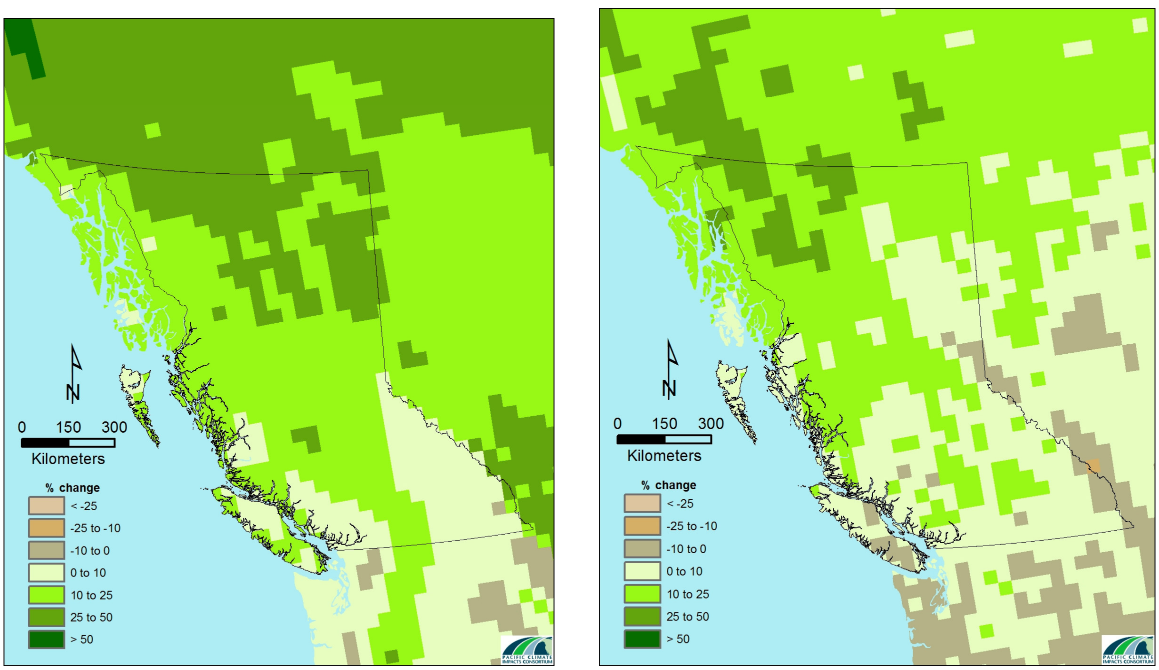
This indicator reports the results of the most recent climate modelling to project changes in precipitation for British Columbia by mid-century.

Methodology and Data

Methodology is the same as for the temperature projection described in Indicator 1. Figure 10 was produced by the Pacific Climate Impacts Consortium using data from the CRCM4.1.1 (the current Canadian Regional Climate Model developed by Consortium Ouranos and the Canadian Centre for Climate Modelling and Analysis) under the IPCC A2 emission scenario.

The two figures show precipitation differences between the middle of the 21st century (2041–2070) and the 1961–1990 period.

Figure 10: Projected change in precipitation by the middle of the 21st century, relative to historical records (1961–1990). Left: Average winter conditions (December, January, February); right: average summer conditions (June, July, August).



Source: Pacific Climate Impacts Consortium, April 2007 (analysis); Consortium Ouranos and Canadian Centre for Climate Modelling and Analysis (data and modelling).

Notes: Initial boundary conditions for the Canadian Regional Climate Model used (CRCM4) were specified by output from the larger scale Canadian Global Climate Model CGCM3, using the IPCC SRES A2 emissions scenario. Resulting grids were mapped using ArcGIS software.

Interpretation

Global climate models suggest that by mid-century there should be a small net increase in global precipitation and a redistribution of rainfall from the tropics into temperate and northern latitudes. A recent analysis of global observations from 1925 to 1999 showed that precipitation increased by 6.2 mm per decade in the latitude band of 50 to 70 degrees North, which includes almost all of British Columbia (Zhang et al. 2007). The analysis showed that human influence on atmospheric greenhouse gases could account for 50–85% of this observed trend.

Contrary to historical precipitation patterns, the model output shows precipitation may increase marginally over most of the province during winter, which is when much of the total rainfall for the year occurs. Summers, however, may become drier over much of the coast, especially in the south. On an annual basis (not shown in the figure), the entire province may become wetter. Less of the winter precipitation is likely to fall as snow, particularly at low elevations, because of the predicted rise in temperature.

There is some evidence that rainfall events are increasing in intensity (the amount of rain per unit time) and in magnitude. An analysis of precipitation data within Metro Vancouver (Greater Vancouver Regional District) found increases in rainfall intensity at about half the sites measured, especially for durations of less than 2 hours. In addition, high intensity events appear to be more frequent, especially in spring (Murdock et al. 2007). Modelling of mid-century precipitation using seven global climate models projects that the Vancouver area is more likely to experience drier summers and slightly wetter conditions in the other three seasons (Murdock et al. 2007).

4. Secondary Indicator: Changes in the spring snowpack in B.C.

This is an impact indicator. It addresses the question: Is the pattern of snowfall changing as a result of climate change?

This indicator presents the results of the analysis of trends in the accumulated snow water equivalent (SWE) in the snowpack over the last 50 years. SWE is the amount of liquid water contained in a volume of snow. Snow conditions in British Columbia vary widely from year to year as a result of natural variability in weather patterns due to the El Niño/Southern Oscillation (ENSO) effects and Pacific Decadal Oscillation (PDO) effects (see text box, above).

Methodology and Data

The B.C. Ministry of Environment operates a network of approximately 250 sites for manual and automatic sampling of snowpack. Some stations have been used since 1936 and many in the current sampling program have been in use since the 1950s, providing useful data on long-term trends in snow conditions. Sampling is done about April 1 each year, when there is a peak in the accumulated snowpack from the preceding winter.

For this indicator, April 1 SWE data for 73 long-term active manual snow courses were compiled from the River Forecast Centre snow archive website (*http://aardvark.gov.bc.ca/apps/mss/stationlist.do*) for the 50-year period, 1956–2005.

Monthly ENSO and PDO data were compiled from the National Oceanographic and Atmospheric Administration (NOAA) (*www.cpc.ncep.noaa.gov/data/indices*). An average ENSO and PDO variable for each April 1st snow survey was calculated as the numeric average of the monthly values from the preceding five months (November to March), corresponding to the winter snow accumulation period.

The data were analyzed with Systat v.11. First, a linear regression was fitted to each of the raw 50-year SWE data sets for each snow course. In general, the regressions were not statistically significant because there is such a large scatter from year-to-year. The trend from 1956 to 2005 was calculated from the regression slope and intercept coefficients.

