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Short Communications

CLIMATE CHANGE DURING 1953 – 2007 IN THE CANADIAN ARCTIC

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ABSTRACT

Hourly measurements of relative humidity, temperature and pressure along with daily precipitation totals recorded at 26 stations in the Canadian Arctic during 1953-2007 were analyzed. The data were first checked for discontinuities. A sudden decrease in relative humidity occurred in the 1970s and 1980s due to an instrument change making it impossible to reliably discern a relative humidity trend due to climate change. A statistically significant warming averaging 5.6 ^{o}C has occurred in winter over the Western Arctic but no change was found in either the Eastern or Northern Arctic. Precipitation varied considerably from year to year and no trends were evident. A statistically significant pressure change averaging -5.8 hPa occurred during winter. The observed temperature increase and pressure decrease during winter may be indicative of changing circulation patterns.

I. INTRODUCTION

Evidence showing how human activities are affecting the global climate is steadily accumulating as summarized by the reports of the Intergovernmental Panel on Climate Change [1,2]. This anthropogenic effect is largely due to the rising concentration of greenhouse gases such as CO_2. Climate change is predicted to be more significant in the Arctic than at mid latitudes since rising temperatures will release methane trapped in the permafrost and increase water vapour [3-5]. These two gases are also greenhouse gases and therefore further amplify the warming. This in turn may increase relative humidity and

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precipitation as well as affect weather circulation patterns. Hence, climate observations in the Arctic may very well act as the “early warning canary” of climate change. Indeed, the extent of Arctic sea ice during 2007 was the smallest ever recorded in modern history [6-8].

The Canadian Arctic archipelago juts into the Arctic Ocean. The station of Alert on Ellesmere Island, located at 82.5^{o} N latitude, is significantly closer to the North Pole than northern Alaska and Siberia. Hourly and daily observations of climate have been made since the 1950s at a number of stations in the Canadian Arctic and are available in digital form from Environment Canada. These measurements are taken at the surface and are more extensive than the observational record of the upper atmosphere. The dataset also covers a longer period than is available from satellite observations. The latter must be calibrated using ground based station measurements. This can be problematic as shown recently in the Antarctic where temperatures as determined from satellite observations were found to be in error by as much as 10 ^{o}C [9]. These station observations are also an essential input to global circulation models that attempt to interpolate the climate between observing stations [10]. This is obviously a challenge in the Canadian Arctic which encompasses an area of several million square kilometers where “neighbouring” stations are separated by several hundred or even a thousand kilometers.

This paper is organized as follows. First, the extent of the data record and the limitations of the various measurements are discussed. It is essential that effects due to changing instruments and/or procedure be understood to allow the proper determination of climate trends. An example is given showing the effect on relative humidity caused by the replacement of the psychrometer by the dewcel. Next, observations of temperature, precipitation and pressure are discussed and trends are plotted. Finally, conclusions are presented.

II. DATA ANALYSIS

Hourly observations of relative humidity, temperature and pressure along with daily observations of precipitation were retrieved from the Environment Canada archive for the 26 stations listed in Table 1. Most of these stations were opened in the 1950s. Archival records show each station received regular inspections to ensure that instruments were properly calibrated and that data taking procedures were properly implemented. Table 1 shows the percentage of missing hourly observations was less than 10% for most stations. Only three stations, Alert, Cape Hooper and Longstaff Bluff have slightly greater than 50% missing data. Most of the missing hourly data occurred in the 1950s and early 1960s when data were only measured every 6 hours at some stations.

Figure 1 shows the total number of measurements recorded each year. This number increases as additional stations were opened in the 1950s and 1960s. There was a slight decrease in the mid 1990s due to budget cuts that affected station operations. The station density in the Arctic is lower than in Southern Canada. Nevertheless, the total number of measurements analyzed in this study exceeds 10 million, which is considerable.

Data was analyzed as follows. Average values were computed for the seasons defined as follows: winter (December – February), spring (March – May), summer (June – August) and fall (September – November). For the case of hourly data, averages were also found for the

Table 1. Station List. The percentage of missing data is rounded to the nearest 5%. A star denotes daily precipitation records that were available and analyzed in this study.

Province/ Territory	Name	Station Number	Latitude	Longitude	Hourly Data	
					Start Date	% Missing
Yukon	Burwash	2100182	61.37	139.17	Oct. 1, 1966	15
	Mayo	2100700	63.62	135.87	Jan. 1, 1953	15
	Watson Lake*	2101200	60.12	128.82	Jan. 1, 1953	<1
	Whitehorse*	2101300	60.72	135.07	Jan. 1, 1953	<1
NWT	Cape Parry	2200675	70.17	124.72	Jan. 1, 1956	5
	Fort Simpson	2202101	61.77	121.23	Jan. 1, 1953	<1
	Fort Smith*	2202200	60.02	111.97	Jan. 1, 1953	<1
	Hay River*	2202400	60.83	115.78	Jan. 1, 1953	<1
	Inuvik*	2202570	68.3	133.48	Jan. 1, 1953	<5
	Norman Wells*	2202800	65.28	126.8	Jan. 1, 1953	<5
	Yellowknife*	2204100	62.4	114.43	Jan. 1, 1953	<1
Nunavut	Baker Lake*	2300500	64.3	96.08	Jan. 1, 1953	13
	Coral Harbour*	2301000	64.2	83.37	Jan. 1, 1953	<5
	Alert*	2400300	82.52	62.28	Jan. 1, 1953	57
	Cambridge Bay*	2400600	69.1	105.13	Jan. 1, 1953	<5
	Cape Hooper	2400660	68.28	66.48	Mar. 1, 1956	60
	Clyde	2400800	70.48	68.52	Jan. 1, 1953	15
	Eureka*	2401200	79.98	85.93	Jan. 1, 1953	35
	Hall Beach*	2402350	68.78	81.25	Jan. 1, 1953	<5
	Iqaluit*	2402590	63.75	68.55	Jan. 1, 1953	<1
	Longstaff Bluff	2402684	68.54	75.09	Dec. 1, 1955	55
	Resolute*	2403500	74.72	94.98	Jan. 1, 1953	10
Manitoba	Churchill*	5060600	53.97	101.1	Jan. 1, 1953	<1
Quebec	Inukjuak	7103282	58.47	78.08	Jan. 1, 1953	30
	Kuujjuarapik*	7103536	55.28	77.77	Jan. 1, 1953	<1
	Kuujjuaq*	7113534	58.1	68.42	Jan. 1, 1953	<5

