Climatic changes along the Canadian Cordillera during the last thirty years based on actual measurements and the need for continuing monitoring.

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Abstract: Over the last thirty three years, a network of climate stations has been set up at high altitude mountain permafrost sites from Plateau Mountain near Claresholm, north to Sheldon Lake on the North Canol Road in the Yukon. Taken together with the data from the US National Weather Service and the Canadian Atmospheric Environment Service, the results indicate a cooling of mean annual air temperature south of Calgary, no significant change in Calgary, a slight warming at Jasper, and a major warming at Summit Lake, west of Fort Nelson. In contrast, the southern Yukon shows only minor warming that lies well within the limits measured by the Atmospheric Environment Service for a sixty year record. Along the Mackenzie valley and on the North Slope of Alaska, the mean annual air temperature is rising. It therefore appears that changes in climate vary considerably from place to place, and even where warming may occur, it may not continue indefinitely. Careful monitoring of the climate needs to be continued and expanded in the National Parks in the mountains in order to provide factual data on any changes that may be taking place. This data can then provide a sound basis for interpreting ecological and other weather-related data. The existing climatic models are not working satisfactorily because we do not know enough about the causes and processes involved in climatic change.

Introduction.

There are very few weather stations with long records that are maintained along the Rocky Mountains in Alberta. Those that exist and have 30 years or longer records that are maintained by the Atmospheric Environment Service are located on the valley floors near or in settlements, e.g., Banff and Jasper. These urban stations do not really indicate the climate experienced in the higher parts of the mountains, but often show urban heat-island effects (Hinkel et al., 2003; Klene, 2007). Other stations in the National Parks tend to come and go, and the data is not accessible to most other research workers.

When commencing the study of permafrost distribution in the Eastern Canadian Cordillera in 1974, weather stations equipped with temperature recorders were used at key sites with the ground temperature cables. There was no previous work on the climate at the permafrost sites, and there were virtually no other long-term weather stations at high elevations in the mountains. The results obtained proved invaluable in providing the first data on the climate at permafrost sites (Harris and Brown, 1978), and also enabled the effect of different depths of snow cover to be evaluated. This, in turn, led to the development of a new method of predicting permafrost occurrence based on seasonal freezing and thawing indices (Harris, 1981).

The number of weather stations expanded as the work progressed, but the stations to be used in the long-term study were selected for being typical of a given area. The others were removed. Measurements using data loggers and thermistors gradually replaced the earlier methods after 1990, following a trial period for comparison of the results of the two methods (Harris and Pedersen, 1995). The most important weather stations are still active, and this paper reports the results of 32 years of work, showing that there are changes occurring that do not match the predictions of the various GCM's. North of the 60th parallel, the AES and US Weather Service weather stations can be used to provide additional data for comparison, although the AES stations were often only used for limited periods. The results from these government-run stations confirm the results from the stations discussed here (Harris, 2007).

Methods used.

1. Instrumentation.

Initially, Lambrecht monthly temperature recorders were deployed in Stevenson screens at sites where studies of ground temperature were being carried out. Above tree line, they were placed in western red cedar boxes on the ground. The sensors were attached to poles and were shielded by an inverted can painted white to reflect direct sunlight. Tests showed the two methods gave comparable results. The main disadvantage was that the charts had to be changed each month, limiting the number and location of the stations. After 1990, data loggers became available and Lakewood data loggers with YSI thermistors were chosen as a standard. The use of data loggers also permitted additional measurements such as relative humidity, and the network was expanded into the Yukon Territory to overlap with the Atmospheric Environment Service stations. Figure 1 shows the resulting network. Use of a second station nearby provided backups for periodic loss of data when batteries or data loggers failed or when skiers, snowmobilers, hikers, etc., interfered with data collection.

