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Gabriola's changing climate and its effect on groundwater

by Nick Doe

Changing climates are fashionable, so I thought I'd look specifically at Gabriola's. Before talking about future changes in Gabriola's climate, it might be as well to first look at what appears to be happening right now. To keep things simple, I'll forget about wind, snow, fog, hours of sunshine, cloudiness, and things like that, and only talk about:

- temperature and its seasonality. Is "Gabriola warming" for real? …and if so, how is this reflected in changes in summer and winter temperatures; and
- precipitation and its seasonality. Is there a trend, and are we already getting more rain in winter and less in summer, as some climate models predict?

After that, I'll move on to predictions for climate change, and consider the possible effect of changes in temperature and precipitation on groundwater.

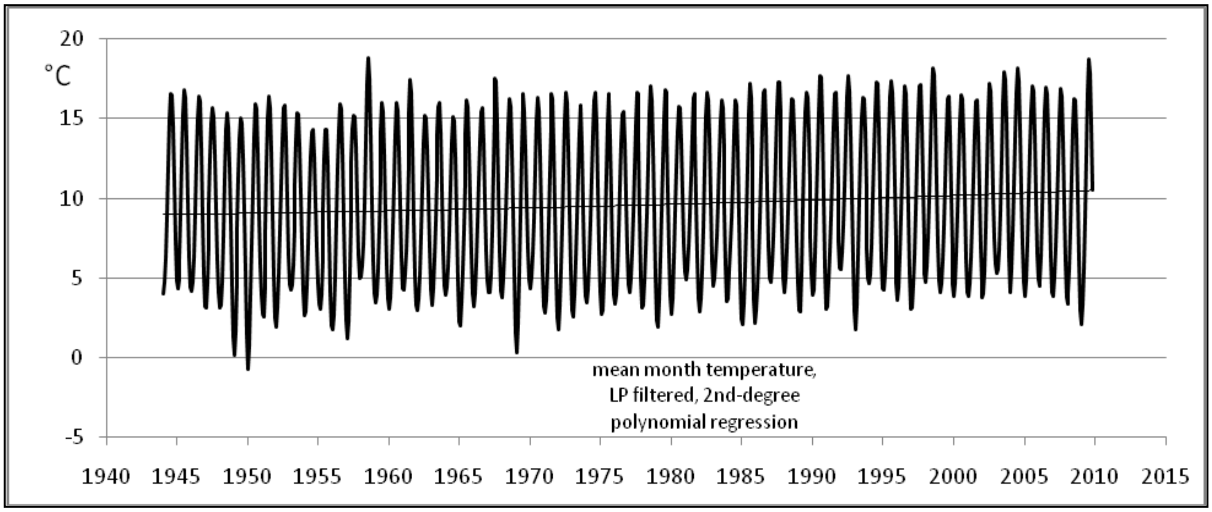
Current temperature trends

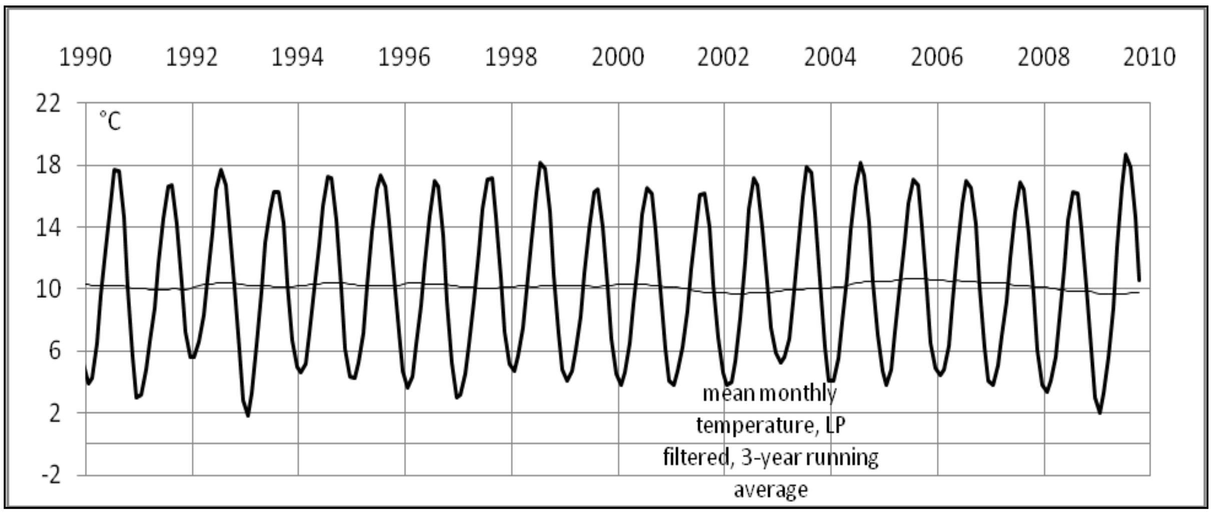
All of us have in our own way, I'm sure, noted that temperatures are increasing. Some birdwatchers I was talking to recently noted that Anna's hummingbirds are becoming more common on Gabriola in winter. Back in the 1940s, they weren't found north of California. My own personal list of "casual observations" includes:

- vultures, once rare, are now common in summer
- the sea doesn't freeze anymore
- some flowering plants in our "annuals" tubs survive the winter
- cedars show more "red-flagging" than they used to at the end of summer
- red tide hangs around longer and sometimes extends into the late fall
- kelp beds are diminishing. Although nobody is sure why, it may in part be due to higher water temperatures
- there is an increase in the frequency of blooms of bioluminescent marine organisms in False Narrows (to my delight) in late summer; and
- I worry much less than I used to about putting antifreeze in the car.

