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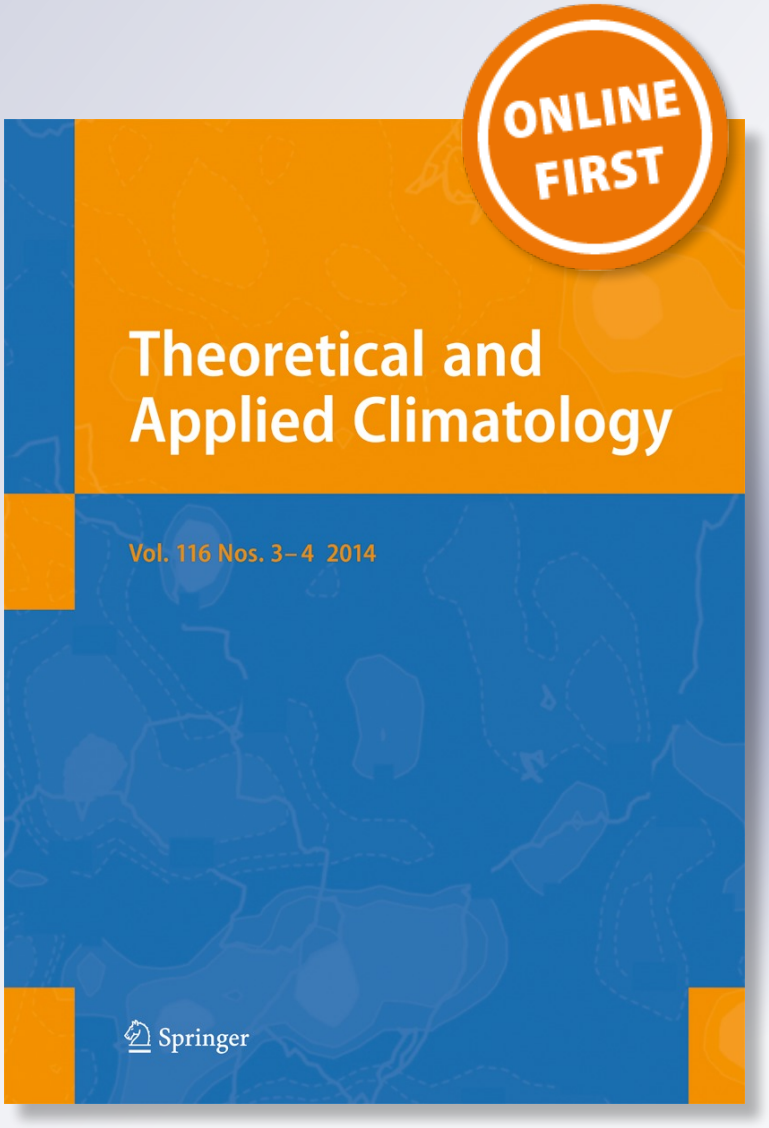

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ORIGINAL PAPER

Temperature trends in the Canadian arctic during 1895–2014

W. A. van Wijngaarden

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Abstract The average January, July and annual temperatures were examined at 27 stations located in the Canadian Arctic. Some of these stations have temperature records extending as far back as 1895. Nearly all stations exhibited warming trends. For each station, the difference between the temperatures relative to the average value found during 1961–1990 was found. The resulting temperature change averaged over the 27 stations was then plotted to give a time series covering the period 1895–2014. Trends were found for the January, July and annual temperatures of 3.1, 1.6 and 1.9 °C per century, respectively. Similar trends were found in the western and eastern Arctic. The warming occurred primarily in the first and last decades of the twentieth century. For the period 1915–1995, the annual temperature trend was only 0.4 °C per century.