night (0 – 5 am), morning (6 – 11 am), afternoon (noon - 5 pm) and evening (6 – 11 pm). No discernible difference between trends observed during these four different periods of the day were found for relative humidity, temperature and pressure. A linear function was then fit to each time series given by

$$y_t = a + bt + e_t \quad (1)$$

where y_t is the seasonal value observed at the station of interest at time t and e_t is the residual. A t-test then determined whether the slope or trend given by b was statistically significant at the 5% confidence level.

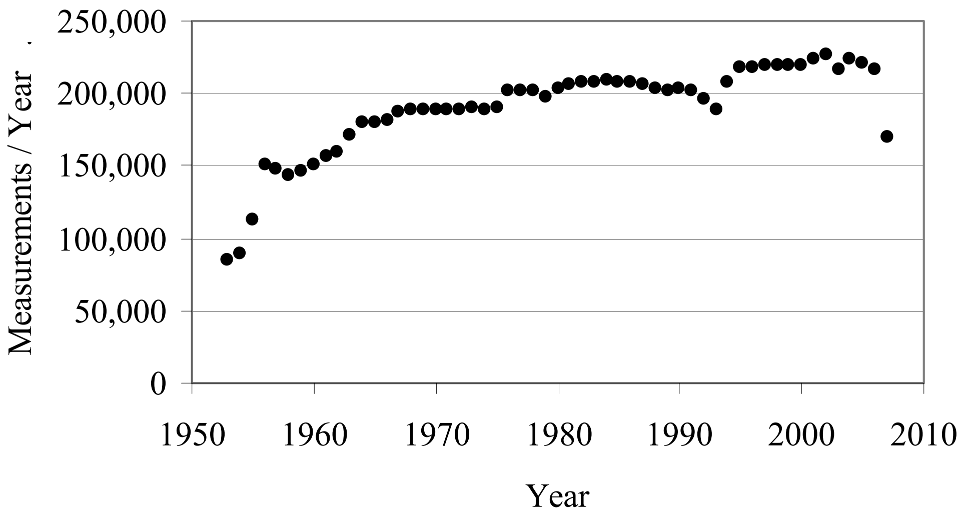


Figure 1. Number of Hourly Measurements per year taken at 26 stations in this study. The number of measurements increased in the 1950s and 60s as stations were opened. The small dip in the early 1990s reflects budget cuts which resulted in staff reductions. The number is anomalously low in 2007 because only data taken before Oct. 2007 were considered.

a) Relative Humidity

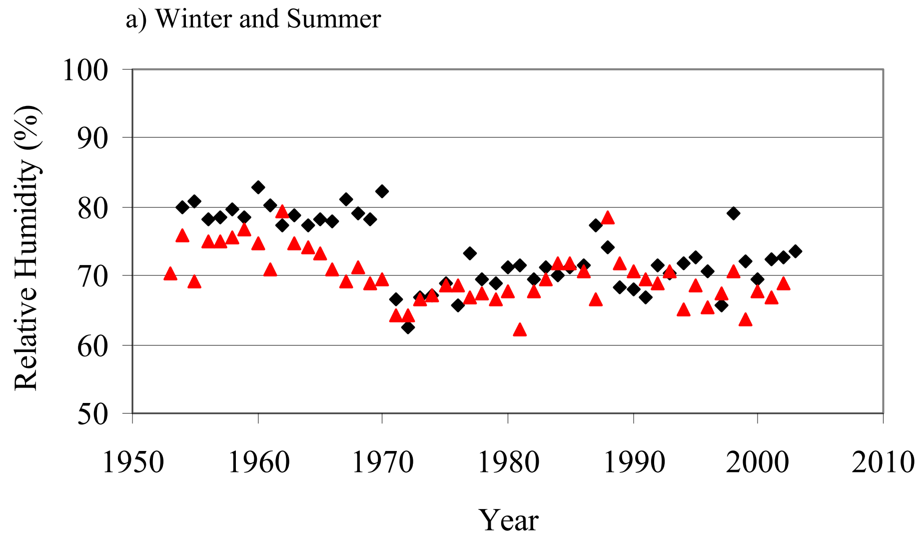
Examination of the relative humidity data found a discontinuity for nearly every station. Figure 2 shows the relative humidity decreased suddenly in 1970 at Hay River, with the largest decrease of about 20% occurring in winter. Data was examined for step inhomogeneities such as shown in Figure 2 by fitting the time series by

$$y_t = a + bt + cI_t + e_t \quad (2)$$

where I_t equals 1 for $t \geq p$ and zero otherwise. The value of p providing the minimum residual sum of squares then determines the most probable year of a potential step [11]. The F statistic was then used to determine whether the data is fit better using either equation (1) or (2) [12].

Nearly all the Arctic stations were found to have step discontinuities occurring sometime during the 1970s or 1980s [13]. The station histories showed the date of the observed discontinuity coincided with the replacement of the pscyhrometer by the dewcel. For Hay River, this instrument change occurred in 1970. The psychrometer measures the temperature difference between a wet and a dry bulb thermometer. At very low temperatures, the wet bulb freezes rapidly and the temperature difference if any, is very small. This leads to anomalously high values of relative humidity as are evident in Figure 2.

Data observed at a given station can be corrected for inhomogeneities by comparing time series obtained at neighbouring stations. This has worked well for correcting temperature time series for stations that are in close proximity in southern Canada [14]. In the case of the Arctic, stations are separated by large distances and considerable caution should be exercised when attempting this procedure [15].