Over twenty years ago, I visited northern BC, the Yukon, and the Alaska Panhandle and remember being told by park guides that although most of the many glaciers in the region were retreating, there were some on the seaward side of the mountain ranges that were advancing. This summer (2009) when I again visited the area, I had an opportunity to talk with glaciologists and other scientists at the Glacier and Environmental Research facility in Atlin. They told me that all glaciers in the area, *without exception*, are now in retreat. What were formerly counted as "advances" were "surges" engendered by increased snowfall and by meltwater lubrication of the base of the glaciers.

Based on analyses of changes in glaciers over the past few thousand years, they consider that current conditions ought to be favouring the growth of glaciers. There are estimates that all the glaciers in the region, a UNESCO World Heritage Site including four parks—Kluane/Wrangell-St. Elias/Glacier Bay/Tatshenshini-Alsek—will be gone by 2070.





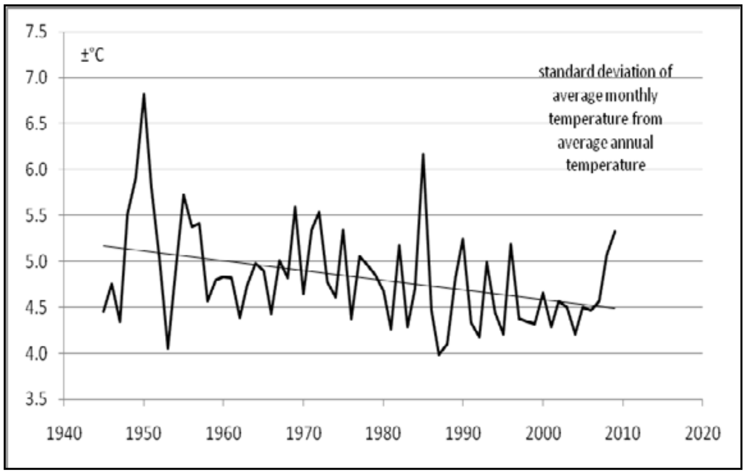
Mean monthly temperatures for Nanaimo Airport. *Above* for 1944–2009 with a 2nd-degree polynomial trend, and *below* for 1990–2009 with a 3-year running-average trend. The monthly readings have been digitally filtered* to remove abrupt month-to-month changes. The long-term trend shows temperatures have been rising since at least 1944, even though the rise is not what one might call "dramatic".

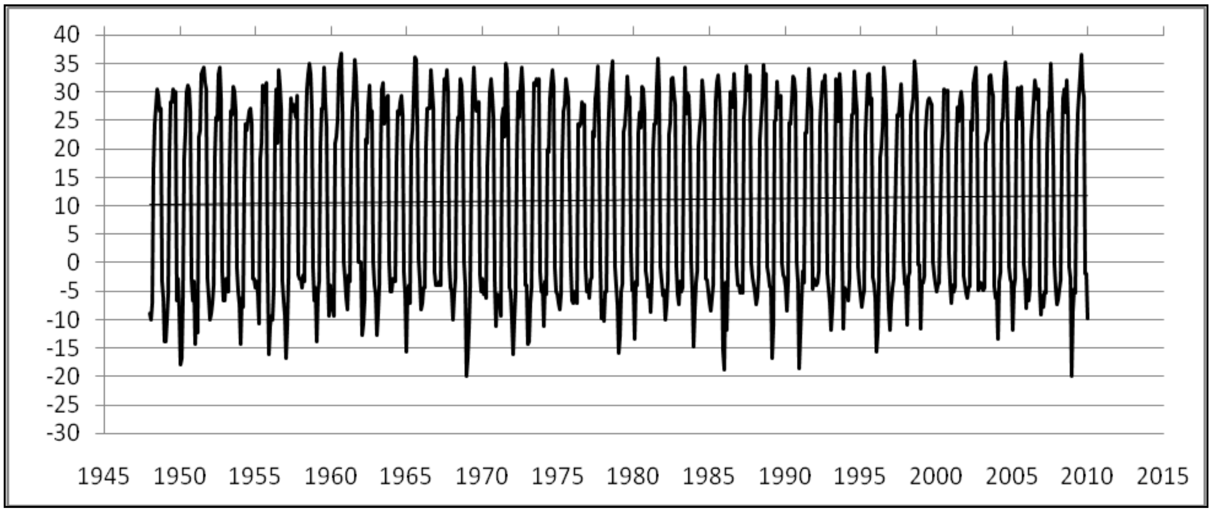
* $y_n=(1/16)(x_{n-2}+4x_{n-1}+6x_n+4x_{n+1}+x_{n+2})$

An analysis of mean monthly temperatures from 1944 to 2009 for Nanaimo Airport shows a statistically-significant warming trend of +0.23°C per decade, and also, rather surprisingly to me, a detectable acceleration in the warming over the past decade, as reported for global temperatures by climate scientists.