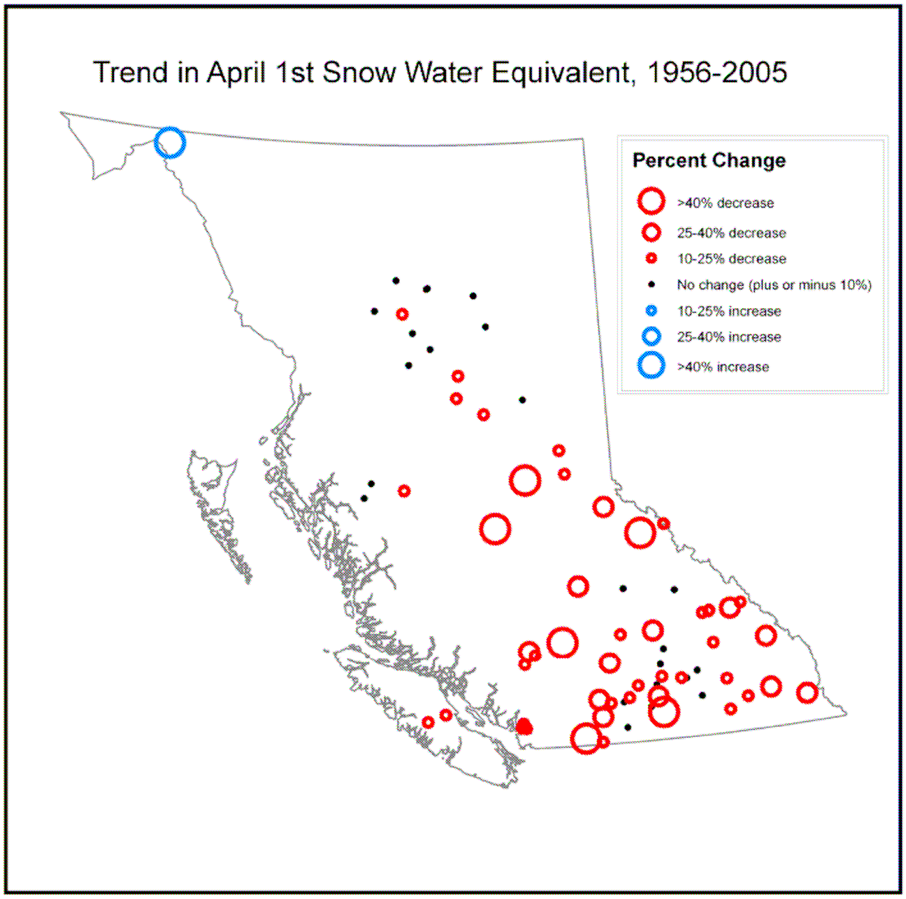
Overall, there were substantial downward trends in SWE from 1956 to 2005 (Figure 11 shows individual survey sites; Table 4 shows basin-wide averages). For the 73 long-term snow courses analyzed, SWE decreased on 63 courses and increased on ten. The largest decreases were in the mid-Fraser basin (Chilcotin Plateau, Bonaparte, Nicola, etc.; 47% reduction), Kettle (32%), Thompson (22%), Kootenay (23%), Upper Fraser (21%), and Columbia (20%) basins. The Peace, Skeena, Nechako basins had no notable change over the 50-year period. On average, across the province, the SWE was 18% lower in 2005 than in 1956.

Table 4. Average change in snow water equivalent for major river basins in B.C., 1956–2005.

Basin	Overall change (%)
Upper Fraser	–21
Nechako	–2
Middle Fraser	–47
Thompson	–22
Columbia	–20
Kootenay	–23
Kettle	–32
Okanagan	–14
Similkameen	–19
South Coast/ Vancouver Isl.	–17
Skagit	–39
Peace	–7
Skeena	+4
Yukon/Liard	+23

Source: River Forecast Centre, B.C. Ministry of Environment 2007.

Figure 11. Trend in April 1 snow water equivalent at long-term B.C. snow survey sites, 1956–2005.



Source: River Forecast Centre, B.C. Ministry of Environment 2007.

At the time of the 1976 PDO shift, there was a discontinuity in the raw SWE data and in the residuals of the regression analysis for many snow courses; the data were therefore also analyzed to test for relationships to the ENSO and PDO signal. The SWE data sets were regressed against the ENSO and PDO indices separately and in a multivariate model in an attempt to remove a signal in the snow data that may be related to ENSO and PDO. The residuals from the multivariate model were then examined for trends over the 1956 to 2005 period, on the assumption that trends in the snow data, with the ENSO and PDO effects removed, may indicate impacts of climate change.

The further analysis showed that variability associated with the ENSO and PDO signals may account for about one-half to two-thirds of the change over time. The PDO effect may be the dominant influence, because a substantial reduction in the snowpack occurred with the shift of the PDO from a cool phase to a warm phase in 1976. Although the average change in most basins was very small, there were some exceptions: the SWE for the mid-Fraser showed reductions of 27% over the 1956 to 2005 period, consistent with the general climatic trend, which has been towards decreasing snow water, except in the north of the province. The Peace, Skeena, Liard, and Yukon basins all show increasing SWE.

Interpretation

Overall, the amount of water stored in snow and glaciers is expected to decrease globally as a result of climate change (IPCC 2007b). The results presented in this indicator may show such an effect in many of British Columbia's river basins, but this conclusion remains tentative. This is because the natural variability from other causes, such as the PDO and ENSO phenomena, is known to be large and complex and may also be shifting unpredictably due to climate change. Because these phenomena are not well understood, the statistical methods used to correct for these signals in the data may not be sufficient.

Declining snowpacks are a concern because they affect many aspects of water resources, from instream flows for fish to community water supply, soil moisture, groundwater, and aquifer recharge. Reinforced by the warm phase of the PDO, the raw B.C. snow survey data show declines of up to 73% in the Fraser Basin since 1951. Springtime snowpack has declined 20–40% in the Columbia River Basin (Sandford et al. 2006). It is not yet clear whether the warm phase of the PDO may be coming to an end, nor how much the loss in snowpack might recover when the PDO shifts to its next cool phase.

Supplementary Information: Increasing glacial melt and earlier stream flow

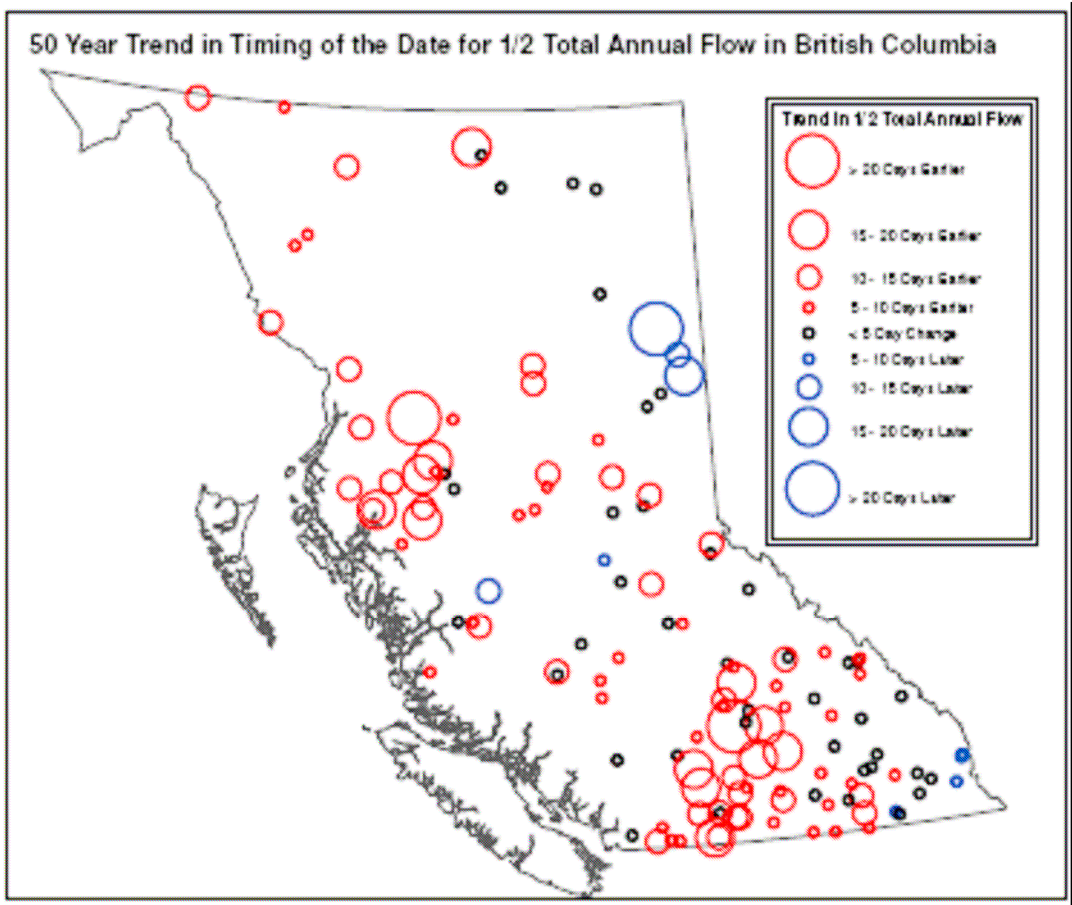
Mountain glaciers in temperate zones are highly sensitive to changes in the climate. Maritime glaciers, such as the Place, Helm, and Sentinel glaciers in the Coast Mountains, are highly sensitive to variations in winter precipitation, whereas glaciers in the Rockies, such as the Peyto glacier in Banff National Park, are more sensitive to summer temperatures (Lewis and Smith 2004).

