MULTI-CRITERIAL ANALYSIS OF SURFACE AIR TEMPERATURE PATTERNS IN ARCTIC CANADA

By

Charles E. Taylor

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
in Partial Fulfillment of the Requirements for
the Degree of Bachelor of Science: Environmental Science

April, 2012, Halifax, Nova Scotia

Approved: Dr. Cristian Suteanu

Honours Supervisor

Approved: Dr. Philip Giles

Second Reader

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ABSTRACT:

Interest in monitoring global climate has increased in recent years as the potential implications of climate change have come into the conscious of the public. Climate models and observations have shown that the polar regions are especially sensitive to climate change. This is especially concerning since the polar regions could experience several positive feedbacks as a result of increasing surface temperatures and/or change in their variability. The purpose of this study is to analyze surface air temperature data from nine weather stations in Arctic Canada to gain a better understanding of the status of the region's climate. Nine stations spread across the Canadian Arctic region were chosen from a larger database of homogenized surface temperature time series extracted from the National Climate Data Archive. The nine stations were chosen based on their length (equal or greater than 50 years). A multi-scale analysis was conducted to explore whether surface temperature patterns in Arctic Canada appear to be changing from the point of view of overall trends and temporal variability in the region. Pattern change was analyzed using a height-height correlation analysis of time series of different lengths. Statistical patterns examined using these methods include mean, standard deviation, range, moments on n^{th}, and the Hurst-exponent (for analyzing pattern persistence). The results indicate that there are spatial correlations in pattern persistence, and that the correlations change over time.

April, 2012

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Thank you goes out to all my friends for supporting me as well. You have been inspiration and support over the past years.

I would also like to thank Lucie Vincent from Environment Canada for providing Dr. Suteanu, myself, and the Environmental Studies department with the homogenized data used in this study.

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1.0 Introduction

According to observations and many climate models, the polar regions are especially vulnerable to global warming. These regions should experience the greatest and most rapid changes in both average daily temperatures and temperature variability at decadal-scales moving into the 'near' future (Przybylak, 2000).

The vulnerability of the polar regions is particularly concerning given the potential for several positive feedback situations to contribute to additional increase in temperatures and/or variability. According to a number of sources, positive feedbacks could include: "…ice and snow melt leading to decreases in surface albedo, atmospheric stability trapping temperature anomalies near to the surface, and cloud dynamics magnifying change." (Houghton et al.., 1990; Chapman and Walsh, 1993). Another concern is the large amount of carbon stored in the permafrost-covered wetlands of the Arctic region. Bacteria and fungi rapidly consume this carbon as the permafrost melts, and release carbon dioxide and methane. Atmospheric concentrations of methane and carbon dioxide have increase considerably over the last century, and the result of this feedback effect projects contribute to further increases in the future (Wuebbles and Hayhoe, 2002).

The purpose of this study is to analyze surface air temperature data from weather stations in Arctic Canada in order to gain a better understanding of the status of the region's climate in terms of variability. An analysis will be conducted in order to establish whether temperature patterns in Arctic Canada appear to be changing, from the point of view of overall trends and temporal variability in the region. Spatial consideration will also be given during this analysis, since the weather stations analyzed cover a large geographic area.

This analysis is expected to lead to a quantitative assessment of the surface air temperature pattern variability in the Canadian Arctic and its change on different time scales.

2.0 Literature Review

2.1 Influences on Surface Temperature in Arctic Canada

Even considering the large spatial area that comprises the Canadian Arctic, the climate is extremely diverse. Some generalizations of the climate are made here, followed by a look at the detailed subdivision of climatic regions developed by Maxwell (1982).

There are no universally accepted geographic limits for the Arctic or Arctic Canada. Defining criteria used in literature includes latitude, climate, or biogeography. In most cases, the southern limit of the Arctic Canadian region is defined at the 66.5622 ^{o}N line of latitude (thus defining Arctic Canada as the area north of the Arctic Circle) (Pryzbylak, 2003). The area of interest in this study includes the area of Canada located north of this latitudinal line.