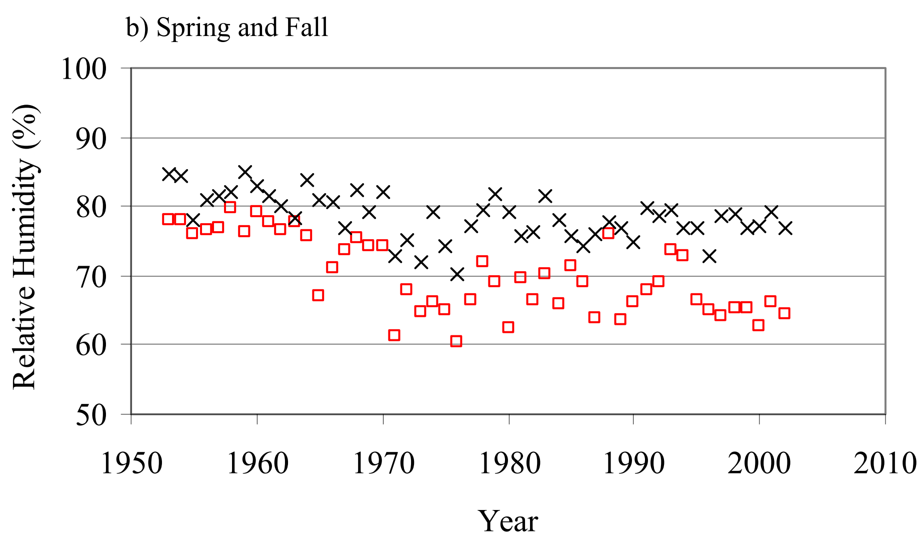


Figure 2. Relative Humidity at Hay River, North West Territories during a) winter (solid black diamond) and summer (filled red triangle) as well as b) spring (open red square) and fall (black cross). The apparent reduction in relative humidity in 1970 coincided with the replacement of the psychrometer by a dewcel as discussed in the text.

b) Temperature

Temperature was measured with a resolution of 0.1 ^{o}F prior to 1977 [16]. These measurements were later recorded in the archive with 1 ^{o}F precision. Beginning in 1977, the Celsius temperature scale was adopted and temperature was observed with a resolution of 0.1 ^{o}C. The earlier archival measurements were then converted to Celsius and recorded with a precision of 0.1 ^{o}C. Examination of daily [14] and hourly [17] measured temperatures have found relatively few inhomogeneities. Moreover, these discontinuities have a much smaller magnitude than was the case for the relative humidity data.

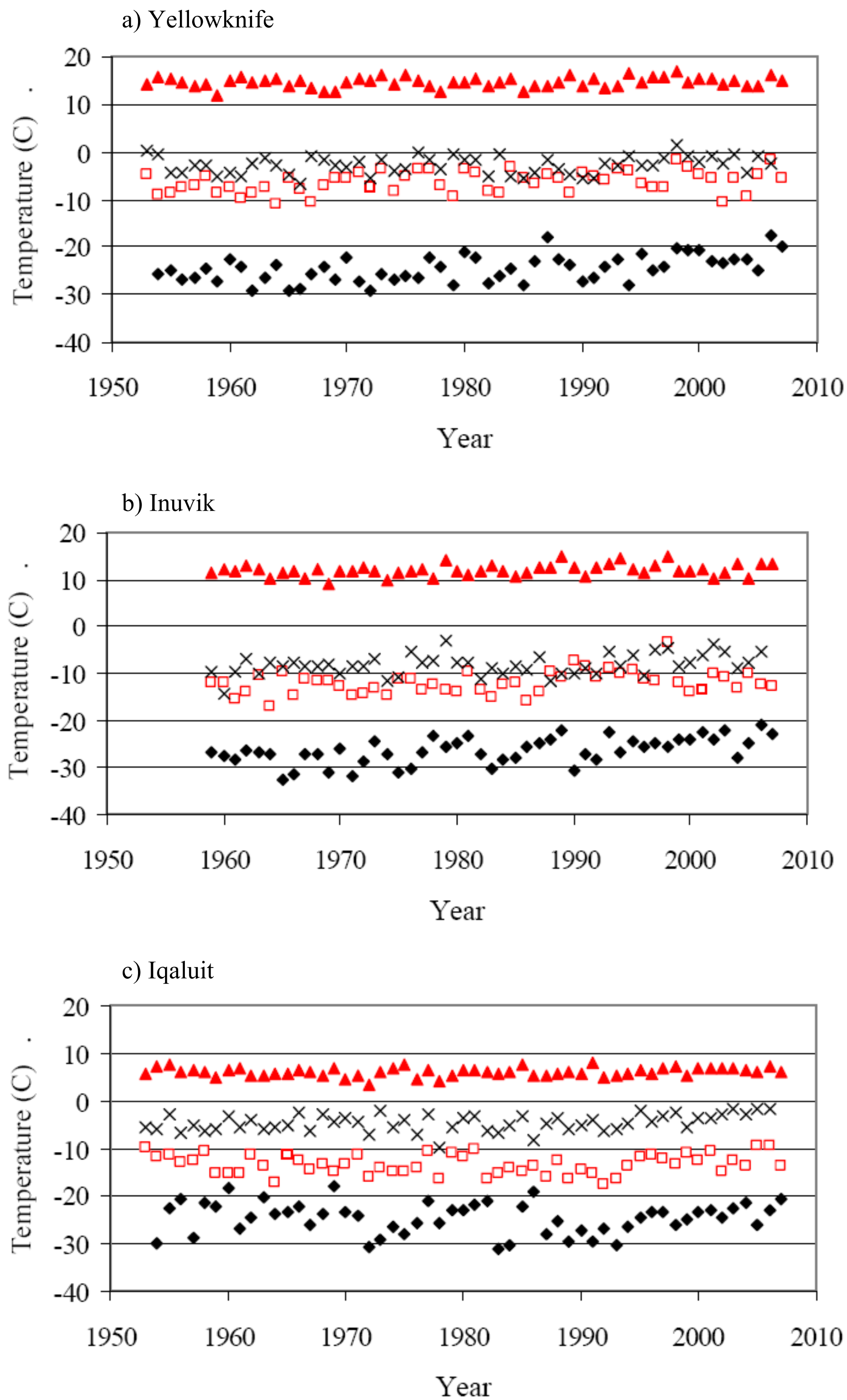


Figure 3. (Continued).