Streams and rivers in much of B.C. are fed by melting ice and snow from the winter accumulation of snow (snowpacks) and from glaciers. In northwestern B.C., glacier-fed streams have become larger, whereas snowmelt-fed streams have become smaller over the period 1953–1999 (Fleming and Clarke 2003). Increasing glacial melt has probably had a greater effect on streamflow than changes in precipitation (Fleming and Clarke 2003).

Warmer winter and spring-time temperatures, especially at elevations below 1200 metres, have caused rivers to swell earlier in the year. Figure 12 shows the 50-year trend calculated for 140 stream-gauging stations where the annual discharge of water mainly comes from snowmelt. Stations in the southwest of the province were not included because the stream discharge there comes mainly from winter rain events rather than snowmelt.

The largest changes in river flow have been in the Okanagan-Kootenays and the north coast region of the province. Several stations show that the half-flow date (when half of all water in the river for the year has been discharged) now occurs more than 15 days earlier. The northeast mountains region is the exception, where three stations show a later half-flow date.

Figure 12. Fifty-year trend in timing of the date for half the total annual stream discharge in B.C., 1956–2005.



Source: River Forecast Centre, B.C. Ministry of Environment, July 2007.

B.C.'s Retreating Glaciers

The effect of changing temperature and precipitation on glaciers is extremely complex because it depends on the size, elevation, and location of the glacier, variations in the ENSO/PDO signal, as well as on climate change. For example, glaciers on the south coast have lost considerable mass since 1976 when the Pacific Decadal Oscillation (PDO) entered a phase with dryer winters and higher temperatures (Lewis and Smith 2004).

As observed in other parts of the world, many glaciers in B.C. are shrinking:

- Garibaldi Provincial Park: Despite brief periods of advancing, overall the glaciers in the park retreated through most of the 1900s. The area of ice in the park has decreased by about 240 km^2 (38%) since the late 17th or early 18th centuries (at the end of the cool climate period known as the Little Ice Age). Some glaciers in the park may vanish completely this century if present trends continue (Koch 2006).
- Strathcona Provincial Park: Moving Glacier has retreated almost a kilometre from its maximum extent in the early 1800s and had lost 90% of its surface area by 1992 (Smith and Laroque 1996).
- Mt. Waddington area of the central coast: The Tiedemann Glacier has retreated 2.1 km over the last century (Laroque and Smith 2005).
- Columbia River Basin: In the 15 years up to 2000, glaciers in the Columbia Basin lost an average of 16% of their area, with the Slocan watershed losing 47% and the Bull watershed losing 60% of total glacier area. These recession rates are consistent with rates being observed worldwide (Sandford et al. 2006).

5. Key Indicator: Mean sea level

This is a status indicator. It addresses the questions: Is sea level rising along the B.C. coast? This indicator was reported in greater detail in the British Columbia Coastal Environment: 2006 report (BCMOE 2006) and is summarized here (see *www.env.gov.bc.ca/soe/bcce/03_climate_change/sea_level.html*).

The average rate of sea level rise is increasing globally due to the acceleration of global warming. Observed global sea level rise in the period 1993–2003 was 3.1 mm per year, which is 72% higher than the observed average for the period 1961–2003 (IPCC 2007a). About half of the recent rise is estimated to be due to the expansion in volume of seawater as it warms; most of the rest is due to the increased flow of freshwater from melting glaciers on land (mainly Greenland) (IPCC 2007a).

Sea level rise is not uniform over the globe. It varies from one ocean basin to the next, reflecting variations in ocean heating and the effect of ocean currents and circulation. Along the B.C. coast, this includes large-scale variation in ocean circulation from the ENSO phenomena. Sea level along the B.C. coast is also affected by the geological movement of Earth's crust.

Rising sea level may be expected to result in more frequent flooding and salt contamination of low-lying areas. In combination with extreme weather, high tides and storm surges may be expected to damage areas and structures previously above high water.

Methodology and Data

Water levels along the British Columbia coast are recorded by tide gauges at stations maintained by the Canadian Hydrographic Service and the Water Survey of Canada. This indicator reports data from four tide gauge stations with long records that broadly represent three coastal oceanic regions (Table 5).

Table 5. Annual change in mean sea level since first year of records at four locations on the B.C. coast.

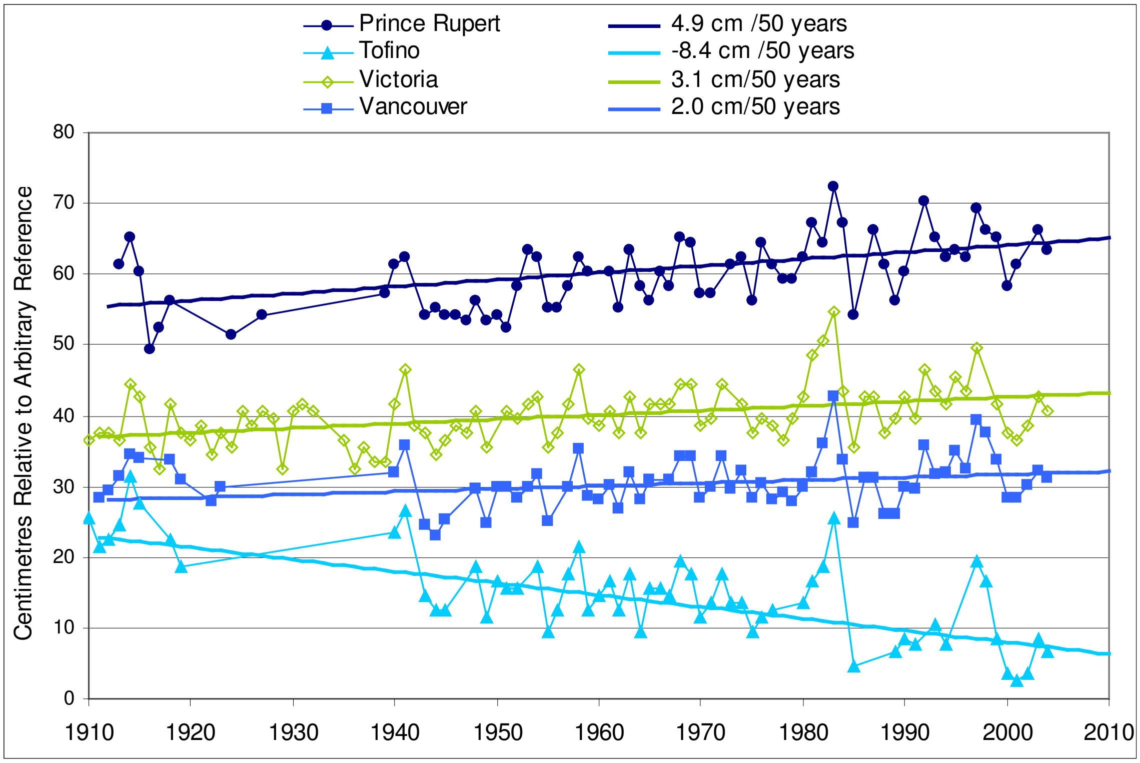
Station	First full year	Latest full year	Years used	Annual mean (cm)	Standard deviation (cm)	Trend (cm/50 years)	Chance of no trend
Prince Rupert	1913	2004	68	384.7	4.9	4.9	<0.05
Tofino	1910	2004	60	213.5	6.3	–8.4	<0.001
Vancouver	1911	2004	69	305.7	4.8	2.0	>0.1
Victoria	1910	2003	90	187.4	4.0	3.1	<0.01

Source: Marine Environmental Data Service, Fisheries and Oceans Canada.