2. Definitions.

For the purposes of this paper, three parameters are used for studying air temperature. The *mean annual air temperature* (MAAT) is the average temperature for the calendar year calculated from the mean daily air temperatures. The result is equivalent to the balance in an annual bank statement. Large areas of western North America have a climate dominated by air masses. In order to understand their effects, this paper uses *seasonal freezing* and *thawing indices*. The *seasonal freezing index* (SFI) is the sum of the negative mean daily air temperatures for July 1st to June 30th, i.e., it is a measure of the seasonal cooling during the winter from all sources, primarily the cA and cP air masses coming from the north. The *seasonal thawing index* (STI) is the sum of the positive mean daily temperatures for the calendar year (January 1st to December 31st). This is a measure of the seasonal warming by both insolation, rainfall, and by advection of hot cT air from the deserts of Arizona, Nevada, and California in summer. Together, these represent measures of the effects of the seasonal air masses affecting the climate of

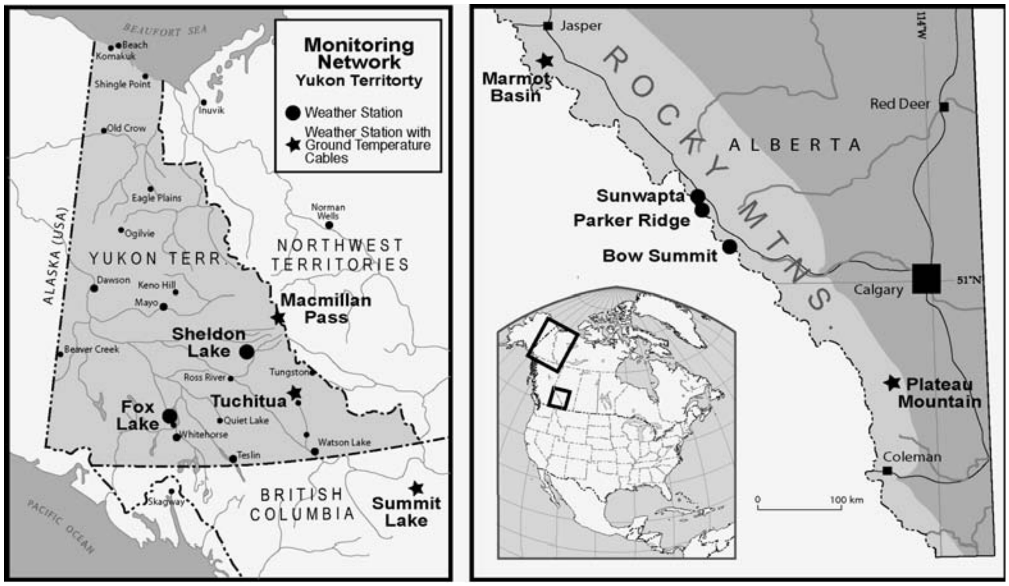


Figure 1. Location of the climate stations established by the author.

the region. Where the data for a month is missing, either the STI or the SFI may be calculated but the other cannot. The mean annual air temperature for that calendar year will also be missing.

Data from the government-run stations in the Yukon Territory and Alaska were compared with the results from the stations discussed here (AES, 1993; Harris, 2006; 2007). The three data sets match very well, and when put together, provided a snapshot of the mean annual air temperature variations that have been taking place in the last 30 years across the region. These can then be compared with the predictions of substantial global warming projected to reach a maximum across Alaska and the Yukon Territory.