The Arctic region is dominated by low net radiation (cold temperatures). Insolation levels are low because of the low angle of the Sun's rays on the region. In addition, about 75 to 90% of incoming solar radiation is reflected away from the surface by clouds, snow, and ice (Barry and Hare, 1974). Annual net radiation for Canada's Arctic islands ranges from about 0.3 to 0.9 GJ $m^{-2}y^{-1}$, while the southern Canadian city of Toronto receives about 1.9 GJ $m^{-2}y^{-1}$.

Proximity to the coast is a major influence on temperature in the Arctic. Generally, temperatures are significantly warmer at the coast during the winter, and significantly cooler in the summer. Interior regions have mean annual temperatures ranging from 2 to 8°C cooler than coastal areas. The warmer coastal winters are predominantly influenced by heat released from nearby seawater. Cooler summers are influenced by melting sea ice that withdraws heat from the lower atmosphere (Vowinckel and Orvig, 1996; Maxwell, 1980).

Topography also has an influence on surface temperatures in the Arctic. Deep valleys experience the lowest temperatures and strongest winds due to cold air drainage. Some of the coldest temperatures recorded in Arctic Canada have occurred at weather stations located in valleys (e.g., Eureka, Pond Inlet) as opposed to northernmost stations (Woo and Ohmura, 1997).

Most of the weather stations in Arctic Canada are located near the coastline, and because of the contrast in surface temperatures between coastal and interior regions in the Arctic, there is the potential for bias in attempting to analyze the entire region using the stations available. However, this is the best approach available given the limited availability of weather stations over the large area (Maxwell, 1982).

The topography of the Arctic Canada can be divided into two regions for the purpose of discussion: Upland and Lowland (Woo and Ohmura, 1997; Rouse et al.., 1997). The Arctic Upland includes the eastern portion of the Canadian Arctic Archipelago, and consists of rugged mountainous terrain, with occasional deep valleys. This mountain range acts as a barrier from the climatic influence of Baffin Bay (Woo and Ohmura, 1997). The result is a regional climate that receives comparatively more precipitation than the rest of Arctic Canada (approximately 400 mm y^{-1} compared to under 250 mm y^{1}) (Koerner, 1979). The Lowlands are shielded from the influence of Baffin Bay because of the high elevations to the northeast. The Upland region experiences some of the coldest temperatures as a result of the high latitude and high elevations.

2.3 Arctic Canada's Vulnerability to Climate Change

Interest in analyzing climate patterns has been increasing over the past few decades as scientifically viable evidence for contemporary global warming continues to build (Houghton et al.., 1995; Pryzbylak 2000). Special attention is being paid to the polar regions, as those areas are particularly sensitive to climate change. The Arctic and Antarctic are expected to experience the greatest change in climatic variability over the next number of decades (Ford et al.., 2006; Overland et al.., 2008; Kaufman et al.., 2009).

It is expected that the polar regions will experience the greatest magnitude of changes in climate, and experience change earlier than other areas (Pryzbylak, 2000).

The exceptional vulnerability of the region to climate change is due in large part to the great influence of ice and snow on the local climate (as described previously). Any changes to the annual temporal duration of snow and ice on land or in nearby seawater is certain to trigger significant changes to local microclimates. Any decrease in ice or snow on the surface produces a definite and immediate increase in net radiation at the surface, as the surface albedo decreases. Snowmelt one month earlier in the tundra regions of the sub-Arctic, for example, would increase net radiation levels during the spring and summer about 18% (Rouse et al.., 1992). The positive feedback cycle of ice and snow surface area loss resulting in increasing net radiation at the surface is a phenomenon that could have significant impacts both at local levels in the Arctic, as well as globally (Woo and Ohmura, 1997). Other feedbacks that may contribute to increasing surface temperatures include: atmospheric stability trapping temperature anomalies near to the surface, and cloud dynamics magnifying change. (Houghton et al.., 1990; Chapman and Walsh, 1993).