1 Introduction

It is now well recognized that anthropogenic climate change is occurring, as has been well documented by the most recent report of the Intergovernmental Panel on Climate Change (Climate 2013). The average global temperature has increased by about 1 °C over the past century (Mann 2014). This increase has not occurred uniformly over the Earth but has been most noticeable in the Arctic (Serreze and Barry 2011; Walsh et al. 2011; van Wijngaarden 2008; Przybylak and Vizi 2005). Arctic temperature increases have resulted in a dramatic reduction in the extent of summer sea ice (Jeffries et al. 2013). Ocean water reflects much less sunlight than ice. This increases the evaporation of water, which also is a greenhouse gas, and further amplifies the warming. As the permafrost melts, methane, which is a more potent greenhouse gas than carbon dioxide, is released into the atmosphere (Hodgkins et al. 2014). Noticeable changes in the northern climate have been reported (Krupnik and Jolly 2002), although some recent studies have questioned some of the claims to increased climate variability (Suteanu 2014).

Canada encompasses a significant portion of the Arctic. Its Arctic archipelago extends far north as 82.5° latitude which along with Greenland represents the most northerly land mass. Hourly observations of temperatures have been recorded at a number of stations since the 1950s (Vincent, van Wijngaarden and Hopkinson 2007). Analysis of these data found temperature increases as large as 5 °C during the period 1954–2003 have occurred during winter in the western Canadian Arctic. The warming trends have been smaller in the other seasons and in the eastern and far northern parts of the Canadian Arctic. A similar warming pattern has also been found in neighbouring Alaska (Isaac and van Wijngaarden 2012).

This study examined average monthly temperatures obtained from the daily observations which are available from the Environment Canada archive (Environment Canada 2014) during the period 1895–2014. This is more than twice as long as is available for hourly data and precedes satellite observations by many decades. Temperature measurements were made following procedures specified by the World Meteorological Organization (WMO), and inspections were carried out regularly to ensure compliance (WMO 1976). Canadian temperature data has been checked for inhomogeneities (van Wijngaarden 2004; van Wijngaarden and Vincent 2005). Discontinuities can arise from changes in instruments. For example, errors as large as 1 °C arising

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from the composition of the thermometer glass has been shown to have affected some data observed in the mid-1800s (Winkler 2009).

Data recorded at 27 stations located throughout the Canadian territories of Nunavut, Northwest Territories and the Yukon as well as stations bordering Hudson Bay in Manitoba and Quebec were studied. The annual temperature was examined as well as the January and July temperatures to see whether the trends in coldest and warmest months are changing differently.

2 Data analysis and results

The list of stations considered in this study is given in Table 1. The stations are located as shown in Fig. 1. An average of 80 years of observations was available for each station. In the case of Fort Simpson and Hay River, temperatures were recorded beginning in the 1890s. Some stations located in the very far north such as Alert were included even though operation began only in 1951, relatively later than the other stations. Average monthly temperature values were available for nearly 90 % of all months. Months for which data was missing tended to occur in the early decades of the twentieth century and after 1995 due to station closures.

The time series for Fort Good Hope was found by combining observations taken at Fort Good Hope 2 during 1910–1966 and Fort Good Hope A during 1945–2014. These two stations are located only 2 km apart. During the overlapping period of 1945–1966, temperatures recorded at Fort Good Hope 2 were

Table 1 Station list

Province/territory	Station	Latitude	Longitude	Period	Centennial trend °C/century
Manitoba	Churchill	53.97	101.10	1929–2014	2.1
NWT	Aklavik	68.22	135.00	1927–2009	1.6
	Fort Good Hope[a]	66.25	128.63	1910–2014	1.3
	Fort Resolution	61.17	113.67	1912–2010	1.5
	Fort Simpson	61.77	121.23	1897–2014	2.6
	Fort Smith	60.02	111.97	1928–2014	3.6
	Hay River	60.83	115.78	1895–2014	2.4
	Mould Bay	76.23	119.33	1948-2013	2.8
	Norman Wells	65.28	126.80	1943–2014	2.8
	Sachs Harbour	72.00	125.27	1956–2014	5.7
	Yellowknife	62.40	114.43	1943–2014	3.3
Nunavut	Alert	82.52	62.28	1951–2006	0.9
	Baker Lake	64.30	96.08	1946–2014	3.4
	Chesterfield	63.33	90.72	1922–2007	1.5
	Clyde	60.48	68.52	1943–2014	−0.4
	Coral Harbour	64.20	83.37	1945–2014	2.3
	Eureka	79.98	85.93	1947–2014	2.8
	Hall Beach	68.78	81.25	1957–2014	4.6
	Iqaluit	63.75	68.55	1946–2014	0.5
	Pond Inlet	74.68	77.98	1923–2014	0.7
	Resolute	74.72	94.98	1948–2014	3.5
Quebec	Inukjuak	58.47	78.08	1922–2014	2.1
	Kuujuarapik	55.28	77.77	1926–2014	2.5
	Kuujjuaq	58.10	68.42	1947–2014	2.4
Yukon	Mayo	63.62	135.87	1925–2014	2.6
	Watson Lake	60.12	128.82	1939–2014	0.9
	Whitehorse	60.72	135.07	1941–2014	1.1