The mean annual temperature on Gabriola was 9.0°C in 1949; 9.6°C in 1979; and 10.5°C in 2009.

At the observed rate of warming, using 2nd-degree polynomial regression, it will be 11.7°C in 2040. By then, the temperature at the top of a thousand-foot mountain will be what it was at sea-level in 1949. On Gabriola in 2040, temperatures will be about what they are now in Portland, Oregon.



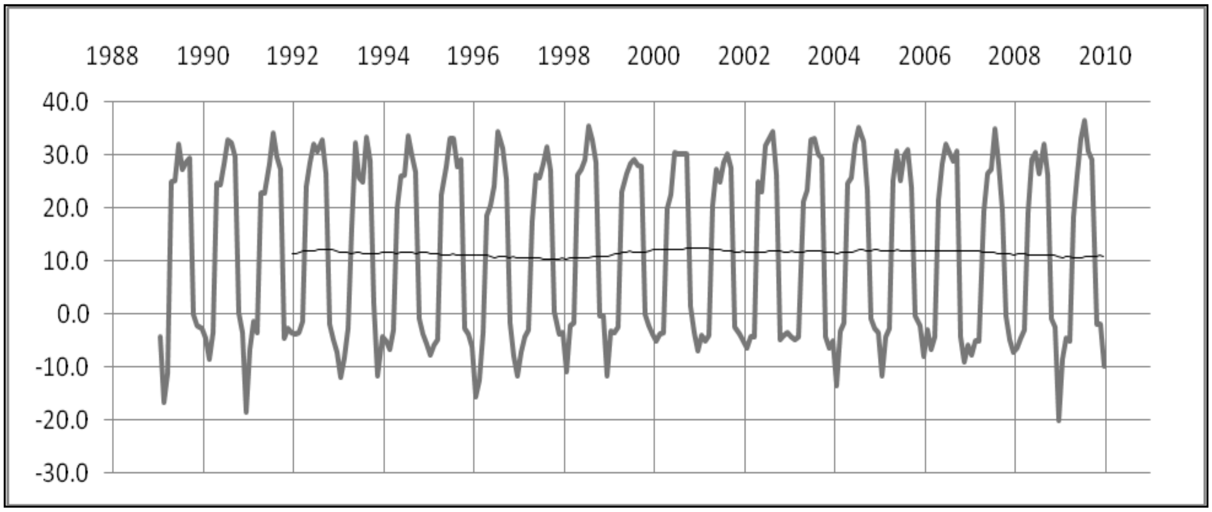


Top: The seasonality of temperature defined as the standard deviation of the mean monthly temperatures from the annual mean temperature for each year, after adjustment of each year's mean monthly temperatures to the same annual mean. No filtering, °C for Nanaimo Airport. The linear trend shows that the seasonality is decreasing—the difference in the mean temperature for one month and any other month in the same year is less than it used to be when long-term changes in mean annual temperatures are discounted.

Below: Extreme temperatures. The highest temperature °C in each of the six summer months, and the lowest temperature in each of the six winter months, unfiltered. Although there is a rising temperature trend (2nd-degree polynomial trend shown), it is easily masked by the variation from year-to-year. Very cold winter days still occasionally occur despite the warming trend, and there's little indication that "the hottest day of the year" is getting hotter.

To check the seasonality of the temperatures over the 1944 to 2009 period, I looked at the standard deviation of the mean monthly temperatures from the mean annual temperatures. A low standard deviation would signify relatively little difference between summer and winter temperatures; and conversely a high standard deviation would mean a greater difference between summer and winter temperatures.

The observations show that temperature seasonality is decreasing. A look at the extreme temperature records—that is the very highest and very lowest temperature for each month—gives a clue as to why.



The highest temperature °C in the summer months (Apr.-Sep.), and the lowest temperature in the winter months (Oct.-Mar.), unfiltered. There's no sign of a trend (3-year running average shown), but what's notable is the run of four winters beginning 1999/2000 during which there was not a single "very cold" day.

Extremely high summer temperatures show no increase in value over the 65 years. It is as if there were a cap on the maximum temperature at around 35°C, probably due to the moderating effect of the ocean.

Extremely low winter temperatures similarly show no decrease in value over the 65 years; however, what is striking is that the number of days on which the temperature is very low has declined in recent decades—strings of winters without a very cold day are more likely. In spite of the warming trend, we can still expect the occasional –20°C winter day, but such days are occurring less often.

One lesson I learned in looking at these statistics is that extreme maximum and minimum temperatures are not a good guide to average trends. A very hot summer day, or a very cold winter day, isn't by itself a good indicator of the general climate trend on Gabriola. It might be, and probably is, different away from the sea.