2.4 Recent Climate Trends in Arctic Canada

Most studies of surface temperature patterns in the Arctic have indicated a period of relatively steady warming from 1890 – 1970, a cooling trend from around 1965 - 1985, and another period of steady warming from 1980 – present (Thomas, 1975; Maxwell, 1980; Kaufman et al.., 2009). The rate of warming in the '1980 – present' period is greater than the rate of warming during the 1890 - 1970 (Przybylak, 2000).

According to proxy records, even if this period of cooling (1965 – 1985) is included, there is a significant increase in temperature anomalies since around 1980. This appears to reverses a long-term decrease in temperature anomalies over the past 2000 years (Kaufman et al.., 2009).

It should be noted that temperature records from most weather stations in the Arctic (especially in Arctic Canada) only begin post-World War II, and thus proxies have to be relied on for analyzing long-term trends dating beyond approximately 100 – 125 years. This study uses data provided from weather stations only.

Recent reports have shown significant reductions in the mass and surface area of the Arctic sea ice, as well as reductions in snow and ice cover on land. Permafrost also appears to be expanding in distribution northward, and diminishing to the south (Kaufman et al.., 2009). The summer of 2007 saw a 40% reduction in sea ice extent compared to all previous records of summer sea ice loss (Overland, 2008). The ice retreat observed over the recent half decade has been greater than projected by IPCC climate models (Stroeve et al.., 2007). Current projections of sea ice loss show that the Arctic could experience the first ice-free summer sometime between 2060 and 2080 (Boé et al.., 2009).

2.5 Multiscale Analysis of a Time Series

Multiscale analyses are useful for examining the variability and patterns of complex systems. Many natural patterns, such as climate systems, are indeed complex, and rigorous statistical analysis often have to be performed to acquire quantitatively viable representation of what is occurring over time in terms of variability and patterns. For interpreting patterns of surface temperature systems, multiscale analyses are often applicable (Suteanu, 2011).

A multiscale analysis is used in this study to analyze the temporal patterns and variability of surface temperature data sets in Arctic Canada. The height-height correlation method is used here for quantitative pattern analysis. By assessing complex patterns at different temporal scales, important properties can immerge, such as the irregularity of the pattern, or conversely, the persistence. The height-height correlation method has been shown to be especially useful for patterns showing self-affinity over time. Self-affinity is the characteristic of an object (in this case, a time series of surface temperatures) that demonstrates repeating patterns over time. Objects that show self-affinity are called fractal structures. Though self-affine time series can appear to be chaotic and irregular, when the pattern is smoothed and analyzed at different time scales, simple quantitative results can be obtained that allow for deciphering whether a the time series is experiencing pattern persistence or anti-persistence. The self-affinity of a pattern can be quantitatively represented by a power law function. In systems that reflect long-range correlations and patterns of approximately fractal repetition, multi-scale analyses can be used as effective methods for researching trends and patterns (Rybyski et al., 2008; Trinidad Segovia et al., 2012).

The multi-scale analysis here allows for quantitative measurements over multiple time scales, and plotting the relationship between the measurements and their scales. If there is indeed a power law relationship (i.e., if there is indeed a self-affine pattern), the logarithms of these variables will produce an approximately straight line on a graph. The slope of this straight line represents the exponent of the power law relationship. The exponent is a quantitatively viable description of the self-affine pattern in question (Bassingthwaighte and Raymond, 1995).

In the case of the height-height correlation method, one-half the exponent of the power law relationship of the self-affine pattern in question is called the Hurst exponent (H). This method includes measuring the time series at different scales, looking for any relationships between those different scales, and relating the results with the scales used. The Hurst exponent is the fractal exponent that describes the pattern of self-similarity in applicable complex patterns (Munteanu et al., 1995). The purpose of finding the Hurst exponent of the time series' analyzed in this study is to demonstrate quantitatively how surface temperature variability changes over time.

The Hurst exponent (H) of a *random* and uncorrelated time series is 0.5. This value of H indicates that there is no pattern persistence in the time series. These time series have a tendency for successful values to continuously change direction at every moment.