[a] This data was obtained by joining two time series taken at Fort Good Hope 2 (1910–1966) and Fort Good Hope A (1945–2014) that are separated by 2 km, as discussed in the text

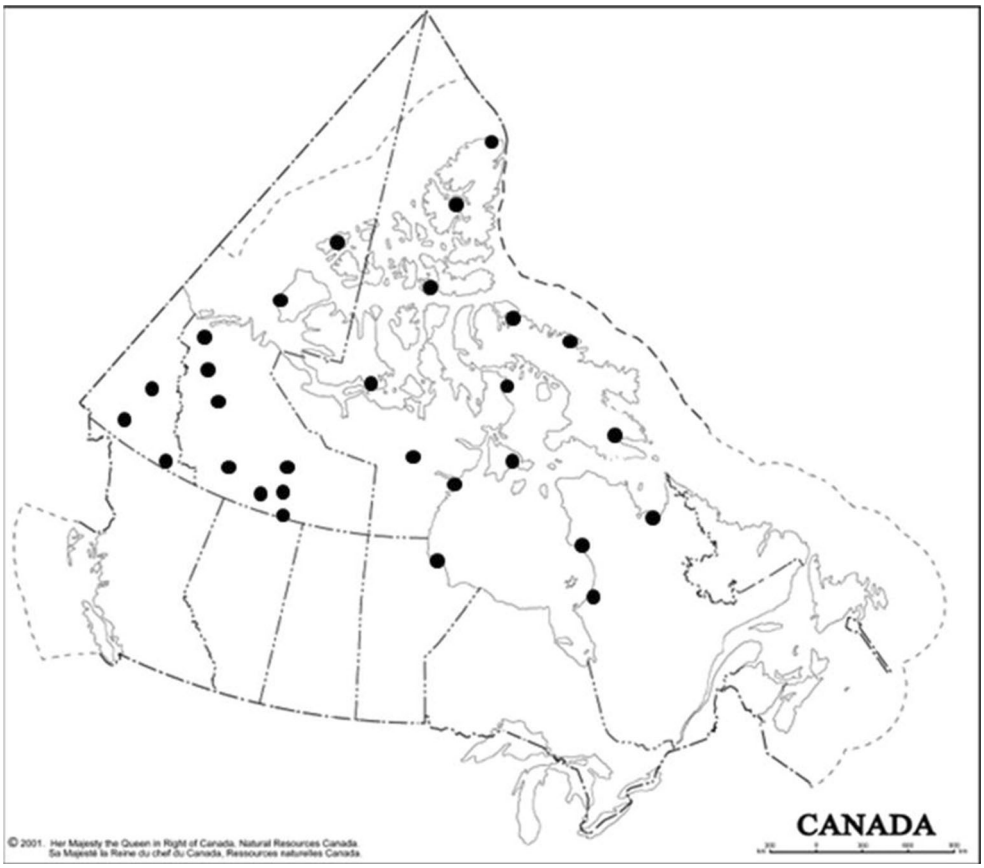

Fig. 1 Locations of Arctic stations examined in this study

consistently 1 °C lower than those observed at Fort Good Hope A. The data of station Fort Good Hope 2 were therefore adjusted by this temperature difference to generate a single homogenized time series encompassing the period 1910–2014 (Vincent et al. 2007).

Examples of January, July and annual temperatures plotted versus time are given in Fig. 2. These three stations are located in very different parts of the Canadian Arctic, yet all exhibit similar upward temperature trends. Trends were found by fitting a line to the data using a least squares fitting routine. Indeed, all but one of the 27 stations experienced increasing January, July and annual temperature trends. Nineteen of the 27 stations experienced larger January warming trends than those in July. The average of the January temperature trends was about 50 % larger than the corresponding value for July.