Sea level data were obtained from the Marine Environmental Data Service (MEDS) of Fisheries and Oceans Canada. Trends were fitted to annual mean values to assess mean sea level rise. Trends were determined using the Microsoft Excel template MAKESENS, and statistical analyses to remove any autocorrelation (using the prewhitening procedure described in Wang and Swail 2001).

For Figure 13, the data were rescaled by adding a unique elevation to all the data for each station so that it could be displayed without overlapping on the same graph.

Figure 13. Changes in annual mean sea level at four locations on the B.C. coast.



Source: Marine Environmental Data Service, Fisheries and Oceans Canada.
Note: Trend lines were fitted using MAKESENS.

Interpretation

The analysis of sea level records shows that relative sea levels have been rising at Prince Rupert, Vancouver, and Victoria, but falling at Tofino. Differences between stations are explained on the basis of geological processes, which cause vertical movements of the shoreline that partly or completely cancel the effects of global sea level rise. The landmass of British Columbia is rebounding vertically (isostatic rebound) after the massive ice sheet melted approximately 10,000 years ago. The rate of rebound along the coast is estimated to be 0 to 4 mm per year. Also, the western edge of the North American continent is sliding over adjacent oceanic plates, resulting in crustal uplift estimated to be as high as 4 mm per year along the southwest coast of Vancouver Island near Tofino (Peltier 1996). The effect is that the measured water level drops as the coast (and the zero datum point) rises.

The magnitude of these effects means that short-term natural variations in mean sea level can be greater than the cumulative rise over the entire period. From 1980 to 1983, mean sea level rose by 12 cm in Victoria and Vancouver and by 10 cm in Prince Rupert. However, from 1983 to 1985 it declined by 19 cm in Victoria, 17 cm in Vancouver, and 18 cm in Prince Rupert. Both of these changes were associated with an ENSO event. Nevertheless, at all stations except Tofino, continuing the long-term trend in sea level would result in relative sea levels higher than have yet been observed.

Total global sea level rise in the 20th century was 170 mm, and the recent rate of global sea level rise was 2.3–3.9 mm/yr for the years 1993–2005 (Bindoff et al. 2007). The IPCC's projection for sea level rise this century is 18–59 cm, with a further 20 cm possible if the rate of ice loss in Greenland and Antarctica increases (IPCC 2007a). A more recent re-analysis of historical data suggests that the IPCC estimates are conservative and that sea level might rise by as much as 0.5–1.4 m during this century (Rahmstorf 2007).

SEA LEVEL RISES AS GREENLAND'S ICE MELTS

As much as 0.6 mm/yr of the annual average sea level rise globally has been attributed to the melting of Greenland's ice (Mitrovica et al. 2001). The bulk of Greenland's ice, more than 3,000 metres above sea level in the centre, is a remnant from the last ice age. Because the centre is so high and the average air temperature over it is so cold, the centre of Greenland is still accumulating snow (Lemke et al. 2007). However, Greenland's ice cap flows naturally from the centre of the island to the edges. The mass of new snow in the interior has been roughly balanced by the loss of ice at the margin (Scheirmeir 2004), but the rate of loss is accelerating (Rignot and Kanagaratnam 2006). Models suggest the ice sheet may become permanently unstable if the average global temperature increases by 1.9–4.6ºC relative to 1960. The lower end of this range could be reached within 50 years (IPCC 2007a).

Supplementary Information: Sensitivity of the B.C. coast to rising sea level

The projected rise in sea level due to climate change is a practical concern on the B.C. coast. Sections of the B.C. coast that are particularly sensitive to rising sea levels are the Fraser Delta region, which is subject to subsidence, and the Naikoon area of the Queen Charlotte Islands, which is presently eroding (Figure 14). In these areas, changing weather patterns coupled with sea level rise increase the risk of erosion and flooding under extreme weather conditions. The parts of the coastline with rocky, relatively steep-sided fiords are not considered sensitive to rising water.

Figure 14. Sensitivity of the B.C. coastline to sea level rise and erosion.

Source: Hay & Co. Consultants 2004.

6. Key Indicator: Trends in greenhouse gas emissions in B.C.

The quantity of greenhouse gases emitted to the atmosphere is a pressure indicator. It is an indicator of human activity that is affecting the global atmosphere and is causing most of the increase in global temperatures. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other trace compounds as well as water vapour.

Globally, the level of atmospheric CO_2 has increased by about 95 ppm since 1780. Of this increase, 84% is estimated to be due to emissions from fossil fuel combustion. The rest of the rise may be due to the alterations in land use, such as reduction in the global CO_2 sink due to forestry and forest fires (Kharecha and Hansen 2007). Carbon dioxide emissions account for more than 78% of the greenhouse gas emission in Canada and 79% of the emissions from facilities in B.C. (Environment Canada 2004).

This indicator examines the trends in total greenhouse gas emissions in British Columbia, as well as per capita emissions. It also shows how the province compares with other jurisdictions in North America.

Methodology and Data

Data on greenhouse gas emissions are from Environment Canada (2007) National Inventory Report, 1990-2005 - Greenhouse Gas Sources and Sinks in Canada: *www.ec.gc.ca/pdb/ghg/ghg_home_e.cfm*. The data were collected by Environment Canada and reported internationally using methods set out by the UN Framework Convention on Climate Change. The data were gathered by sector and subsector for industrial, commercial, and institutional sources, as well as for other sources such as transportation, agriculture, and land use change. Per capita greenhouse gas emissions shown in Table 6 and Figure 15 were calculated using population data from Statistics Canada's CANSIM database (*http://cansim2.statcan.ca*) using Table 051-0001, estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual (persons), 1971 to 2007.

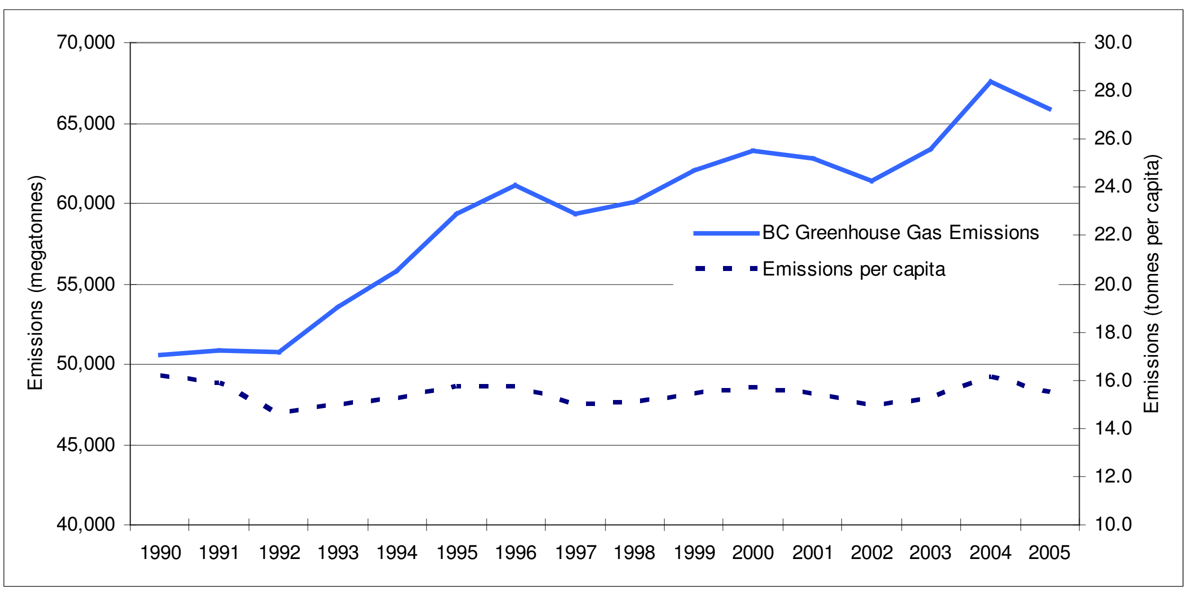
Emissions from specific industries were generated using the online inquiry function of Environment Canada's greenhouse gas emissions database: *www.ec.gc.ca/pdb/ghg/onlinedata/dataSearch_e.cfm*.