Time series that are quantitatively *persistent* have an *H* value between 0.5 and 1.0. Persistent time series have a tendency for successive values to continue in a similar direction as previous values, with less fluctuation against the pattern at greater scales. If the values of a time series tend to be increasing previous to a certain point, there is a greater probability for next successive values to also increase, as opposed to changing. Persistent time series appear to have a ‘smoother’ pattern on a graph with increasing values of *H*.

Time series with an *H* value between 0.5 and 0.0 are quantitatively *anti-persistent*. Anti-persistent time series have a greater tendency for successive values to change direction at each moment. This differs from a random time series (*H* = 0.5), in that successive values reverse direction more often. Anti-persistent time series have many fluctuations, and have are ‘noisy’ when plotted on a graph (as compared to the ‘smoothness’ of a persistent time series).

Time series can be persistent whether the time series is trending in a positive direction, negative direction, or without change. For studying climate change, a quantitative value of persistency does not convey information regarding temperatures warming or cooling, but rather relates to temperature variability. If the Hurst exponent is increasing, fluctuations for the overall pattern are decreasing, and the pattern is becoming smoother. Therefore, for surface temperatures, there is a decrease in daily temperature fluctuations, and in this sense, a decrease in variability. Average temperatures might be changing, but fluctuations from the overall pattern at different scales are decreasing (Bassingthwaighte and Raymond, 1995).

This method can be greatly skewed by unusual trend changes and outlying data, but this disadvantage can be overcome by normalizing and smoothing the time series to eliminate these trends. Another potential disadvantage is that the method is only useful for large datasets with at least 1000 datum per set (Malamud and Turcotte, 1990; Suteanu and Ioana, 2007).

3.0 Methodology

3.1 Study Area

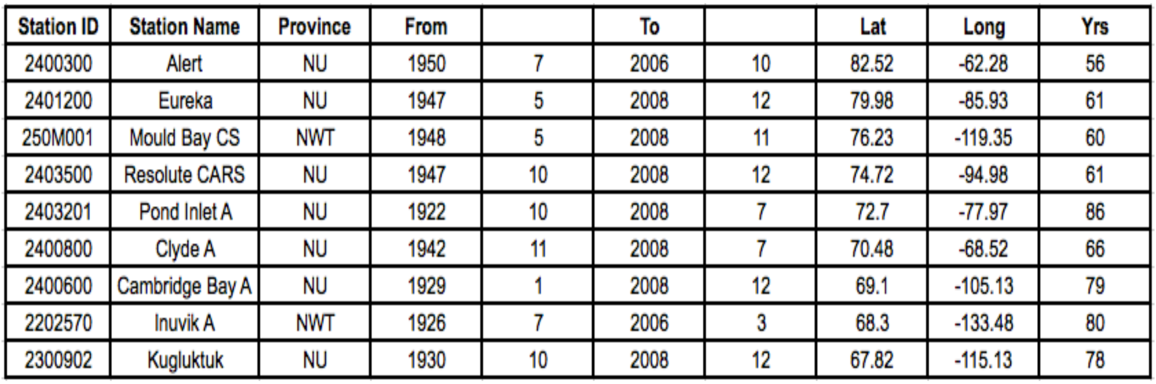
This study is concerned with analyzing surface temperature variability over time scales allotted by the availability of data in the Arctic region of Canada. Specifically, this includes the area of Canada north of the Arctic Circle (66.5622^{O}N). There are a total of sixteen weather stations in this region with readily available, homogenized, maximum and minimum daily temperature data sets. The data sets were provided by Environment Canada (Environment Canada, 2007).

The weather stations of interest for this study are located in: Alert, Cambridge Bay, Clyde, Eureka, Inuvik, Kugluktuk, Mould Bay, Pond Inlet, and Resolute (Figure 1).

Figure 1. Arctic Canada. The weather stations analyzed in this study are labeled.

Data sets with time periods greater than fifty years were chosen for analysis for this study. Under this criterion, nine of sixteen Arctic Canadian weather stations were chosen for analysis (Table 1).