The data observed at each station is available for different periods of time as listed in Table 1. To examine climate change during the twentieth century, the average temperature experienced during 1961–1990 was found for each station and subtracted from the data, as shown in Fig. 2. The change in temperature was averaged over all the stations having data in a given year to generate the time series, as shown in Fig. 3. The resulting trends of 3.1, 1.6 and 1.9 °C per century were found for the January, July and annual temperatures, respectively. These values changed by only about 10 % when only the 12 stations were considered that began operation before 1935.

The trend determination depends on the time interval considered. This occurs because the trends are strongly affected by the phase of the decadal temperature fluctuations at the starting and end points of the time series. For example, during the period 1953–2014, the trends were 4.8, 3.5 and 3.3 °C per century for the January, July and annual temperatures, respectively. The reason for the larger trends is that temperatures were somewhat lower in the 1950s. This agrees with results found in studies that analyzed hourly measurements during 1953–2004 (Isaac and van Wijngaarden 2012 and Vincent et al. 2007). Temperatures appear to have increased during the first and last decades of the twentieth century. Before 1915, however, some caution is warranted since data was only available at four stations all located in the Northwest Territories. For the period 1915–1995, the annual temperature trend was only 0.4 °C per century. Figure 3 shows the increase in annual temperature

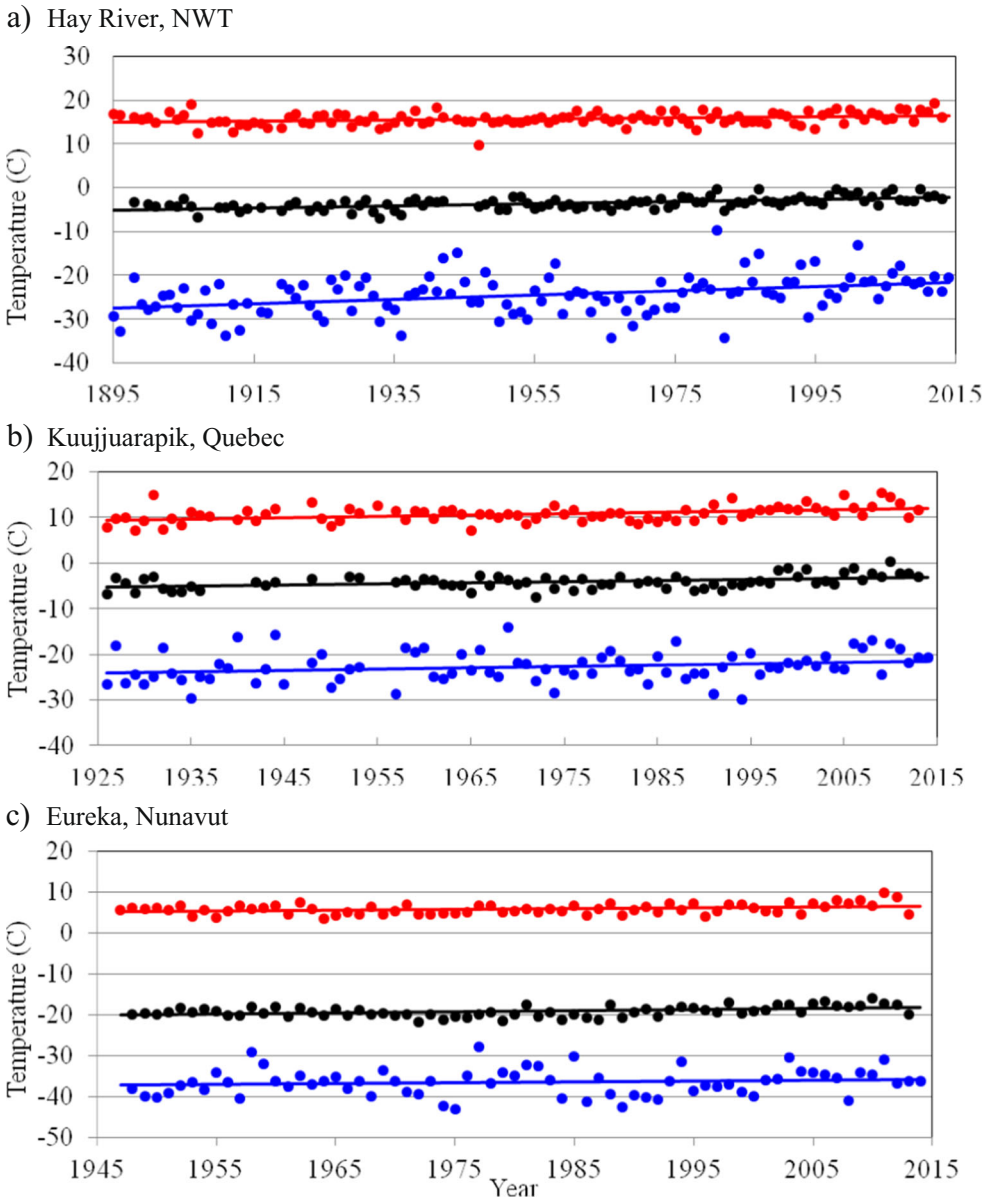