Table 6. Total and per capita greenhouse gas emissions in B.C., 1990–2005.

Year	B.C. population x 1,000	Total greenhouse gas emissions (tonnes)	Per capita greenhouse gas emissions (tonnes)
1990	3132.5	50,600	16.2
1991	3212.1	50,837	15.8
1992	3476.9	50,756	14.6
1993	3574.6	53,540	15.0
1994	3670.8	55,806	15.2
1995	3762.9	59,300	15.8
1996	3882.0	61,100	15.7
1997	3959.7	59,300	15.0
1998	3997.5	60,100	15.0
1999	4028.1	62,100	15.4
2000	4039.2	63,300	15.7
2001	4078.4	62,800	15.4
2002	4115.4	61,400	14.9
2003	4154.6	63,400	15.3
2004	4201.9	67,600	16.1
2005	4257.8	65,900	15.5

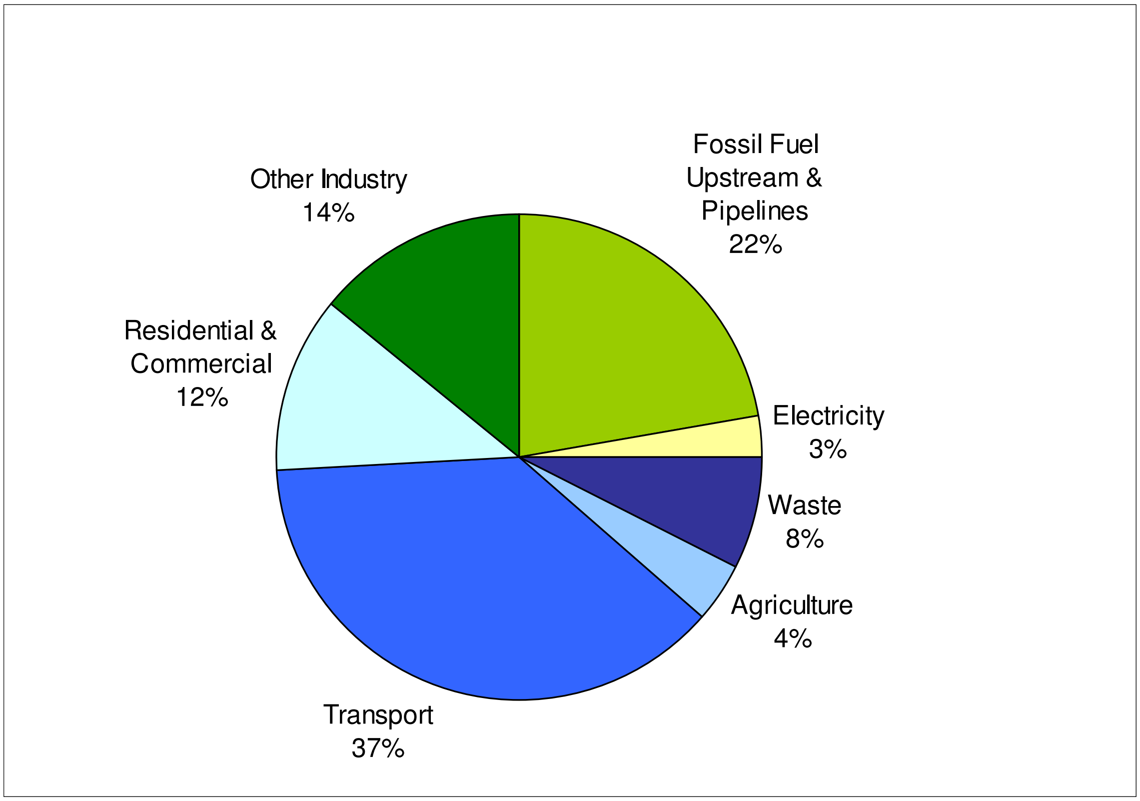
Source: Emissions data from Environment Canada (2007); population data from Statistics Canada.

Figure 15. Trends in total and per capita greenhouse gas emissions in B.C., 1990–2005.



Source: Emissions data from Environment Canada 2007; population data from Statistics Canada.

Figure 16. Greenhouse gas emissions in B.C. by sector, 2005.



Source: Environment Canada 2007.

Interpretation

Total greenhouse gas emissions for British Columbia rose 29.7% between 1990 and the end of 2004 (Figure 15, Table 6). This increase is slightly higher than the Canadian national average of 27%. The increase in emissions closely matched the provincial population growth of 28% over that period. There was a slight decrease in total emissions for B.C. in 2005, but it is too soon to tell whether this is the beginning of a longer trend.

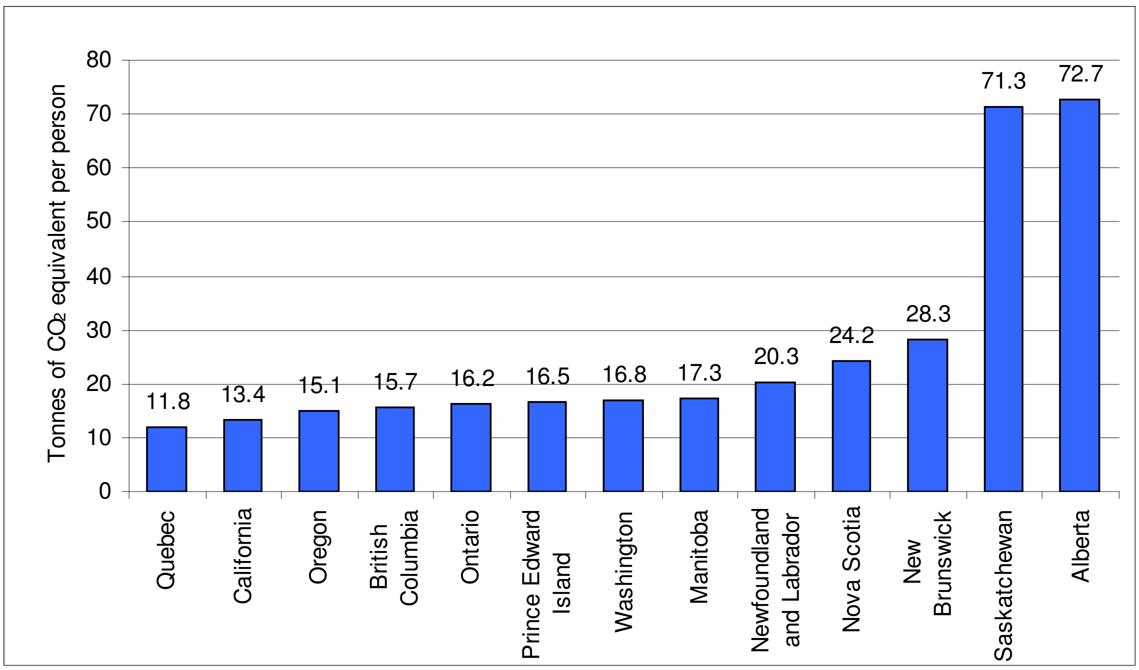
Of the various sectors, transportation has consistently been the largest source of greenhouse emissions (Figure 16). In B.C., transportation emissions have grown 42% since 1990, considerably faster than the national average of 30%. The transportation sector in B.C. produces a relatively larger fraction of total emissions (37% of the provincial total) than the national average (24%). This is because electricity generation and the home heating sector are relatively less important sources of greenhouse gases in B.C. Electricity generation for Canada is the source of 17% of emissions, whereas in B.C., which relies mainly on hydroelectric power, it accounts for only 3% of emissions.