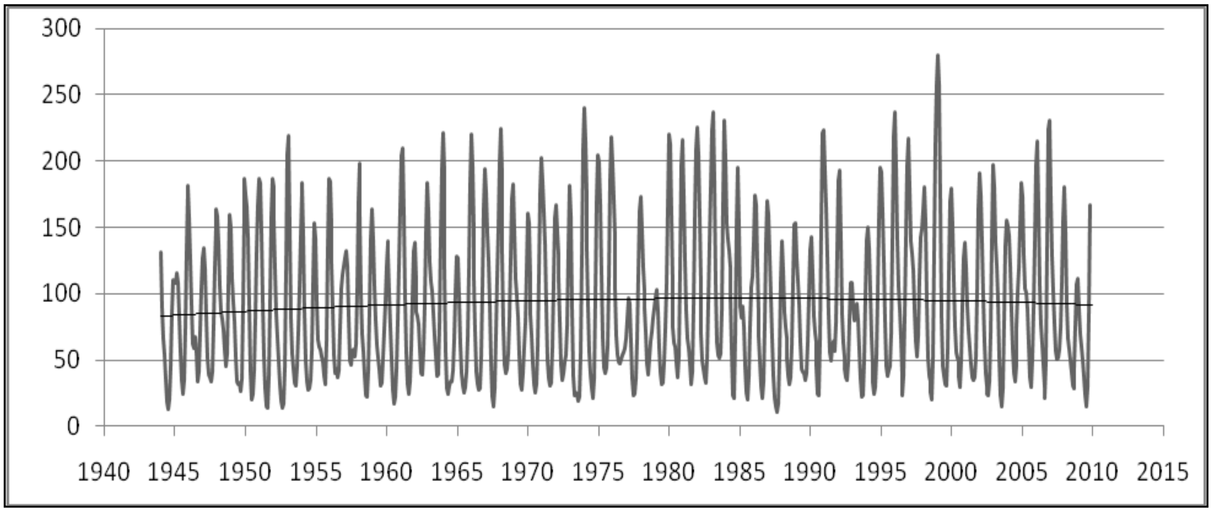
There is absolutely no doubt however that Gabriola along with the rest of the world is getting warmer.

Current precipitation trends

An analysis of monthly precipitation from 1944 to 2009 for Nanaimo Airport shows what might be an upward trend of +15.5 mm per decade; however, if so, it has decreased in recent years and there is no knowing what it will do in future. Currently, the total annual precipitation, using second-degree polynomial regression, is about 1102 mm. In 1949, it was slightly less at about 1032 mm, and in 1979 it was slightly more at 1153 mm.

To check the seasonality of the precipitation over the 1944 to 2009 period, I looked at the standard deviation of the monthly precipitation from the annual mean precipitation. For each year, I normalized the actual precipitation to a standard 1000 mm. A low standard deviation would signify relatively little difference between summer and winter rainfall; and conversely a high standard deviation would mean a greater difference between summer and winter rainfall.

The observations show no trend at all in seasonality. The division between summer



Monthly precipitation mm for Nanaimo Airport. The record has been digitally filtered as before to smooth out abrupt changes from month to month. The thin line shows the 2nd-degree polynomial regression. Cyclical long-term variation is evident, but there's no statistically significant steady increase or decrease over the sixty years.

and winter rainfall is very variable from year-to-year, but there is no long-term change in this division that I could detect.

Future climate

Seven years ago, Justine Pearson—who is now a Gabriolan—wrote an article on "climate change". In it, she expressed her thoughts on the possible changes to Gabriola's environment it might bring. It was published in *SHALE* 5 in December 2002. The following is a summary of information that has become available since then. Practically all that Justine wrote still applies.

The IPCC

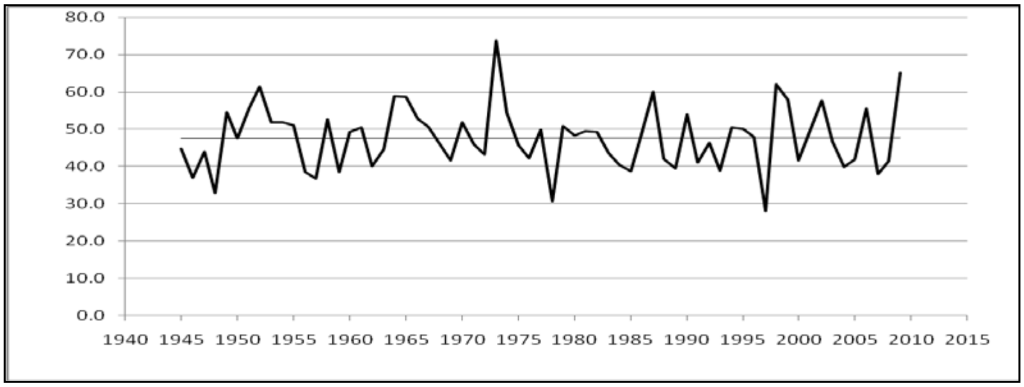
By far the most authoritative and comprehensive source of information on "global warming" is the Intergovernmental Panel on Climate Change (IPCC). The IPCC was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988.

The IPCC has now issued four assessment reports. The first was in 1990, the second in 1995, the third in 2001 (TAR), and the fourth in 2007 (AR4). This note focuses on Working Group I, as did the *SHALE* 5 article. Working Group I assesses the scientific basis of climate change and the group's conclusions in AR4 are based on critical reviews of several thousand peer-reviewed technical papers published by experts from many different, but related scientific disciplines, a fact worth remembering when listening to the forcefully-expressed opinions of those with little science background of their own.

IPCC WG1 AP4

Few, if any, of Working Group I's views have been substantially altered in the past six years, but there have been improvements in the quality of the data and in the confidence in the predictions of climate models. Significant advances have been made in the simulation of past climate variations.