Fig. 2 Average temperatures observed at **a** Hay River located in the western Arctic, **b** Kuujuarapik in Quebec and **c** Eureka in northern Nunavut. The temperatures were found for January (*blue*), July (*red*) and annual (*black*). For Hay River, the slopes of the trend lines are 4.9, 1.1 and 2.4 °C per century for the January, July and annual data, respectively. The corresponding January, July and annual trends at Kuujuarapik are 2.9, 2.8 and 2.5 °C per century and at Eureka are 2.0, 2.3 and 2.8 °C per century

in the late 1990s appears to have levelled off after 2000 which is consistent with that found for the global average temperature (Climate 2013). Figure 4 shows the temperature change averaged over the four stations having the longest data record: Fort Good Hope, Fort Resolution, Fort Simpson and Hay River, all located in the Northwest Territories. In both Figs. 3 and 4, the moving 5-year average shows fluctuations of several degrees have occurred over decadal time scales.

The possibility of regional differences in trends between the western and eastern Arctic was also examined. For the 13 stations located in the Yukon and Northwest Territories, trends for the time period 1895–2014 were found of 2.3, 1.6 and 1.7 °C per century for the January, July and annual temperatures, respectively. At the 10 stations located in Manitoba, Quebec and in Nunavut at a latitude south of 70° N, the corresponding trends were 2.8, 2.1 and 1.4 °C per century. The data for these eastern stations was only available after 1923. Hence, both western and eastern parts of the Canadian Arctic have undergone a comparable warming.

3 Conclusions

Temperatures have increased in the Canadian Arctic during the period 1895–2014. The warming has been larger in January than in July. No major regional