Greenhouse gas emissions from industry, including the production of oil and gas, amount to 36% of B.C.'s total. In 2005, emissions from B.C.'s 10 largest industrial sources (e.g., natural gas plants, cement plants, aluminium smelter) accounted for almost 15% of B.C. total emissions.

Supplementary Information: How does B.C. compare with other jurisdictions in North America?

Greenhouse gas emissions per capita in B.C. are the second lowest in Canada (Figure 17). Emissions per capita are much lower in B.C. than in Alberta and Saskatchewan, largely due to B.C.'s abundant hydroelectricity. In Alberta, electricity generation and the production and refining of fossil fuels generate 72% of that province's emissions (Alberta 2005); about 50% of Alberta's electricity production comes from coal-fired generating plants. Saskatchewan's energy production industry, combined with a relatively low population, account for that province's high per-capita emissions.

Figure 17. Per capita greenhouse gas emissions for jurisdictions in Canada and the west coast US states.



Source: Canadian emissions data from Environment Canada 2007; 2004 population estimates from Statistics Canada; US data compiled by the Climate Change Section, B.C. Ministry of Environment.

Supplementary Information: Conventional and alternative energy sources in Canada

More than 80% of Canada's greenhouse gas emissions comes from the combustion of various types of fossil fuel. About half of the fuel emissions come from combustion of oil and petroleum products, and most of the rest comes from natural gas and propane (Environment Canada 2007).

Although the production and consumption of energy in Canada continues to rise, the use of oil, petroleum products, and natural gas cannot continue to expand indefinitely. Canada's production of natural gas, for example, reached a peak in 2005, and Natural Resources Canada projections show natural gas usage is likely to decline, especially after 2015 (NRCan 2006). Production of conventional oil in Canada is also expected to decline, with Alberta's oil sands becoming the main source of oil by 2020 (NRCan 2006).

Energy analysts do not agree on how long the recoverable supply of oil and gas can support the current demand (USGAO 2007). Regardless of whether more conservative or more growth-oriented predictions are borne out, analysts question whether the global atmosphere can safely accommodate the carbon emissions associated with burning the recoverable reserves (e.g., Foucher 2007; Witze 2007). Replacing a unit of oil-fired electricity with a unit of coal-fired electricity without sequestering the carbon will increase CO_2 emissions by 24% (Environment Canada 2006b). Carbon sequestration technology would capture CO_2 and dispose of it in long-term storage in the ground, but currently (2007), no coal-fired generation plants with a carbon capture and storage facility were in operation at full-scale (Chipman 2007).

Part of the solution is replacing conventional oil with fuels derived from plants and organic waste. Biomass combustion is considered to be carbon neutral because the CO_2 emitted on combustion was previously removed from the atmosphere as the biomass grew. Currently, B.C. leads Canada in the use of biomass for energy. The province has 50% of Canada's biomass electricity generating capacity. In 2005, the B.C. forest industry generated the equivalent of $150 million in electricity and roughly $1.5 billion worth of heat energy. The use of biomass has also displaced some natural gas consumption in the pulp and paper sector (BCMEMPR 2007).

Ethanol is another plant-based fuel made from starch, sugar, or cellulose from corn or other crops. It already replaces a portion of fossil fuels in motor gasoline. The B.C. Energy Plan will implement a 5% average renewable fuel standard for diesel by 2010 and will further support the federal action of increasing the ethanol content of gasoline to 5% by 2010. However, agricultural production limits the degree to which ethanol made from corn can be substituted into gasoline, and there are concerns that fuel with a high ethanol content may increase the smog from vehicles (Jacobson 2007). Pure ethanol has less energy content per litre than gasoline, therefore a car fuelled with a 10% ethanol blend burns more fuel to travel the same distance as a car running on pure gasoline. As a result, the net greenhouse gas emissions using ethanol blends are only 3–4% lower (NRCan 2007b).

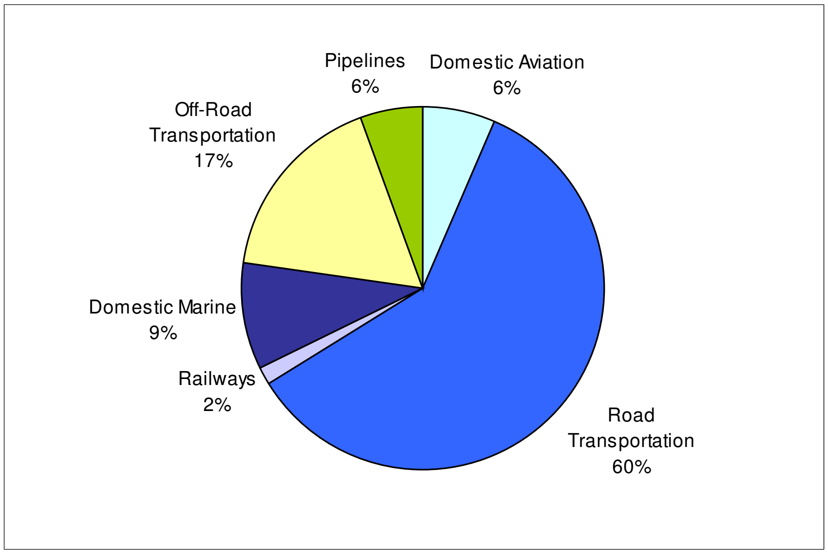
Methane gas captured from decomposing waste is being used to power electrical generators at a growing number of B.C.'s landfills. Power generation from renewable resources is increasing rapidly. Canada's installed wind energy generation capacity doubled in 2006, to 1,341 Mw (CWEA 2006). Although currently none of that installed capacity is in British Columbia, B.C.'s first wind plant is scheduled to bring 25 Mw of capacity online in 2007 (CWEA 2007).

7. Secondary Indicator: Trends in fossil fuel use in the transportation sector in B.C.

This is a pressure indicator, showing the trends in automobile types and use patterns in the province.

In B.C., the transportation sector is responsible for more than a third of all greenhouse gas emissions (Figure 16). Most (60%) of the emissions from the transportation sector come from road vehicles (Figure 18), and most of the road vehicle emissions (65% in 2005) comes from the light passenger vehicles (motorcycles, cars, pickups, minivans, and SUVs). Heavy diesels, such as transport trucks and buses, were the source of most of the rest of road transportation emissions (30%; data from Environment Canada 2006a).

Figure 18. Greenhouse gas emissions from the transportation sector in B.C. in 2005.



Source: Environment Canada 2007.

Emissions of CO_2 from road transport are directly related to how much fuel vehicles consume per kilometre and how far they are driven. This means that the type of vehicle people choose to buy has an important impact on greenhouse gas emissions. For example, when driven for 25,000 km, an average light truck or SUV produces about 2 tonnes more greenhouse gases than an average car. Based on data from Natural Resources Canada's Fuel Consumption Guide (NRCan 2007a), a new gasoline-electric hybrid car would produce about one-third the emissions of a new mid-sized SUV.