d) Alert

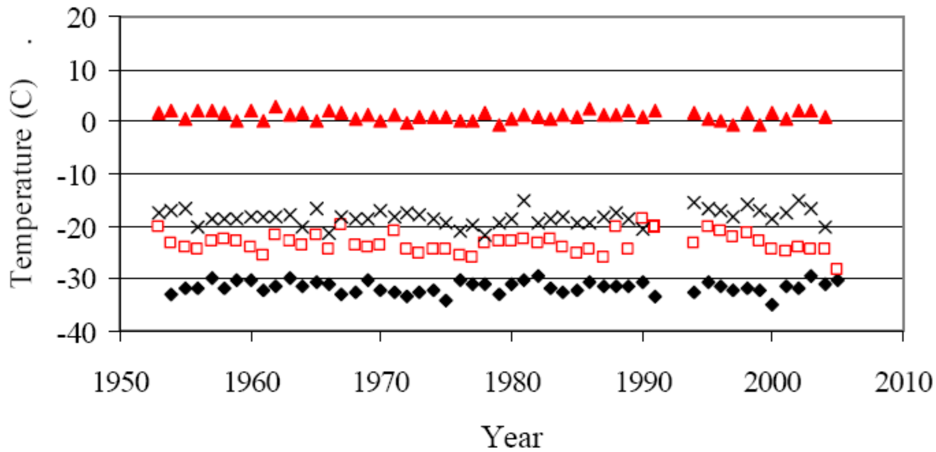


Figure 3. Seasonal Dependence of Temperature at a) Yellowknife, b) Inuvik, c) Iqaluit and d) Alert for winter (solid black diamond), spring (open red square), summer (solid red triangle) and fall (black cross). The gap in the Alert data in the mid 1990s resulted from cutbacks in station operation due to budget reductions.

Figure 3 shows the average temperatures recorded in the various seasons at four stations located in the southern (Yellowknife), western (Inuvik), eastern (Iqaluit) and northern Arctic (Alert). Trend lines were fit to the seasonal time series and are shown in Figure 4. Few statistically significant trends are in evidence anywhere during spring, summer and fall. However, in winter all 11 stations located in the Yukon and Northwest Territories show statistically significant warming trends averaging +5.6 ^{o}C over the period 1954-2007. The three stations further east, Cambridge Bay, Baker Lake and Churchill also report statistically significant trends in winter averaging +2.7 ^{o}C. This is consistent with previous work that found a warming of about 5 ^{o}C during winter on the Canadian prairies during 1954-2003 [18, 19]. The result for the Western Arctic in winter differs from that found for stations in the northern and eastern Arctic where no statistically significant trends occur. This winter warming is consistent with the observation of markedly less ice observed in the Arctic Ocean north of Siberia and Alaska in late summer [6-8]. It appears that the winter warming produces less thick ice which in turn melts faster during the summer.

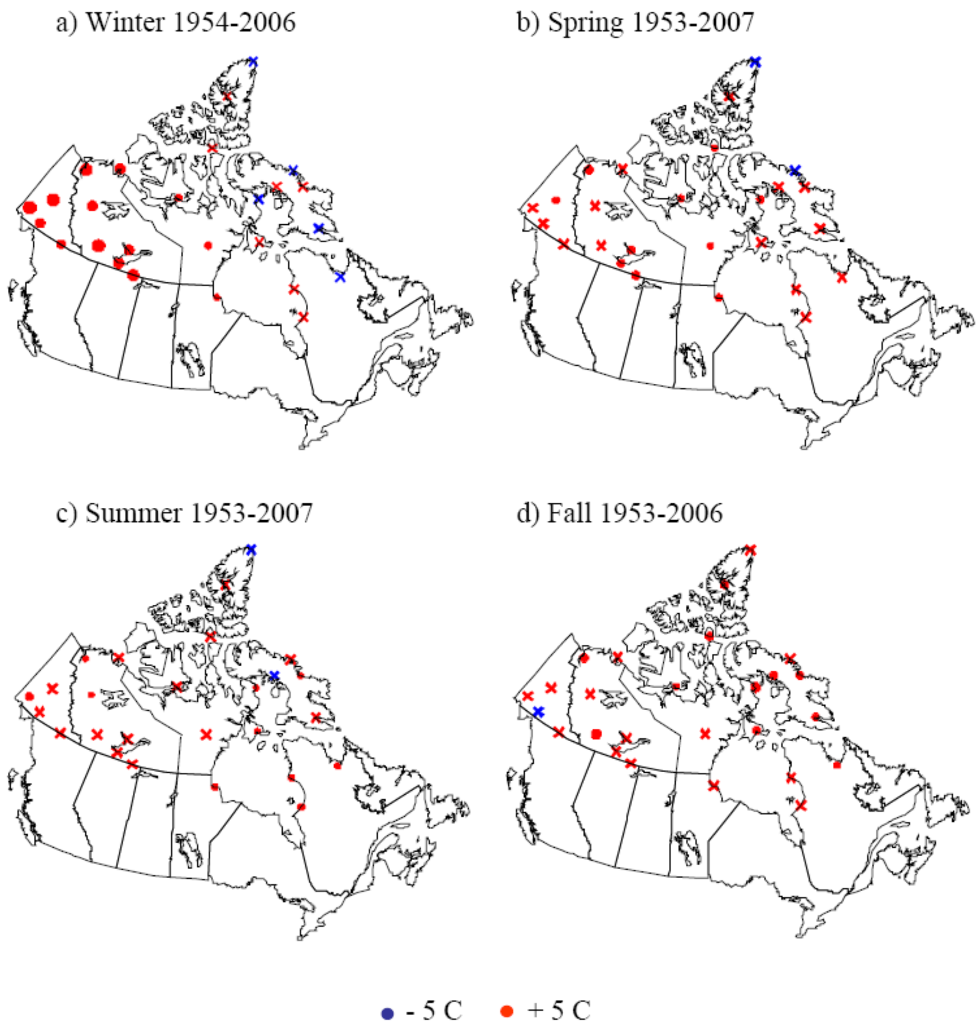


Figure 4. Temperature trends during a) winter, b) spring, c) summer and d) fall. Red (blue) dots represent increasing (decreasing) temperature trends statistically significant at the 5% level. Crosses represent insignificant trends.