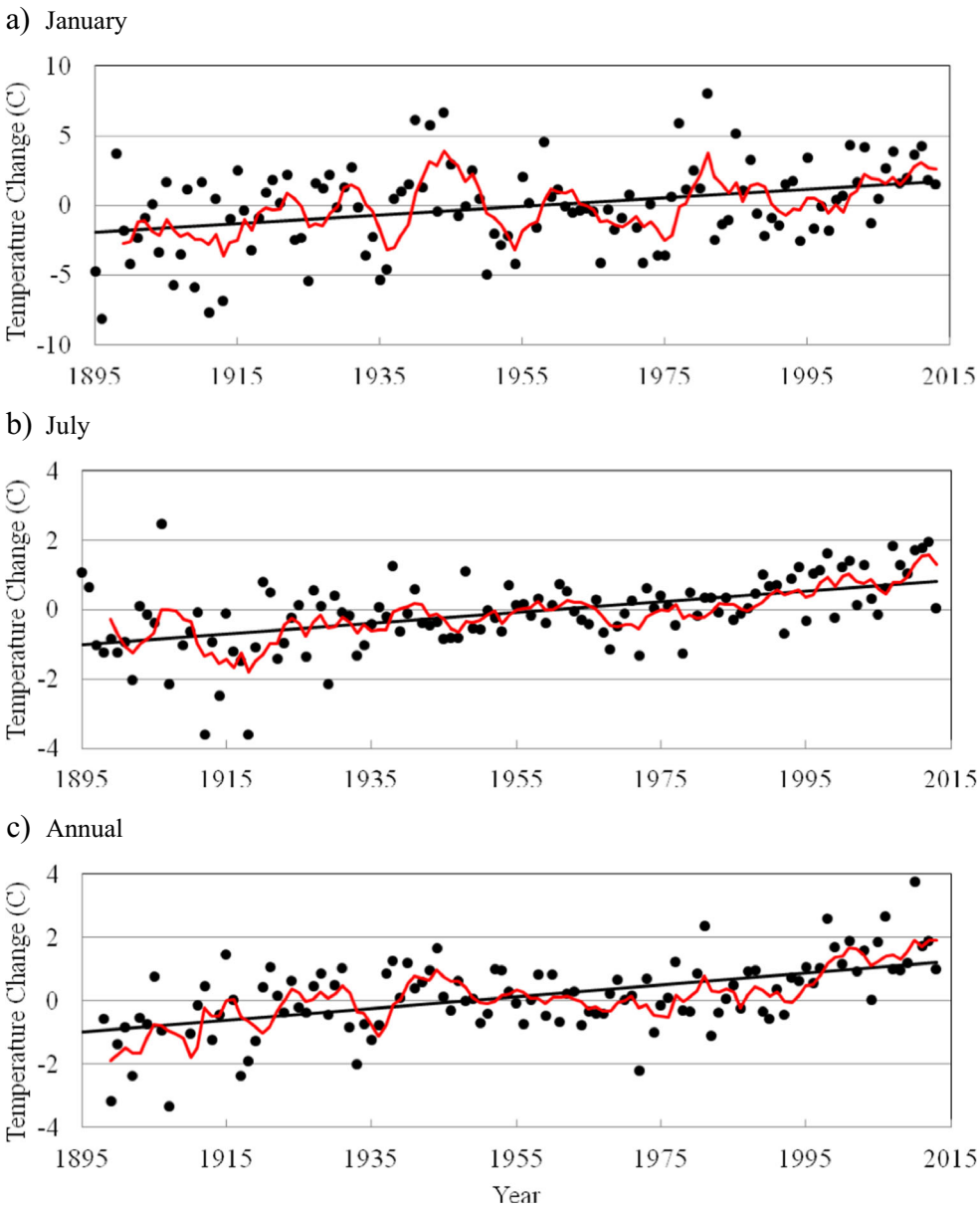

Fig. 3 Average of difference between temperatures observed at 27 stations with respect to the average temperature between 1961 and 1990 for **a** January, **b** July and **c** annual temperatures. The *red curves* are the moving 5-year averages. The *black trend lines* have slopes of 3.1, 1.6 and 1.9 °C per century for the January, July and annual data, respectively

difference between the eastern and western Arctic was evident. However, the warming has not occurred at a steady rate. The data albeit from only a few stations indicate that warming occurred during the 15 years after 1900. This was followed by about 80 years when warming was negligible. The moving 5-year average showed temperatures that fluctuated up and down on time scales of decades. Only in the late 1990s did temperatures increase followed by a levelling off after 2000. It will be interesting to see if this is followed by another upward temperature shift as predicted by global climate models (Climate 2013). The behaviour of temperature does not mirror the steady increase of carbon dioxide (Earth System Research Laboratory 2014). However, the global climate is very complex and is affected by many intertwined factors including variations of the solar intensity (Active Cavity Radiometer Irradiance Monitor ACRIM Total solar irradiance monitoring 1978; Ineson et al. 2011) and composition of various pollutants in the atmosphere such as aerosols (Myhre et al. 2013), volcanic activity (Self et al. 1996; McGee et al. 1997), ocean heat storage (Levitus et al. 2012), etc. Some of these influences are known to vary on time scales ranging from years to decades. Their effects on climate must therefore be carefully considered, and temperature trends determined from only a few decades of data may not obviously reflect the anthropogenic effect on climate.