Methodology and Data

Data for this indicator were current up to the date obtained (January 2007) from Statistics Canada's CANSIM database (Statistics Canada 2007).

New vehicle sales data came from CANSIM Table 079-0001 (Figure 19). The figure shows sales in two classes of vehicles:

- Cars: regular passenger cars only, and
- Other: light trucks, heavy trucks and vans, buses and coaches. Sales of new pickups, minivans, SUVs and crossover vehicles, make up by far the largest proportion of the Other category (see Figure 19).

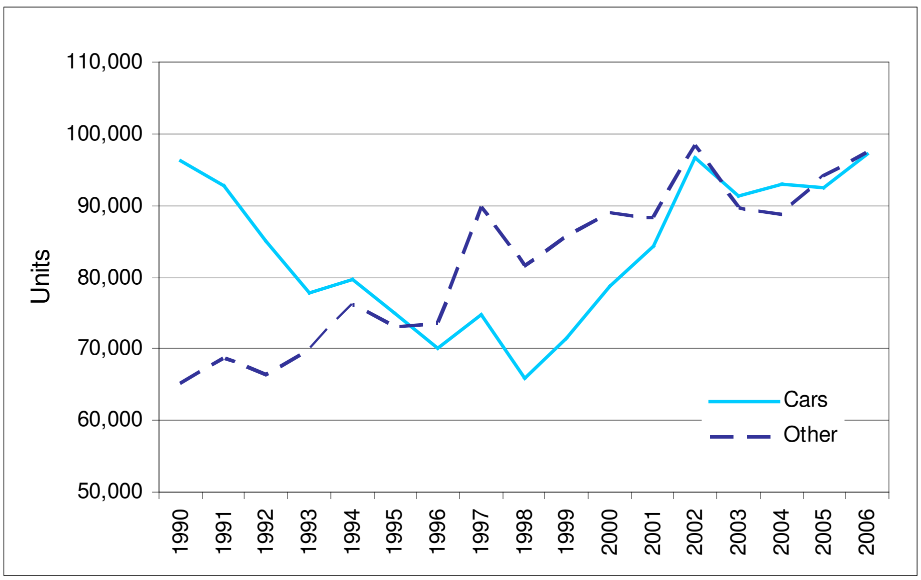
Data on kilometres driven came from CANSIM Table 405-0058 (Figure 20). Statistics Canada assembles the data from a representative sample of vehicle use logs collected using standard survey techniques.

Data on fuel prices came from CANSIM Table 326-0009 and driver registration data from CANSIM Table 405-0056.

Data on the number of licensed drivers in British Columbia were obtained from the Insurance Corporation of B.C.'s annual report series, B.C. Traffic Collision Statistics, available from *http://icbc.com/library/research_papers/traffic/index.asp* (downloaded January 2007).

Data on driver licensing in the United States came from the United States Department of Transportation, Federal Highway Administration (USDOT 2007), Unless another source is cited, the data used to calculate the statistics shown in this indicator came from the above sources.

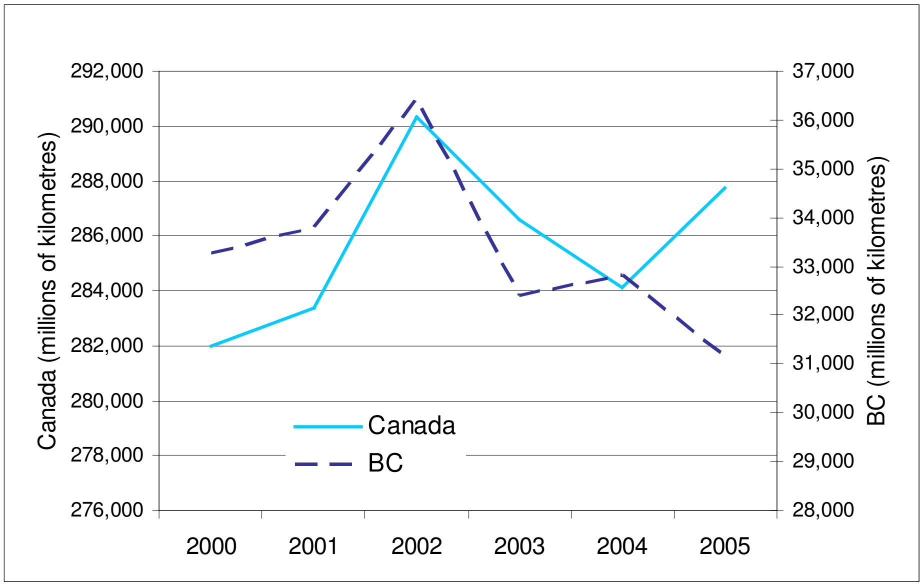
Figure 19. Number of new cars and other vehicles sold in B.C., 1990–2006.



Source: Statistics Canada CANSIM Table 079-0001. January 2007.

Note: "Cars" include regular passenger cars only. "Other" includes light trucks, minivans, SUVs, heavy trucks and vans, buses, and coaches.

Figure 20. Trends in kilometres driven in B.C. and Canada, 2000–2005.



Source: Statistics Canada, CANSIM Table 405-0058.

Note: Data are for light passenger vehicles (less than 4.5 tonnes gross vehicle weight), including all cars, SUVs, minivans and light pickups.

Interpretation

When new vehicle sales in B.C. were reported in Environmental Trends in B.C. 2002, sales of passenger cars had dropped to below 50% of the overall market (BCMWLAP 2002). The sales trend in B.C. during the 1990s was away from conventional cars and toward the light trucks category, which includes pickups, minivans, sport utility vehicles and, more recently, crossover vehicles. This shift meant that, despite a 5% improvement in fuel efficiency of the average new car between 1990 and 2002, the overall fuel efficiency of the average passenger vehicle actually dropped by 1% because more people were buying light trucks, SUVs, and other larger passenger vehicles (Environment Canada 2002). Since 2001 this trend appears to be reversing (Figure 19), and by 2006 passenger car sales were back up to 49.9% of all new vehicle purchases.

In both the car and light truck categories, the fastest growing market share is for smaller vehicles, with fuel-efficient, four-cylinder engines accounting for about half of new sales. It will take a decade or more, however, for today's fuel-efficient cars to replace the fleet of older, less fuel-efficient models now on the road.

The total distance driven by light passenger vehicles in B.C. also appears to be falling (Figure 20). Although total distance driven in B.C. and Canada peaked in 2002, the B.C. figure has continued to decline, while the Canadian figures rose again in 2005. The decline may be at least partly explained by a correlation with rising gasoline prices ($p = .07$) because Vancouver has among the highest urban gas prices in the country. The average price for gasoline was relatively stable from 2000 to 2002, but since then has risen from an average of about 70c per litre to as high as $1.10 per litre (in 2007) in Vancouver. Another reason could be the increasing population density in Vancouver's Lower Mainland, where construction of new high-rise buildings close to the city centre and transit routes has reduced the need to commute by vehicle.

Other statistics show a general decrease in automobile use in B.C. Despite the fact that the number of licensed drivers in B.C. increased from 2.75 million in 2000 to 2.91 million in 2005, the number of registered light passenger vehicles in B.C. dropped from 2.29 million in 2003 to 2.24 million in 2005. It is too early to say whether the drop in B.C. vehicle registrations is significant, but the provincial trend does not follow national registrations, which continued to increase during the same period.

In other areas, B.C. drivers also differ from other North American drivers. Using ICBC data for driver numbers and CANSIM registration data, calculations show that B.C. has a ratio of about 80 light passenger vehicles per 100 licensed drivers. No Canadian average was available, but in the United States, there are currently about 119 vehicles per 100 drivers (USDOT 2007). While the average American driver travels 22,600 km a year, adjusted for vehicle-to-driver ratio using data from USDOT (2007), calculations show that the average B.C. driver travels about half that distance, or only 11,200 km.