c) Precipitation

Daily precipitation is recorded in units of 0.1 mm in the climate archive. A number of factors affect the accuracy of these data. First, missing data can have a larger effect when estimating the total precipitation compared to determining the average temperature. The amount of missing daily data is believed to be less than 5% at most stations. This is somewhat difficult to estimate as sometimes zero precipitation may be recorded on a day when no measurement was made. A second uncertainty results from the introduction of new gauges that has affected the collection efficiency of precipitation by 5% or more in southern Canada [20]. Precipitation measurement in the Arctic is further complicated because a significant fraction of the annual total is received in the form of trace amounts of snow or rain (< 0.3

mm) whose cumulative total is hard to reliably estimate. Distinguishing between blowing snow and new snow fall is also a challenge. Finally, the snow moisture content differs from station to station making it difficult to estimate the so called snow water equivalent [20]. These uncertainties are significant over much of the Arctic which receives less than 25 cm annual precipitation and is therefore a desert.

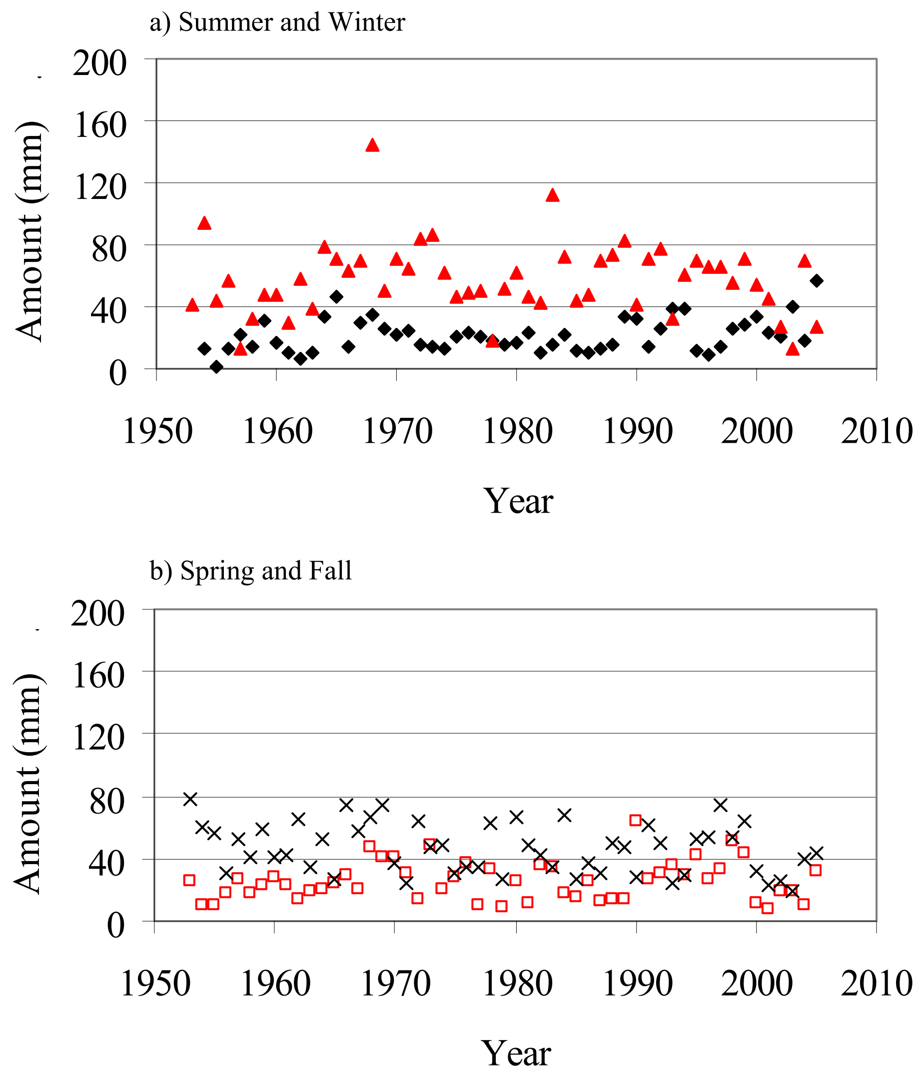


Figure 5. Precipitation at Alert during a) Summer (solid red triangle) and Winter (solid black diamond) and b) Spring (open red square) and Fall (black cross).

Figures 5 and 6 show the precipitation at Alert and Yellowknife in the different seasons. Most of the precipitation is received during summer and fall. This is not surprising as the air contains little moisture at very cold winter temperatures. Similarly, southern stations such as

Yellowknife that experience warmer temperatures than northern Arctic stations such as Alert, receive more precipitation. Figures 5 and 6 show considerable year to year variation in precipitation. Hence, it was not possible to discern any trend at a given station. The average precipitation experienced by the stations indicated in Table 1 was therefore computed to check for any regional trend.