Table 1. The list of weather stations within the Arctic Circle with daily temperature data available. The stations included in this study are those with a time series greater than 50 years. Stations are listed in order of descending latitude. Unlabeled columns are the month of the year listed in the previous column.



Station ID	Station Name	Province	From		To		Lat	Long	Yrs
2400300	Alert	NU	1950	7	2006	10	82.52	-62.28	56
2401200	Eureka	NU	1947	5	2008	12	79.98	-85.93	61
250M001	Mould Bay CS	NWT	1948	5	2008	11	76.23	-119.35	60
2403500	Resolute CARS	NU	1947	10	2008	12	74.72	-94.98	61
2403201	Pond Inlet A	NU	1922	10	2008	7	72.7	-77.97	86
2400800	Clyde A	NU	1942	11	2008	7	70.48	-68.52	66
2400600	Cambridge Bay A	NU	1929	1	2008	12	69.1	-105.13	79
2202570	Inuvik A	NWT	1926	7	2006	3	68.3	-133.48	80
2300902	Kugluktuk	NU	1930	10	2008	12	67.82	-115.13	78

3.2 Data Analysis

The computer program used for data preparation and analysis was MATLAB (version 7.10.00). MATLAB is numerical computing program that allows for statistical analysis using programming language. The program is useful for analyzing large data sets such as those in this study because of its efficiency.

For each station, maximum and minimum daily temperature data sets were analyzed separately, for a total of eighteen similar analyses conducted. Following this stage, the data sets were divided into segmented time intervals, with each interval analyzed using the same methods as used for the whole data sets.

The intervals were chosen based on the Arctic temperature pattern trends discussed by Chylek et al. (2009). Chylek et al. noted that Arctic surface temperatures were experiencing a warming period from the beginning of recorded data until about 1940. There was then a brief cooling period from 1940 until approximately 1970. And then from 1970 until the present, there has been a warming trend.

3.2.1 Data Analysis: Whole Time Series

The maximum and minimum data sets were analyzed using a multi-scale pattern analysis (height-height correlation method previously described) to determine quantitatively if the data shows pattern persistence. The mean daily temperature, maximum daily temperature, minimum daily temperature, temperature range (the difference between the maximum daily temperature and the minimum daily temperature), and standard deviation were also calculated for each data set.

In order to calculate the Hurst-exponent using the height-height correlation method, the data first has to be seasonally detrended (seasonal fluctuations removed). This was done by calculating the average temperature for each day from the whole data set, and subtracting each daily value from this average (Koscielny-Bunde et al., 1996).

Next, the detrended data set was normalized. Normalizing the data means to subtract the mean of the dataset for each daily value, and divide the result by the standard deviation of the data set. In doing so, the pattern is maintained, but the normalized data set has a mean of 0 and standard deviation of 1 (Suteanu and Ioana, 2007).

The trace of the normalized data set is then constructed by building a cumulative sum:

$$x_1 = y_1;\ \ x_2 = y_1 + y_2;\ \ x_3 = y_1 + y_2 + y_3;\ \text{etc.}$$

Here, x is the consecutive values of the new time series, and y is the consecutive daily surface temperatures from the original maximum or minimum temperature data sets (Suteanu and Ioana, 2007). This is a useful statistical application that highlights the patterns and trends of a data set. When the trace is plotted on a graph, the surface temperature trends of each data set become more readily detectable.

As mentioned, the Hurst exponent is calculated using the height-height correlation method. This method is applied to the normalized data set. The "height" differences between points separated by r (according to the y-axis) are taken and squared:

$$h(x) - h(x+r)$$

$M(r)$ is then calculated, which is the average of squared differences for each point pair. This is repeated for differing distances of r. The set of distances of r chosen for this study were beginning with (r=2), with each successive value of r multiplied by the previous by 1.2:

$$M(r) = <[h(x) - h(x+r)]^2>_x$$

If there is a power law relationship between M and r, there should be an approximately linear relationship visible when the two variables are plotted against one another in log-log form (over a certain scale range). The slope of the linear relation is $2H$, where H is the Hurst exponent:

$$M(r) = r^{2H}$$

Finally, the Hurst exponent is analyzed, which indicates the degree of pattern persistence. If the Hurst exponent is greater than 0.5, the pattern is persistent. If it is less than 0.5, it is a pattern of anti-persistence. If it is 0.5, the data is random (representing a stochastic process).