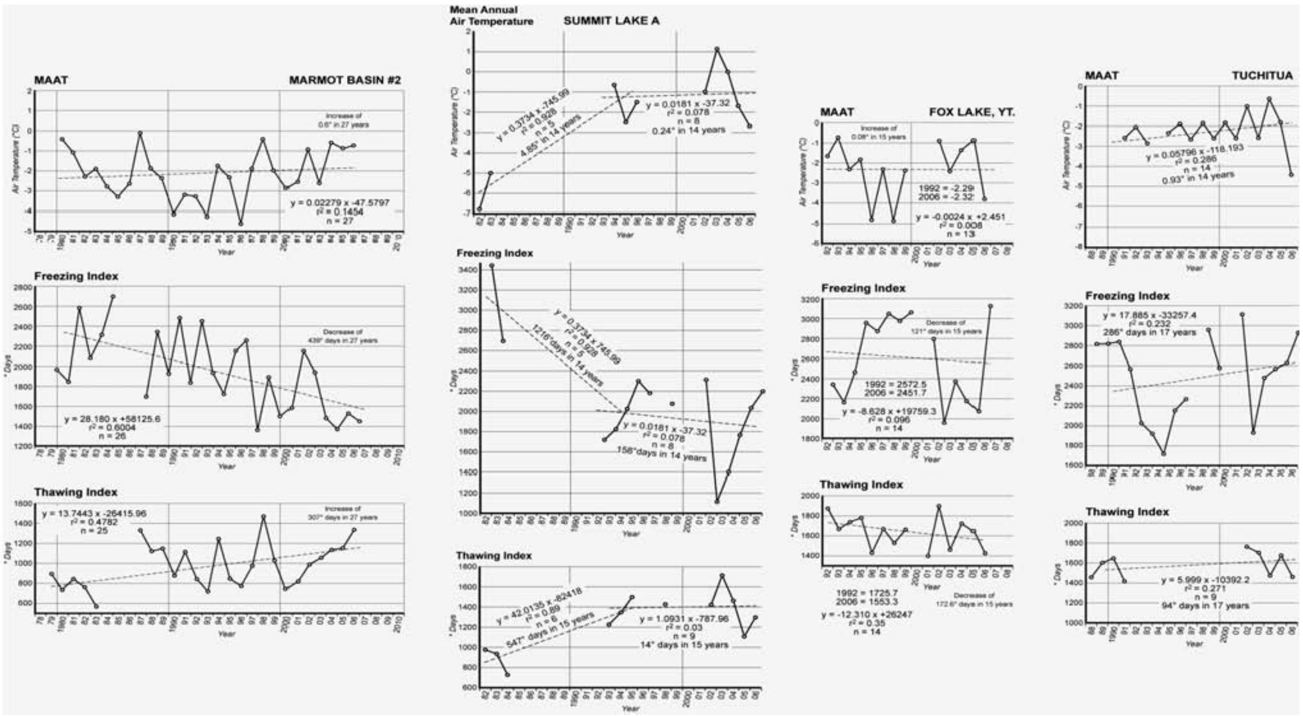
Results

The weather stations form a north-south transect along the Canadian Rocky Mountains. The southern-most site is Plateau Mountain #2 (50° 13’ N., 2484 m) and shows a decrease in mean annual air temperature (MAAT) of 0.49° C in 31 years (Figure 2). Both seasonal freezing (SFI) and seasonal thawing (STI) indices decreased but the STI decreased most. At Parker Ridge #3 (52° 11’ N., 2289 m) the MAAT increased 0.3° C in 24 years due to an increase in SFI of 122°days versus an increase in STI of 35°days over 24 years. These two sites are on mountain tops, but at lower elevations, e.g., Sunwapta Pass (52° 11’N., 2059 m), there was an increase in MAAT of 0.77° C in 28 years.

Marmot Basin #2 (52° 48’ N., 2195 m), again near the mountain crest, showed an increase in MAAT 0f 0.6° C in 27 years (Figure 2). The SFI increased 439°days while the STI increased 370°days over 27 years. Summit Lake A (58° 38’ N., 1524 m) shows the most extreme changes in MAAT (Figure 2), amounting to 4.85° C increase over 14 years from 1982 to 1995, and then only 0.24° C during the next 12 years. This was due to a 1216°day reduction in SFI and a 547°day increase in STI between 1982 and 1995. Thereafter, the STI became virtually constant but the SFI lost another158°days over 12 years.

Figure 2. Time series graphs of MAAT & seasonal freezing and thawing indices for the weather stations.

The data from south-central Yukon is quite different (Figure 2), the MAAT decreasing 0.03° C in 15 years at Fox Lake (61° 10’ N., 804 m). Both STI and SFI decreased. All the Yukon stations are in valleys, although the local relief is subdued.



To the east at Tuchitua (61° 19’ N., 907 m), the MAAT increased 0.93°C in 14 years with both the SFI and STI increasing. A less complete record from Sheldon Lake (62° 38’ N) shows a similar pattern, but the SFI appears to be decreasing.