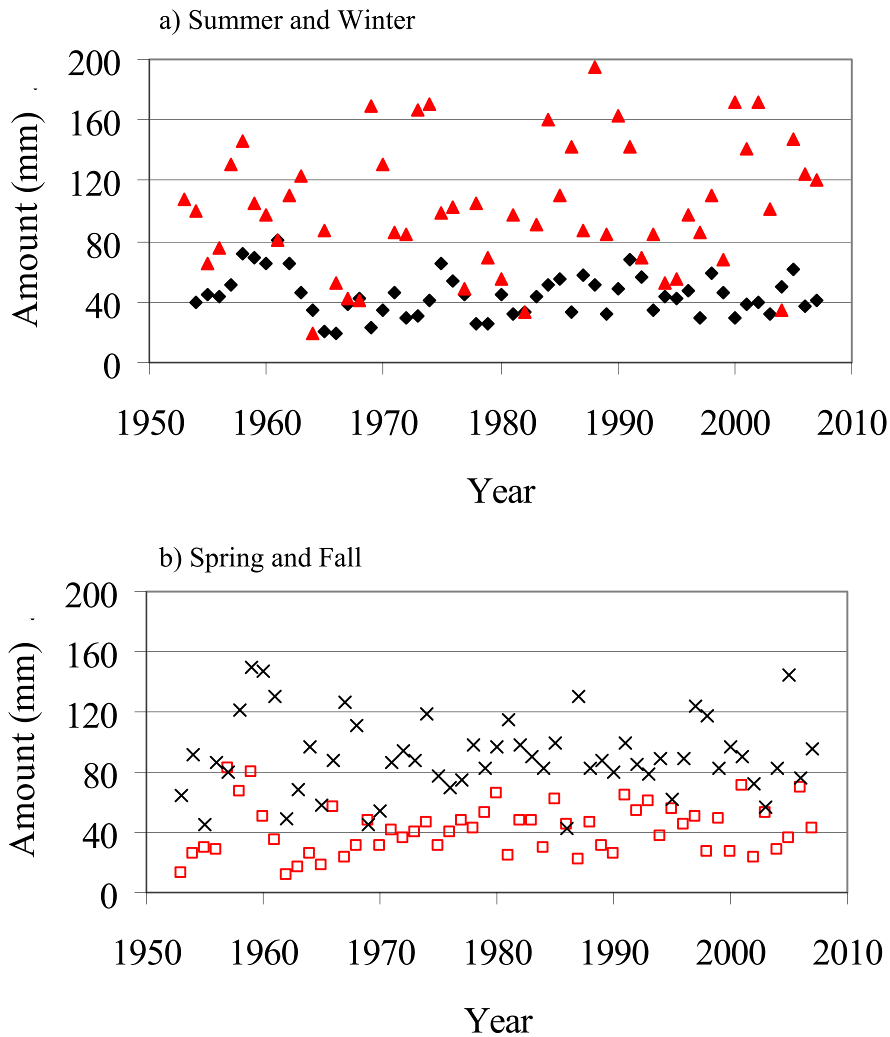


Figure 6. Precipitation at Yellowknife during a) Summer (solid red triangle) and Winter (solid black diamond) and b) Spring (open red square) and Fall (black cross).

Figure 7 shows the average precipitation per station observed for all the stations and separately for stations located in the northern Arctic i.e. Nunavut. The northern Arctic clearly receives less precipitation in every season. Figure 7 does not show evidence of either increasing or decreasing precipitation in any season. These results are consistent with studies for southern Canada that have not found any significant change in precipitation except on the prairies in the winter where a reduction of about 50% has been observed [19, 21].

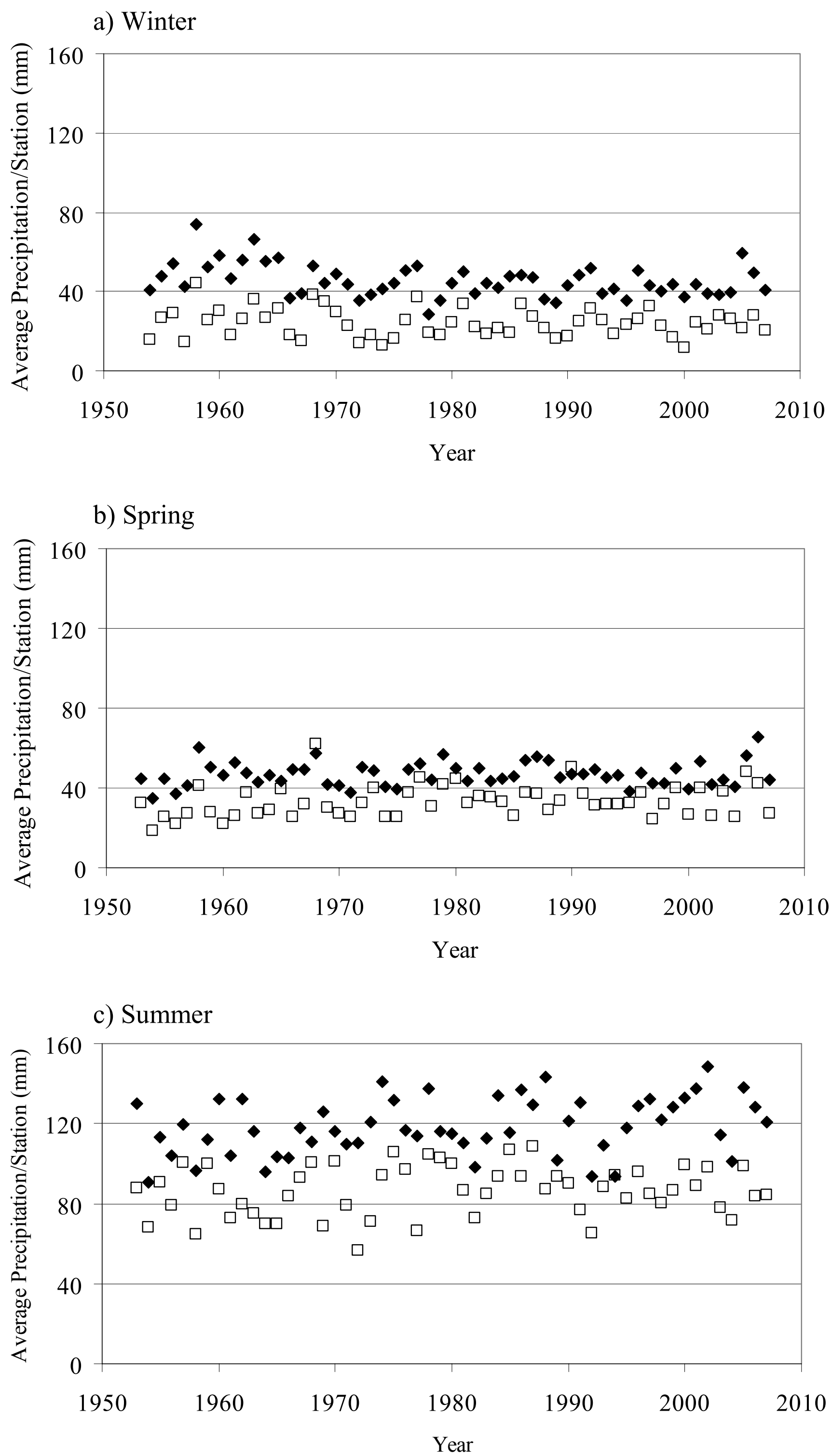


Figure 7. (Continued).