The IPCC's 2007 report notes in its executive summary that:



The seasonality of precipitation defined as the standard deviation of the mean monthly precipitation from the mean annual precipitation in millimetres after normalization to 1000 mm per year at Nanaimo Airport. The linear regression trend shows no change in seasonality.

Warming of the climate system is now unequivocal. This is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea-level, which is now twice the rate it was in the 20th century.

Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in greenhouse gas (GHG) concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica.

Advances since the TAR (in 2001) show that discernible human influences extend beyond average temperature to other aspects of climate [such as heat waves, droughts, floods, and hurricane intensity].

Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change.

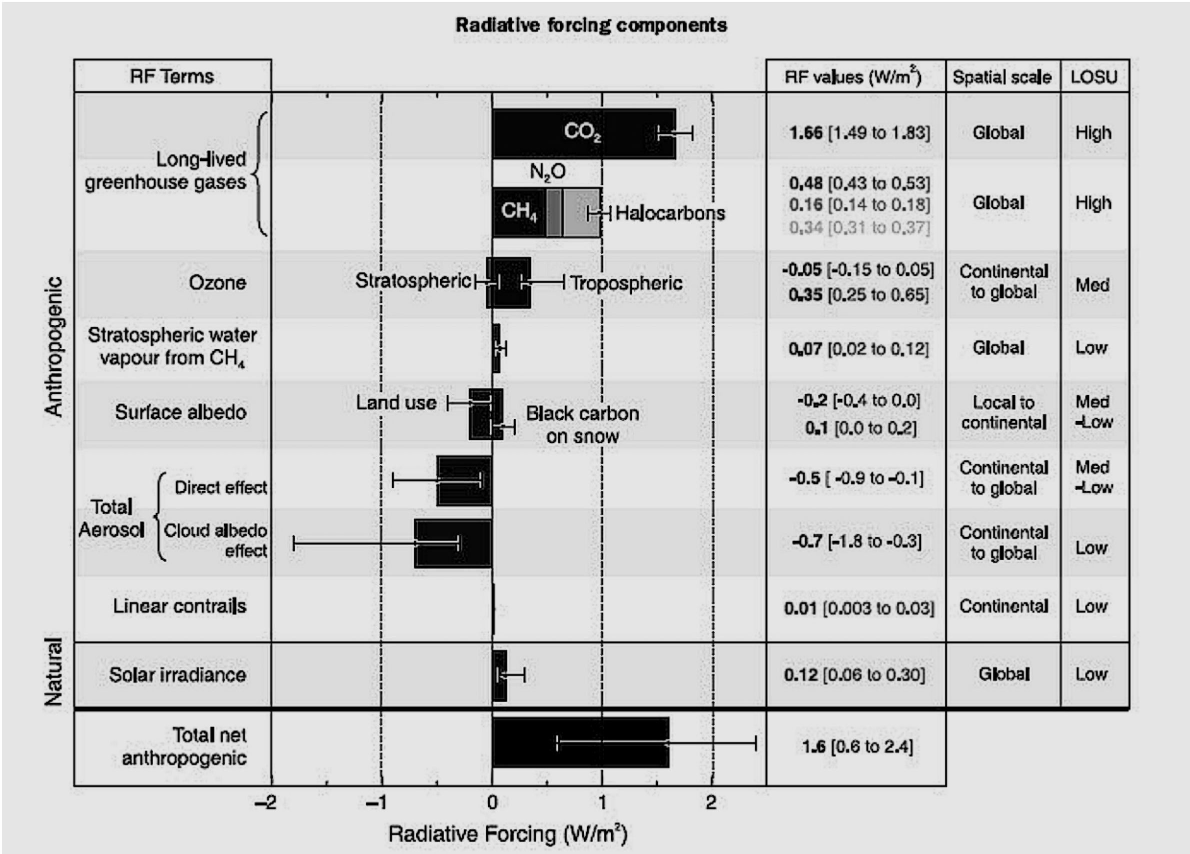
Climate change—the scientific basis

During the last century (1906–2005), the earth's global surface temperature warmed by 0.74 ±0.18ºC, with much of the warming occurring since the 1980s. Three different global estimates all show consistent warming trends. There is also consistency between the data sets in their separate land and ocean domains, and between sea-surface temperature and night-time marine air temperature.

According to practically all atmospheric scientists, the only plausible explanation for this warming is that it is primarily a consequence of the increasing concentrations of greenhouse gases in the atmosphere. The simultaneous increase in energy content of all the major components of the climate system shows that the cause of the warming is *extremely unlikely* (<5%) to be the result of any other process.

Natural and other non-greenhouse gas drivers of climate that *might* be contributing to the warming include:

– changes in the earth's orbit
– an increase in solar irradiance
– a decrease in volcanic activity
– changes in cloudiness
– changes in cosmic ray ionization
– changes in concentrations of aerosols of sulphates, nitrates, and mineral dust
– changes in concentration of ozone
– effects of aviation contrails and cirrus



The contribution to global temperature change by the various factors that determine global temperature (energy from the sun; reflection, absorption, and emission of energy within the atmosphere and at the earth's surface). Factors with contributions on the right are increasing global temperatures; and on the left are cooling. The bottom line shows the total net anthropogenic contribution, which is positive. The match between this estimate and observed temperature rise is good. The LOSU column on the right is the "level of scientific understanding".