The only data on snowfall is from the Marmot Basin Ski Area (Figure 3) and indicates that the snowfall has been decreasing since 1960. Evidence from former avalanche tracks suggests that the snowfall was much higher during the last Neoglacial event (Winterbottom, 1974), while data from tree rings at temperature sensitive sites indicate that the MAAT was not the cause of the last Neoglacial advances (Allen, 1980).

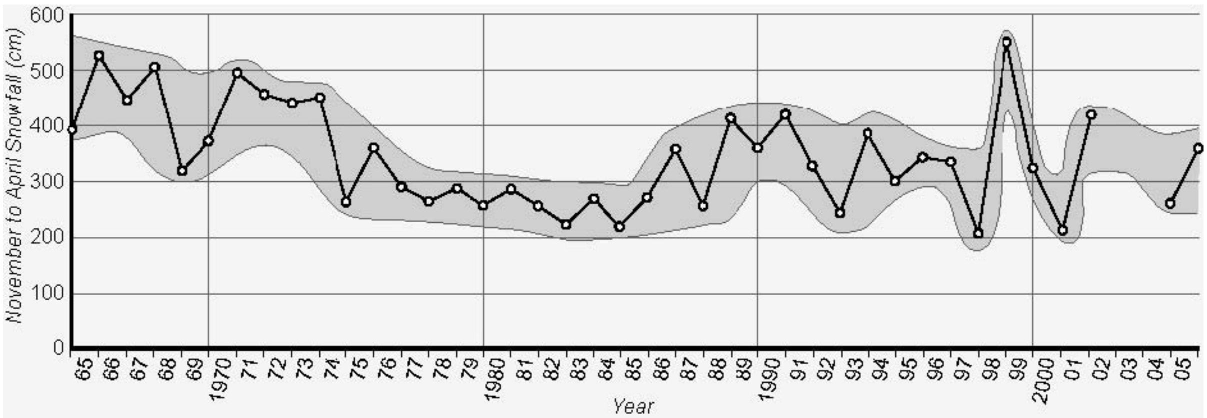


Figure 3. Winter snowfall totals at the middle chalet, Marmot Basin ski area.

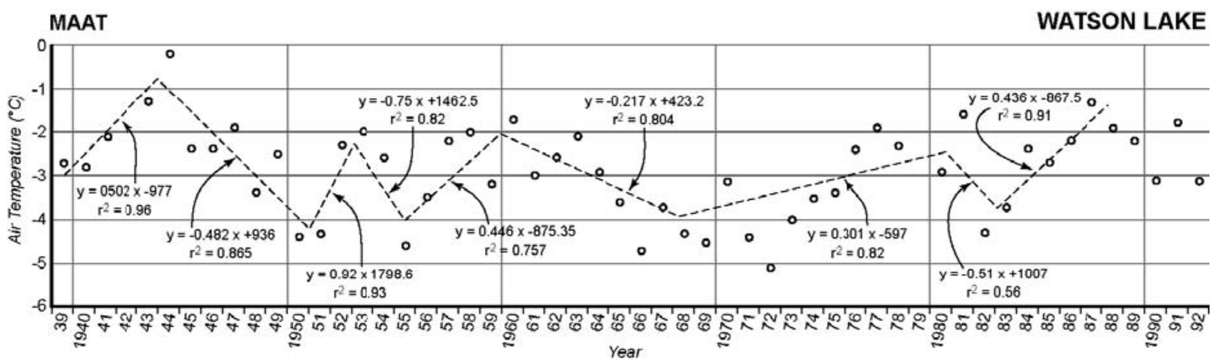


Figure 4. Variations in MAAT measured by AES at Watson Lake, Yukon Territory (data from AES 1993).

Relationship to longer records of MAAT

Figure 4 shows the record of MAAT for Watson Lake since 1939, recorded by the Atmospheric Environment Service (AES, 1993). The warmest temperatures were in 1944, representing the completion of increased temperature after the last Neoglacial event. It was followed by cooling, and there appears to be an oscillation taking place with alternating cooling and warming trends. There are at least four oscillations since 1944, with a periodicity varying from 3 to at least 12 years, caused by fluctuations in the SFI. The MAAT remains within a limited range, the present warming having begun in 1972, paralleling the results obtained in the present study. Note that the present MAAT is still below that recorded in 1944. This oscillatory pattern is present in other climate data for stations in the southern Yukon Territory as well as in tree rings from temperature-sensitive sites in the area. Further south, a study of the long-term records from Calgary by Clark et al (2000) found that the MAAT has not changed, but both the STI and SFI have decreased in the past few decades. Thus these independent results are consistent with those of the present study.