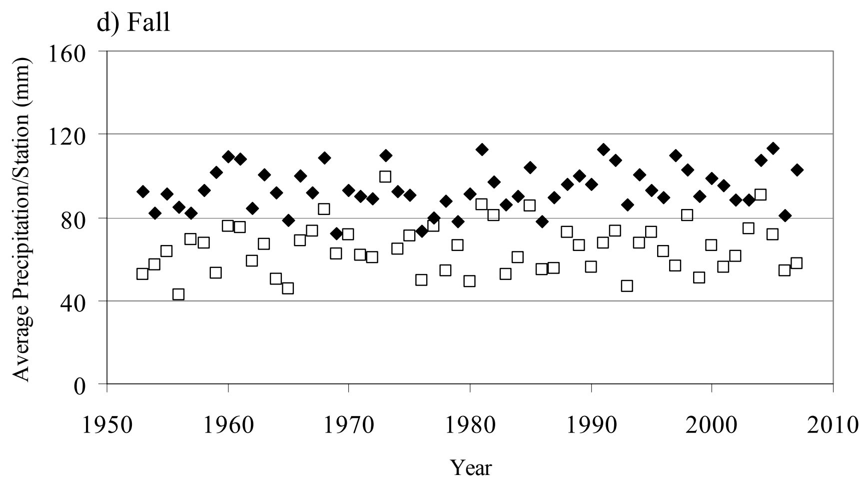


Figure 7. Average Annual Precipitation per Station during a) winter, b) spring, c) summer and d) fall. Solid black diamonds were found for all stations as indicated in Table I while the empty squares represent only data measured at stations located in Nunavut.

d) Pressure

Pressure was recorded with an accuracy of 0.1 hPa using a mercury manometer [22]. The pressure obviously depends on the station altitude which has been taken into account by some studies that consider the adjusted sea level pressure. Unfortunately, a variety of errors have been found in the records of adjusted sea level pressure that arise from changing estimates of the station altitude [23, 24]. In contrast, the station pressure measurements have been found to be relatively free of inhomogeneities [23].

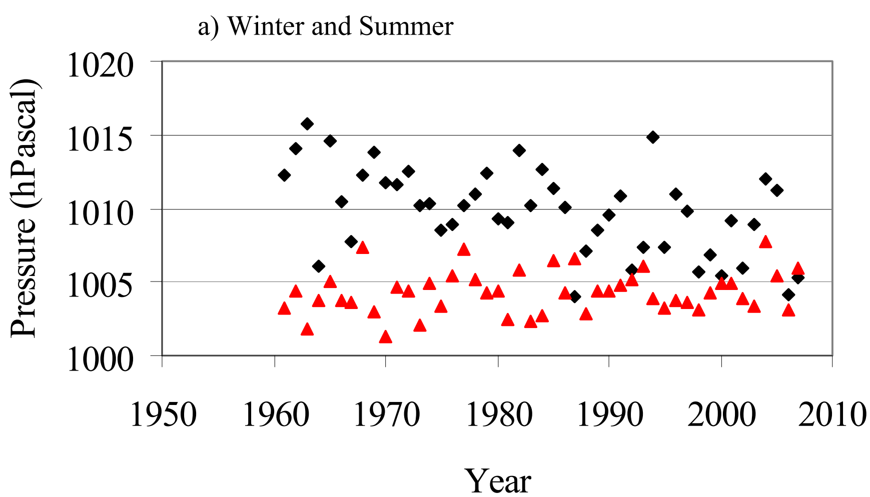


Figure 8. (Continued).

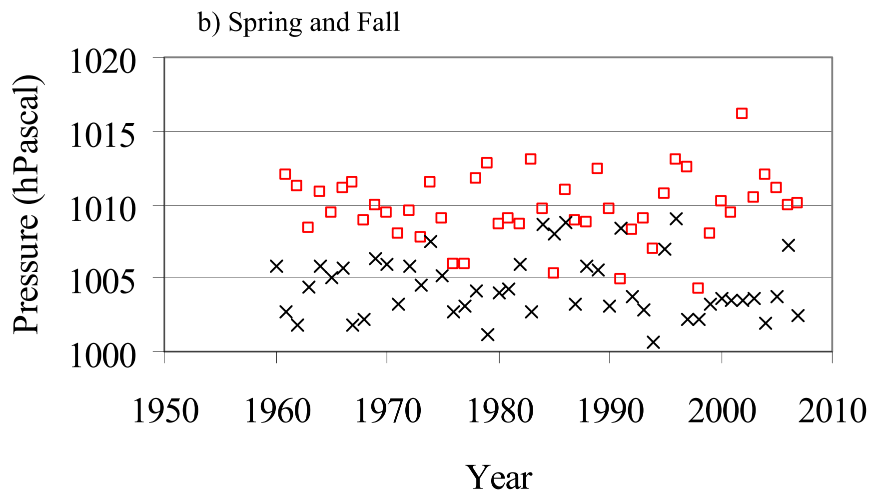


Figure 8. Seasonal Dependence of Pressure at Inuvik for a) winter (solid black diamond) and summer (solid red triangle) and b) spring (open red square) and fall (black cross).