WHAT IS HAPPENING IN THE ENVIRONMENT?

The province has warmed since the 1950s, with the winter season generally experiencing the greatest increase in temperature. Warming since 1976, when the PDO last shifted to the warm phase, is evident over the whole province, and the rate at which temperature is changing is slowly increasing. Most of the province appears to have become dryer in winter and wetter in summer. There is some evidence that high-intensity rainfall events are becoming stronger and more frequent on the south coast. The ocean is slowly warming along the coast, and sea level is rising. Less snow generally lies on the ground in early April (although 2007 was an exception over much of B.C.), especially at elevations lower than about 1200 metres, and the warmer temperatures mean that spring runoff is coming earlier. Glaciers are generally retreating and losing mass over their annual cycle. Although the observed changes do not seem large, they have been accompanied by observable and in some cases, profound, effects on ecosystems, such as the devastating outbreak of mountain pine beetle in the interior of the province.

These changes have occurred because every year the concentrations of greenhouse gases from fossil-fuel combustion that largely drive these changes are increasing in the atmosphere. Greenhouse gas emissions in B.C. increased about 30% between 1990 and 2005, correlated with the growth in the provincial population.

Global climate models show that the increase expected in average global temperature is about 0.2°C per decade for the next two decades (IPCC 2007a). This short-term projection is close to the recent historical trend for British Columbia, which averaged an increase of 0.2–0.3ºC per decade. By mid-century, a regional climate model for B.C. suggests that winters could warm by 2–3ºC in the south and by 4–5ºC in the north. Summers could also warm by 2–3ºC. Regardless of the emission scenario used, all climate model projections suggest significant warming for the province by mid-century (see Pacific Climate Impacts Consortium climate overview at *www.PacificClimate.org*). Modelling suggests that for much of the province, winters will become marginally wetter and summers generally drier by the middle of the century. Extremes in temperature and, perhaps, precipitation events are likely to become more common.

The warming trend is also expected to continue through the last half of the century. Global climate models for the Pacific Northwest, using greenhouse gas emission scenarios corresponding to atmospheric CO_2e concentrations of approximately 620 and 860 ppm at the end of this century Baettig et al. (2007) project hotter conditions for the last 30 years of this century. These authors suggest that the B.C. region may experience 17 to 19 hotter summers and hotter years on average during the 2071 to 2100 period than occurred in the 1961 to 1990 period.

Examples of the effects and implications of climate change on this scale for British Columbia are many, complex, and sometimes surprising. Effects range from the direct effects of increasing temperature, such as a longer growing season, to possible changes to the geography of the landscape. For example, the frequency of large rockslides in northern B.C. appears to be increasing, partly as a result of increased precipitation and partly due to the thaw of mountain permafrost and the failure of steep rock slopes in response to glacier thinning (Geertsema et al. 2007). The following is a summary of some of the main effects.

- **Agriculture**: An increase in the length of the growing season would be favourable, but drier summers could limit crop production. Higher minimum temperatures, a longer growing season and fewer days of frost each year should improve the quality of grapes in the Okanagan (Caprio and Quamme 2002). However, for the Okanagan Valley as a whole, the projected crop water requirement could increase by 37% by the end of the century, making it likely that some water districts will be unable to meet the summer demand (Neilson et al. 2004).
- **Water Quality and Supply**: Changes in ambient air temperature, precipitation, and seasonal streamflow patterns are expected to affect water quality in inland freshwater rivers and streams. In general, rivers that get part of their water from snowmelt will see increased winter flow, earlier peak spring flow, and reduced summer flow as rising temperatures reduce the mountain snowpack. Such changes in timing of streamflow have already been observed in many streams and rivers throughout the Pacific Northwest (Hamlet 2006).

  Streamflow in low-elevation watersheds along the south coast responds directly to precipitation events and generally peaks in mid-winter. These basins are likely to be most affected by changes in October-March precipitation patterns. If winter precipitation increases, or precipitation intensity in individual storms increases, the annual and peak flows in such coastal basins would also change. The changes may mean an increase in the severity of floods and related impacts, such as erosion, damage to infrastructure, and loss of salmon spawn during periods of high river flow.
- **Pest Damage:** The range and impacts of insect pests and diseases, especially of forest trees, is expected to expand. The current mountain pine beetle outbreak in the interior of the province is a direct result of warmer winters that are no longer cold enough to kill the developing larvae (Safranyik and Carroll 2006). Vast areas of central B.C. pine forests have been killed and about 80% of the province's mature lodgepole pine are expected to die by 2013 (Eng et al. 2006). A disease of lodgepole pine, *Dothistroma* needle blight, is also expanding, causing extensive mortality of pine in the northwestern part of the province. In this case, a local trend of increasing summer precipitation appears to be responsible (Woods

et al. 2005). Climate change may also be favouring outbreaks of the Western spruce budworm in the interior Douglas-fir forests (Campbell et al. 2006).

Non-native pests are also expected to expand their range in the province. Insects such as the Asian gypsy moth, the Asian long-horned beetle, and the European wood wasp have the potential to spread in southern B.C., causing more damage as the climate warms (Hunt et al. 2006). The same is true of leaf and root diseases, such as sudden oak death (*Phytophthora ramorum*) and needle blights, which are likely to become more widespread in a warmer and wetter climate (Brasier 2005).

- **Salmon Fisheries:** Warmer river temperatures have serious implications for salmon, whose life cycle is adapted to cool and intermediate temperatures. Sockeye salmon migrate more slowly at temperatures above 18ºC, and show increasing stress with higher temperatures. Chronic exposure to 21ºC causes severe stress and early mortality. Such temperatures are now being experienced: the temperature in the Fraser River at Hope was above 21ºC for several days in a row in 2004 (DFO 2007a).

- **Ocean Productivity**: The B.C. coast is affected directly by changes in the ocean conditions that affect fisheries, change the pattern of ocean currents, and have other effects. Every day, oceanic phytoplankton fix more than 100,000 tonnes of carbon in the form of CO_2, which is roughly half of the Earth's net primary production. Most of this carbon cycles within the ocean's food web, sinking downward as particles and returning upward in the form of dissolved nutrients. With global surface waters of the ocean now warming faster than the deep ocean, there is less vertical mixing and therefore a smaller supply of nutrients to the surface. Research shows that warming since 1998 has reduced the amount of carbon fixed in the ocean by a very small amount, probably because the nutrient supply has diminished (Behrenfeld et al. 2006).

  Over the 21 century, the acidity of ocean water is expected to more than double. As the ocean becomes warmer it becomes more acidic (increasing CO_2 leads to an increase in carbonic acid). Increased acidity erodes the calcium carbonate skeleton that protects many marine organisms, especially plankton (e.g., Riebesell et al. 2000). The increasing acidity also represents a threat to B.C.'s coral reefs.

  Studies show that dissolved oxygen is declining in deeper layers of water in the ocean. The summertime oxygen content in the layer 100 to 200 metres below the surface has declined slowly for at least the last 50 years. This is the result of decreased circulation of oxygen-rich waters from the surface, as the surface ocean waters become fresher and warmer faster than the deep ocean. Although not yet observed off the B.C. coast, low-oxygen water upwelling onto the continental shelf south of B.C. has sometimes caused massive marine mortality (DFO 2007b).

END NOTE

This background paper departs from the format of the other six papers that comprise the Environmental Trends in British Columbia: 2007 report in that the indicators section is not followed by sections about what is being done about the issue and what individuals can do. These areas are changing very rapidly as programs are being developed to address all aspects of climate change from adapting to the consequences of a changing climate to reducing emissions of greenhouse gases.

For the most recent information on what is being done and current links to initiatives, programs, and recommendations for action please refer to the webpages associated with this report. For more information, go to the B.C. Climate Change Secretariat website.

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