Climate Change 2007: The Physical Science Basis, contribution of WG1 to the IPCC 4th assessment report.

– more dirt deposits on snowpack
– more non-GHG energy production
– changes in land use; and
– urbanization.

All of these have been examined in detail and all have been found to have made either too little a contribution to the warming, or to have slowed down the warming by having a cooling effect.

Recent changes in temperature are greater and faster than have occurred at any time in the past thousand years or more, and are matched by increasing concentrations of atmospheric carbon dioxide and methane that now far exceed pre-industrial values found in polar ice-core records of atmospheric composition dating back 650,000 years.

Questions, resolved and unresolved

One of the questions that one was able to pose six years ago was "is global warming" happening?" There is now no doubt that it is. The evidence for it is abundant and comes from a wide variety of sources.

Another question that has been resolved is whether warming is a result of increased solar irradiation. Satellite observations of the sun's irradiance now cover the last 28 years and there is consequently a better understanding of the variation during the well-established 11-year sunspot cycle. No significant long-term trend in variation of solar irradiation has been observed.

What until very recently appeared to be an anomaly, much cited by contrarians in their Internet blogs, is that ice is getting thicker in the east Antarctic, even though it is thinning in the west. This increase is now known to be due to increased precipitation, one of the forecasted effects of global warming in the coldest parts of the planet, and to the effect of the hole in the ozone layer, which is expected to diminish in future years. This growth spurt in the size and thickness of the ice sheet now appears to have come to an end, and starting in about 2006, ice in east Antarctica started to thin, just as it has everywhere else in the world.

The rate of global warming has recently (1998–2008) decreased somewhat, but this is probably consistent with strong short-term weather patterns temporarily masking the longer-term trend. A decrease in the rate of warming I should note, is not the same as a cooling (the rate is not negative), which is what some media commentators seem to think. Climate change does not entail a steadily increasing temperature everywhere, or at every level of the atmosphere. Some parts of the world, including parts of the southeast USA and parts of the North Atlantic have, in fact, cooled slightly over the last century. An enhanced greenhouse effect is expected to cause cooling in higher parts of the atmosphere because the increased "blanketing" effect in the lower atmosphere holds in more heat, allowing less to reach the upper atmosphere.

Sceptics

Although a handful of scientists still consider that the contribution of GHG to global warming has been exaggerated, they are increasingly hard pressed to explain what is causing the current warming, and why the current warming trend shows no sign of reversing, which presumably it would if it were a natural phenomenon. The degree of the current warming and its nature are unprecedented. It could not possibly be caused by such slowly-changing factors as the geographical distribution of the continents or changes in the earth's orbit, which explain why the earth was sometimes much warmer in the geological past than it is now.

Conservative commentators in Canada and the USA have long challenged IPCC reports as reflecting the "scientific consensus" on global warming by highlighting the views of a small number of contrarians who question the IPCC's conclusions. One result is that, in their efforts to provide "balanced coverage", the North American media have given disproportionate attention to the sceptics, creating the impression of less consensus on global warming than exists within the scientific community. Evidence of that consensus was provided in 2009, when the National Academies of Science of thirteen countries, including Canada, China, France, Germany, India, Russia, the UK and USA, urged acceptance of IPCC reports and stressed the need for urgent action.

Much of the content of letters and petitions from dissenters does not cite hard scientific contributions, but rather consists of personal opinions, complaints from scientists that their views have been ignored, arguments based on old science already accommodated in the IPCC evaluations, or data that has been cherry-picked to present a false picture when not seen in its proper context.

The Internet and popular media unfortunately provide a mix of mainstream opinion, pseudoscientific interpretations, masses of misinformation, demonstrations of ignorance, and pure nonsense presented as fact, often seemingly designed to appeal to those with a poor science education, and often by people who appear not to have even read what atmospheric scientists and climatologists are observing and concluding from their observations.

Future global trends

The IPCC predictions of future global trends for the 21st century are:

virtually certain (>99% probability)

- fewer cold days
- more frequent hot days

very likely (>90% probability)

- more warm spells and heat waves
- more heavy precipitation events

likely (>66% probability)

- increase in areas affected by drought
- more intense tropical cyclone activity
- increased incidence of extreme high sea level.

Available evidence indicates that the current warming will not be mitigated by a natural cooling trend towards glacial conditions. Understanding of the earth's response to orbital forcing (Milankovitch cycles) indicates that the earth will not naturally enter another ice age for at least 30,000 years.

Volcanic aerosols perturb climate and a single eruption can cool the global climate for a few years. Many past volcanic events are evident in ice-core observations; yet, there are no indications that such events or their absence influences climate change in other than the short term. Recent volcanic activity and its aftermath was relatively high in the periods 1880–1920 and 1960–2000, but was quiet during the intervening periods, particularly 1940–1960. Nevertheless, the possibility does exist of an eruption or series of eruptions much larger than has ever occurred in historic times, which will have a corresponding longer-term influence on climate.

Changes in temperature in the past are likely attributable in part to long-term variations in solar irradiance, such as reduced irradiation during the Maunder minimum (1645–1715 AD), which coincided with the middle and coldest part of the Little Ice Age. Whether there is a causal connection between low sunspot activity and cold winters is the subject of ongoing debate. Some sceptics won't be convinced that global warming is not natural until we have a better understanding of long-term variations in solar irradiance, which is fair enough, but it is not an easy topic to research because of the lack of historical (pre-satellite) measurements.