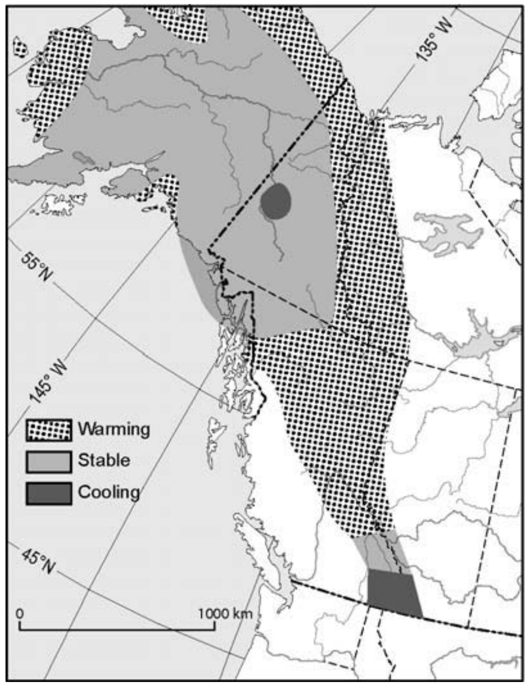


Figure 5. Regional pattern climatic change since 1980, partly after Harris (2007)

The regional pattern of climatic change

Figure 5 shows the regional pattern of climatic change since 1980, based on the published climatic data (Harris, 2007) and the present study. Along the Arctic coast of Alaska, the Mackenzie valley and in the Summit Lake area, there is evidence for substantial warming. In central and southern Yukon and Alaska, as well as south of 52° 25’ N in the Eastern Cordillera, there is negligible change. South of 51°N and in a localized area along the Yukon River valley south of Dawson City, there is cooling.

Causes of the results

1. Maintenance of the mean annual air temperature at this latitude.

What is rarely discussed when considering climate change is the fact that to maintain the MAAT in the higher latitudes of the Northern Hemisphere at the present levels, 30% of the heat absorbed by the Earth in the Tropics must be transported northwards. Without this, the MAAT would be similar to Antarctica. The three agents involved in the transport are ocean currents, thermohaline circulations and movements of air masses. In the case of the latter, the air tends to move according to the gradients in regional air pressure. The first two agents affect the area west of the Cascade Range, whereas the MAAT along the main part of the Canadian Cordillera is controlled by the air masses (Figure 6).

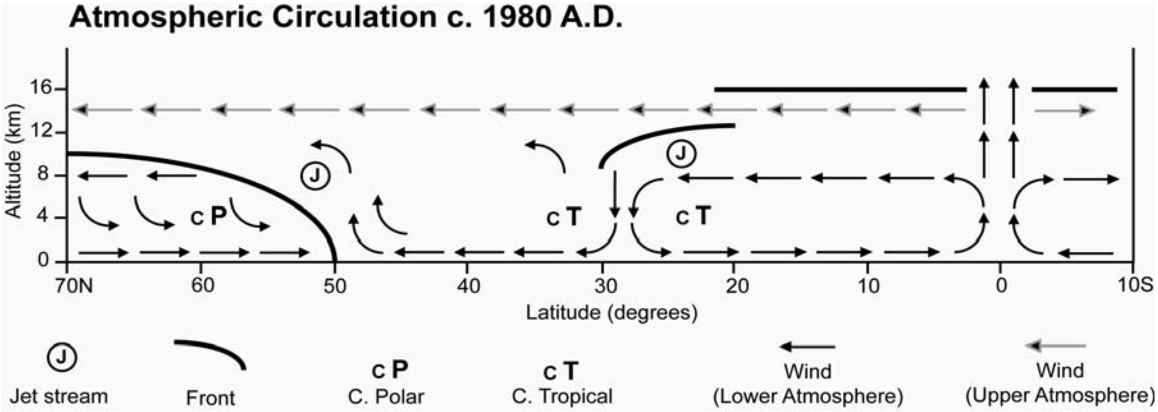


Figure 6. Major south to north air circulation along the middle of the Western Cordillera of the Americas.