Figure 8 shows the pressure observed at Inuvik in the different seasons. There is scatter from season to season but a statistically significant downward trend occurs in winter. Figure 9 shows the pressure trends observed over the entire Arctic. Eighteen of the 26 stations report a statistically significant pressure decrease in winter averaging 5.8 hPa over the 1954 to 2007 period. The number of stations reporting decreasing pressure trends in the other seasons is fewer and the magnitude of these pressure changes is smaller. These results are comparable to a pressure decrease of as much as 4 hPa that has been found by another study over parts of the Arctic during winter in the 1968-1997 period [25, 26].

The pressure reduction in winter may be a result of a strengthening of the so called North Atlantic Oscillation (NAO) whose strength is determined by the difference in pressure over Iceland relative to the Azores [27]. A strong NAO indicates a strong high pressure center over the Azores and anomalously low pressure over Iceland. Trends of a stronger NAO in recent decades are believed to have reduced the severity of winter weather over most middle and high latitude Northern Hemisphere continental regions [28, 29]. The NAO may be part of a much larger oscillation called the Arctic Oscillation (AO) that affects the entire Northern Hemisphere [30, 31]. The AO has recently been linked to Arctic Sea Ice variation [32].

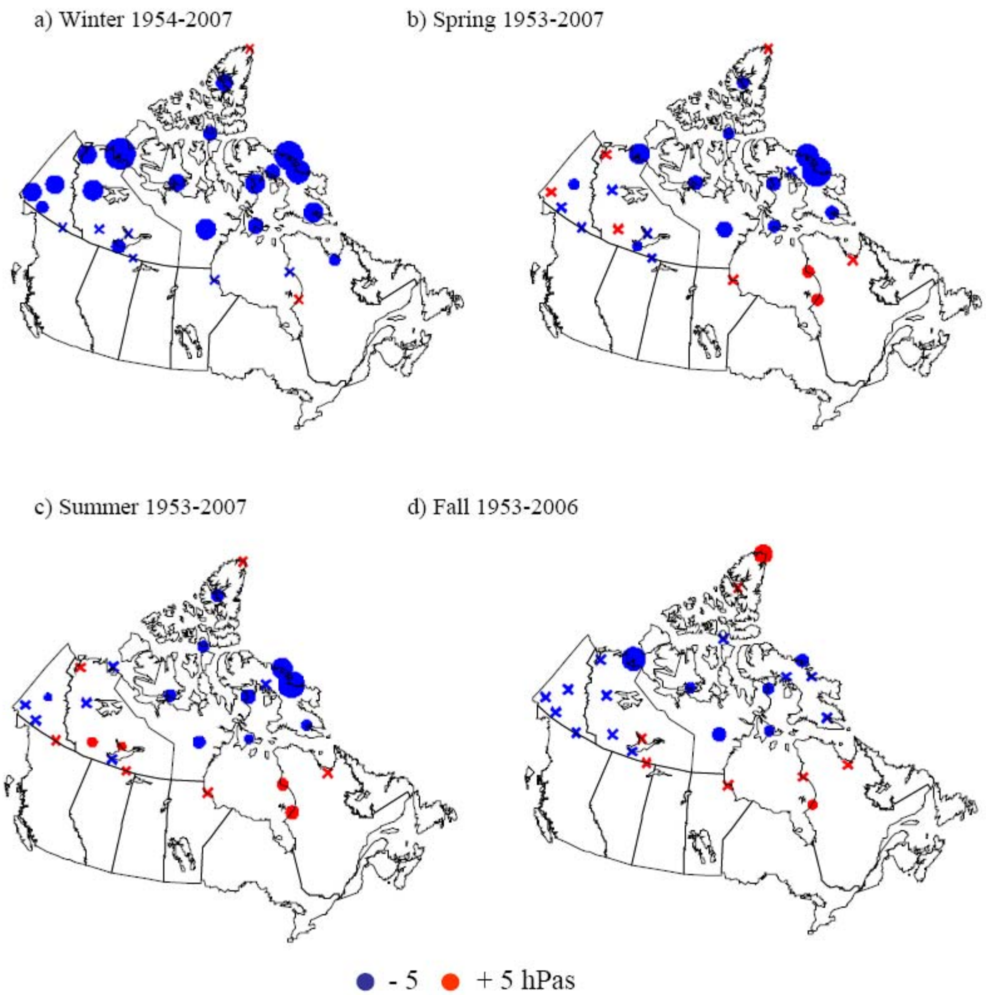


Figure 9. Pressure trends during a) winter, b) spring, c) summer and d) fall. Red (blue) dots represent increasing (decreasing) pressure statistically significant at the 5% level. Crosses represent insignificant trends.

III. Conclusions

This study shows warming is occurring in the Canadian Arctic. However, the data reveal the warming is primarily affecting the Western Arctic and only in the winter season. The average observed temperature increase of 5.6 ^{o}C in the Yukon and Northwest Territories over the past half century is very rapid when compared to geologic time scales. Hence, an anthropogenic cause for this heating is likely. The close relation between this temperature increase and the average decrease of pressure of 5.8 hPa found at 18 of the 28 stations is intriguing. This could be a clue that the winter warming has resulted from changing weather circulation patterns. Indeed, there has been speculation of an anthropogenic effect on pressure [33].

It is important that these observed changes in the Arctic climate be understood to comprehend how the global climate will be altered in the coming century. It would be useful to analyze archival measurements of wind speed and direction. These do exist but caution must be exercised as the calibration of these instruments must be checked frequently to ensure their performance does not degrade in the harsh Arctic environment. Moreover, surface wind measurements are very sensitive to the local topography and easily perturbed by a change in surrounding structures. Upper atmosphere measurements of wind would be more useful but are not readily available for as extensive a time period as hourly surface measurements.

It will be especially interesting to see if statistically significant changes of temperature become evident in the future in the seasons other than winter and whether the eastern and northern Arctic also begin to experience winter warming. These changes could also be accompanied by increased precipitation since warmer air can hold more moisture. Air moisture may be expected to further increase due to increased evaporation from the unfrozen Arctic Ocean. Hence, continued monitoring of the Arctic climate is essential to improve our understanding of global climate change in the 21st century.

ACKNOWLEDGEMENTS

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