In the absence of any major naturally-caused climate-changing events, it is estimated that global-warming trends would continue unabated for at least the next twenty years even if there were no increase in GHG emissions starting today.

Regional effects

While climate models have successfully captured the broad features of climate change, they remain weaker and less consistent at modelling regional trends, particularly where climate is generated by local topography. There is a gap between what can be achieved with very long-range weather models and very short-range climate change models. Climate models remain limited by the spatial and temporal resolution that can be achieved with present limited computer resources.

Here on the west coast, uncertainties as to the effects of climate change persist because of a relatively poor understanding of some long-term weather patterns out in the Pacific. The creation and dissipation of clouds, especially low clouds, and their effect on the heat balance remains a source of uncertainty. Surface and satellite observations disagree on total and low-level cloud changes over the Pacific Ocean.

The short-term decadal variability of the weather due to Pacific Decadal Oscillation (PDO) and to lesser degree El Niño-Southern Oscillation (ENSO) events may or may not change. Lack of agreement between various climate models precludes a definitive projection, and the link between these events and longer-term global warming is not clear and is controversial.

These events currently mask perception of long-term climate trends along the Pacific coast—some summers, for example, can be quite cool, and some winters quite dry, in spite of global warming. At times, heat is being absorbed by deep ocean water, well away from prying thermometers.

Future local trends

The likely consequences of climate change locally are:

- temperatures will increase. A prediction is that the rise will be between +0.6°C and +1.9°C by 2020. One of the several effects of this will be a higher risk of wildfires, a serious consideration for Gabriola because a major component of its natural Coastal-Douglas-fir-zone ecology is fire
- there will be a longer frost-free season
- sea-level will rise but not in accordance with global sea-level because land levels locally are not stable. Along western Vancouver Island, stress by the Juan de Fuca tectonic plate as it descends beneath North America results in uplift that will eventually be reversed by a major earthquake during which subsidence of up to two metres is possible. This effect diminishes moving east across Vancouver Island and is reversed in the Fraser Delta, which is sinking due to sediment compaction. It is there that sea-level rise will be most severe.

  In the Gulf Islands, sea-level rise will mean increased salt-water intrusion into wells along the coast
- there will be an increase in frequency and intensity of winter storms. This will be a major contributor to coastal erosion. It is not generally appreciated how much atmospheric pressure affects sea-level during a storm. Low atmospheric pressure commonly raises sea-level above the level predicted in tidetables by a foot, and this is often intensified by gale-force winds
- there will be changes to local ecosystems. Some species will prosper or be new arrivals on the island; others will be stressed and may virtually disappear. Salmon and cedar in the southern Strait of Georgia are likely to become endangered. On Gabriola, Western hemlock will probably go, but, based on early- to mid-Holocene paleobotanical evidence, we may see the return of Oregon ash
- insect outbreaks will intensify with drier soils, which many agricultural pests prefer
- there will be an indeterminate, quite possibly only small, change in net annual precipitation—predictions range between –9% and +12% by 2020—but winter precipitation will tend to increase and summer precipitation to decrease.

Bottom lines

Compared with other parts of the world, Gabriola's climate is likely to be only moderately affected because of its existing temperate climate and the limiting effect of the ocean on weather extremes. Gabriola as an economic entity, however, depends more than it sometimes cares to admit on the state of off-island economies, which are expected to be severely impacted by climate change.

For several thousand years during the hypsithermal period, ending about 4000 years ago, temperatures in southern BC were above those of the present day and conditions were drier. Rainforests are a surprisingly "recent" development in local ecosystems. Global warming may thus be returning us to climatic conditions that existed here in the past. If so, we can expect rainforests to revert to scrubby grasslands and savannahs dominated by Garry oaks or Douglas fir. Smaller islands will lose all their trees. We won't be alone in these far-reaching changes—the province as a whole, for example, is looking at the loss of 80% of its pine forests.

Groundwater

Groundwater will decrease. The several reasons for this are:

- run-off in creeks during intense rainfall periods will be greater
- groundwater seepage will be accelerated following days of heavy rain due to backup in the downward movement of water through the rocks
- evaporation in summer will increase as summers get warmer
- a longer growing season will result in an increased demand for soil moisture by plants.