The evidence in Figure 2 clearly indicates a reduction in the depth and size of the winter cA and cP air masses coming south from the Yukon and Alaska. They follow a trajectory towards Winnipeg, but only back up against the higher mountains further south if they are deep enough. For the period of study, these air masses have decreased in size resulting in a decrease in SFI. The summer arctic air pressure has also decreased, allowing the jet stream with hot cT air from the deserts of southwestern United States to move further north to latitude 58° N along the west side of British Columbia more frequently before turning east and south, as suggested by Nkemdirim & Budikova (2001). The change occurred mainly between 1982 and 1995, resulting in the pronounced increase in the STI in that area. Southern Alberta is now spared some of the advection heating and so has a lower STI. It indicates that the Alberta high has strengthened due to a positive PNA (Sheridan, 2003). There is no correlation with the El Niño events.

2. Local modifications.

The enhanced warming along the Arctic coast is probably due to the change from snow cover (reflecting 85% of the incoming radiation) to bare soil (absorbing c. 75% of the radiation) or to water, which being translucent, absorbs 5-7 times the incoming radiation absorbed by soil (Pavlov, 1999; Harris, 2002). The air takes its temperature from the source area, modified by the temperature of the surface over which it passes, hence the increased warming in that area.

The marked warming in the Summit Lake area is the result of changes in the position of the summer jet stream, as discussed above, but this warm air also heats the area around the Great Slave Lake, warming the water that subsequently flows north along the Mackenzie valley. Its role in increasing the air temperature along the Mackenzie valley has not been examined to date.

The lack of change in the mountain valley floors of central and southern Yukon appears to be due to the buffering effects of inversions, steam fog, and cold air drainage (Harris, 2007). Both the cloud cover developed due to warm air over-riding cold air trapped in the valleys and the steam fog that develops over large water bodies such as lakes increase in frequency and density if there is summer warming. These therefore counteract any such warming. Since cold air drainage only occurs in the winter when the temperature of the air mass drops below a threshold temperature, there is a small reduction in the buffering effect of this stabilizing agent with warming, but the overall effect is little change compared to other areas.

3. Relationship to "global warming".

Since the field work began, interest in climatic change has come into vogue with the coming of the concept of "global warming", usually ascribed to the effects of increased levels of carbon dioxide in the atmosphere. This has caused models to be made of its theoretical effects called Global Circulation Models (GCM's). The products from these models suggest that the area north of 60° latitude in the northern Cordillera should show the maximum effects of the warming (Anisimov and Poliakov, 2003). They do not take into account the local modifications discussed above.

An examination of the available climatic data for stations in Alaska and the Yukon Territory from the most reliable Government sources indicates much of Alaska and the Yukon Territory is not showing the predicted warming trend (Harris, 2006; 2007). Instead, the evidence suggests that the best available data from at least 50% of Alaska and 75% of the Yukon Territory do not show any strong warming trends (see also Sergeev, 2007), although marked warming is recorded by the same sources for the northern parts of Alaska and the Mackenzie Valley (Osterkamp and Romanovsky, 1999; Kershaw, 2003). The climatic changes that are occurring vary greatly from place to place in the region.

These results illustrate the fact that climatic changes do not have the same effect across the world as suggested by the term "global warming". Instead, there are significant variations from one region to another that cannot be readily predicted in our present state of knowledge.

Conclusions.

Studies of both the best available government data and of data collected by the author indicate that there are substantial variations in the changes in mean annual air temperature from one part of northwest North America to another. The GCM's that are currently available do not predict these differences, and therefore are a poor substitute for actual data. It is difficult for government organizations such as Parks to monitor long term weather stations, yet there is an obvious need for such data. It is therefore recommended that climate-monitoring networks such as the one described in this paper should be facilitated by all the Parks agencies at all three levels of government to obtain actual data that can then be used by other researchers whose studies need accurate climatic data.

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