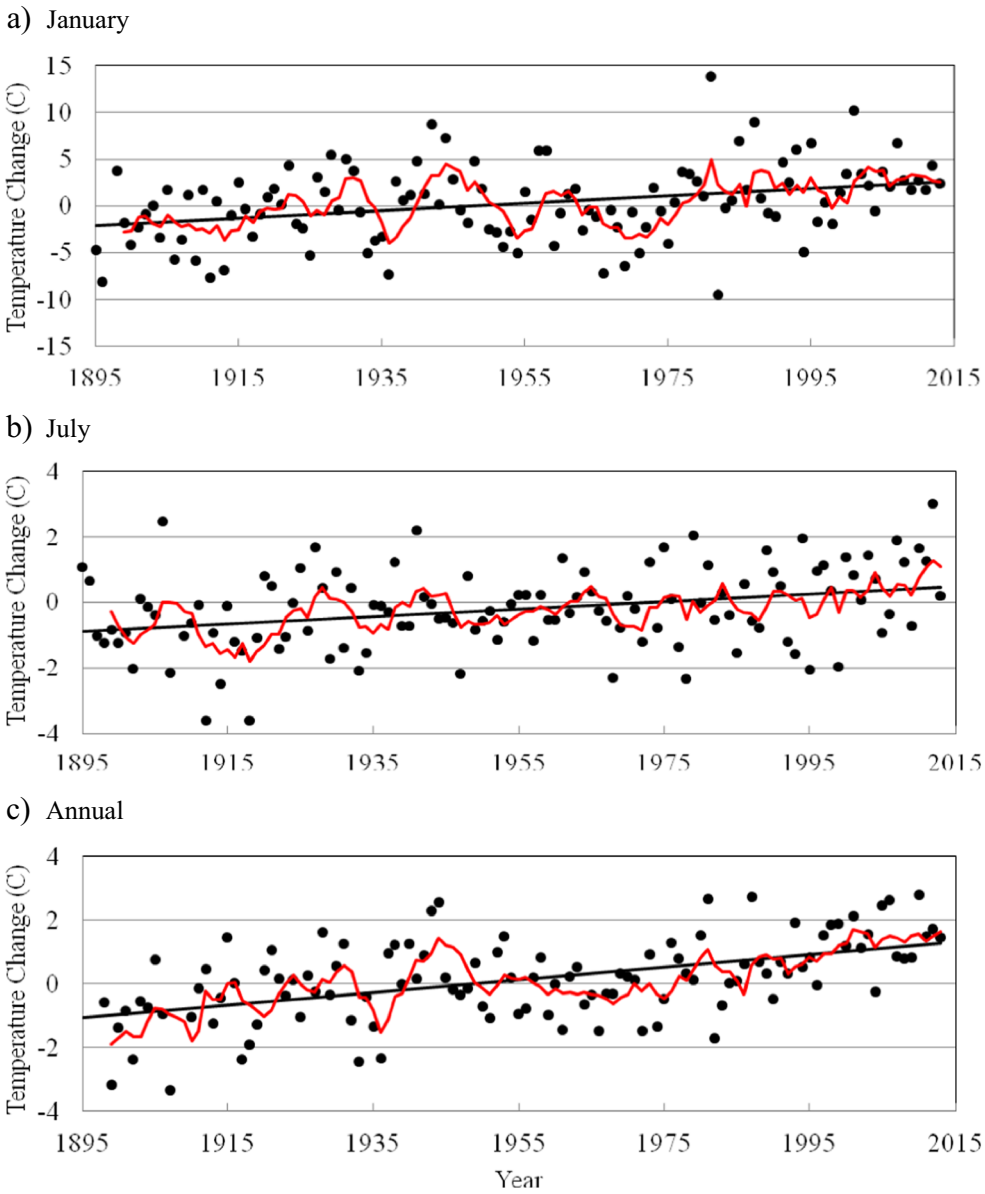

Fig. 4 Average of difference between temperatures observed at the four stations having the longest data record: Fort Good Hope, Fort Resolution, Fort Simpson and Hay River, with respect to the average temperature between 1961 and 1990 for **a** January **b** July and **c** annual temperatures. The *red curves* are the moving 5-year averages. The *black trend lines* have slopes of 3.9, 1.1 and 2.0 °C per century for the January, July and annual data, respectively

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