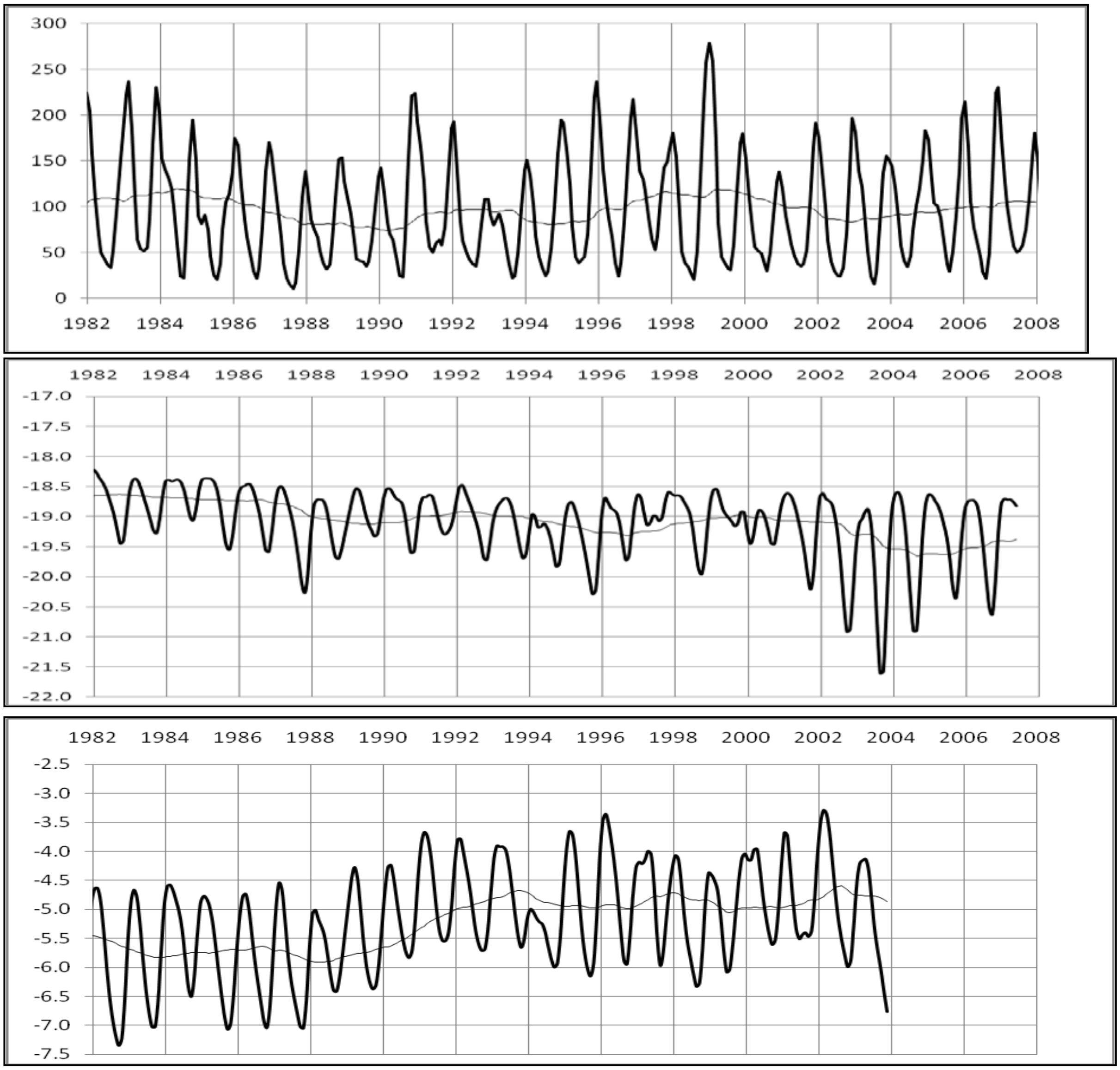
It is uncertain whether total annual precipitation will change, and if it increases, whether the increase will be sufficiently large to offset these factors—almost certainly not. Portland, Oregon's current annual precipitation for instance is 922 mm, which is less, not more than ours.

A look at variations in the height of the watertable in past years adds something to these observations. It looks to me that the "wells-going-dry" phenomenon is linked to the nature of our aquifers. These are, as most people know, fractured bedrock, or they are "perched aquifers" supported by beds of clay.

What is observable in the graphs on the next page is that some aquifers have a well-defined maximum capacity. This is consistent with them being rather like a saucer. When the saucer is full, adding water just causes it to spill over the brim, and in real life, run off in ephemeral creeks. This is bad news if precipitation in fact does become more intense in winter at the expense of precipitation at other times of the year.

Another characteristic of Gabriola's aquifers is demonstrated in the graphs—the relationship between yield and the height of the watertable. In an idealized aquifer, the drawdown—the drop in the height of the watertable—that results from the withdrawal of a certain fixed volume of water remains constant, and continues indefinitely. In Gabriola's aquifers however, because they have a finite and sometimes quite small capacity, the drawdown may sharply increase as the watertable gets lower and exhaustion of the aquifer approaches.

Think of it this way. If you take gulps from a conically-shaped glass—a Martini glass for example—the drop in the level increases with each gulp, and increases rapidly as the level approaches the bottom of the glass—you may have noticed this.



Top: Monthly precipitation for the last 26 years for Nanaimo Airport. The record has been filtered as before to smooth out month-to-month changes. The thin line is the 3-year running average.

Middle: Variation in watertable height m at Hydrographic Observation Well 194 (Emcon yard).. The trend lines are three-year running averages. Note the apparent “cap” on height and that a small decrease in precipitation can sometimes lead to a disproportionate drop in watertable.

Bottom: Variation in watertable height m at Hydrographic Observation Well 197 (North Road). The greater sensitivity to precipitation suggests this aquifer has rock with a lower porosity than the one in the Emcon yard.

Small reductions in recharge and small increases in withdrawal from some aquifers can therefore lead to disproportionately large drops in the watertable once the watertable is low. It happened in the summer of 2009, and it’s a fair bet this will happen more often in future. ◊