The Hurst exponent was calculated for each maximum and minimum daily surface temperature data set at each of the nine weather stations.

3.2.2 Data Analysis: Temporal Segments

The segments for this analysis are based on Chylek et al. (2009):

1. Start of time series – December 31, 1939.
2. January 1, 1940 – December 31, 1969.
3. January 1, 1970 – End of time series.

For some weather stations, the data set begins after January 1940, so these sets are divided into two segments (Alert, Clyde, Eureka, Kugluktuk, Mould Bay, Resolute). The weather stations with data beginning before January 1940 are divided into 3 (Cambridge Bay, Inuvik, Pond Inlet).

Each segment was then analyzed using the same methodology as was used in the previous section for the whole data sets. The Hurst exponent was calculated, along with the mean temperature, maximum temperature, minimum temperature, range, and standard deviation.

4.0 Results

4.1 Summary Tables

The following tables (2 – 4) provide a summary of the results.

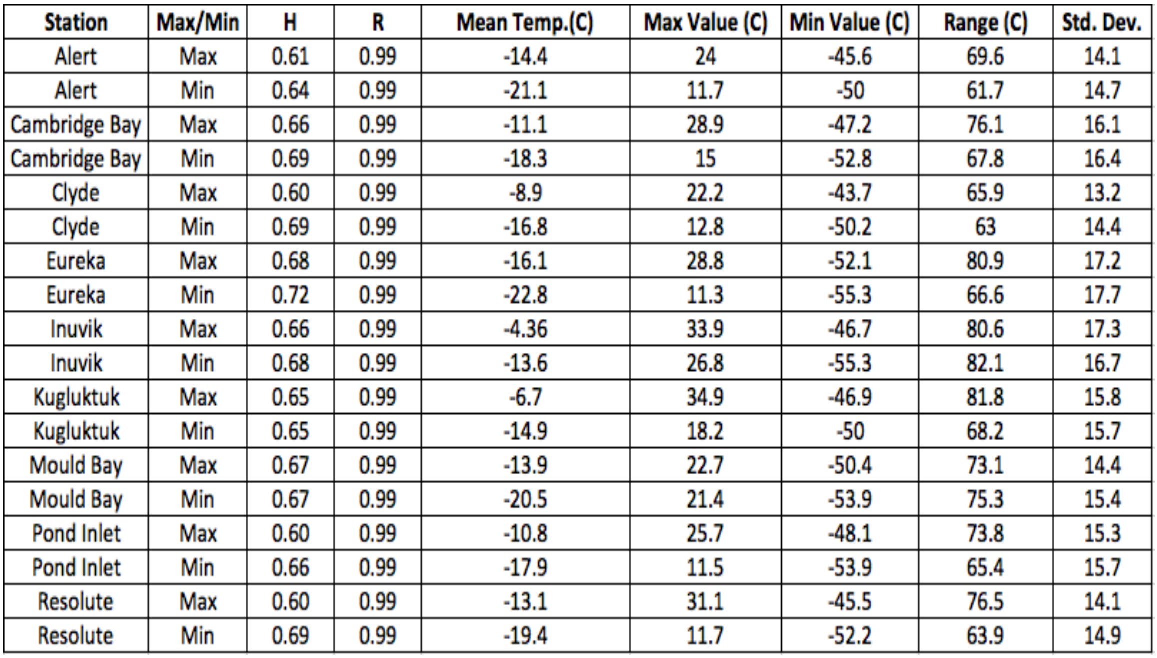
Note**:** Data is missing in the following datasets:

- Pond Inlet: Data missing from Dec. 1, 1960 – Dec. 21, 1974

- Cambridge Bay: Data missing from Jan. 1 1939 – Dec. 31, 1939

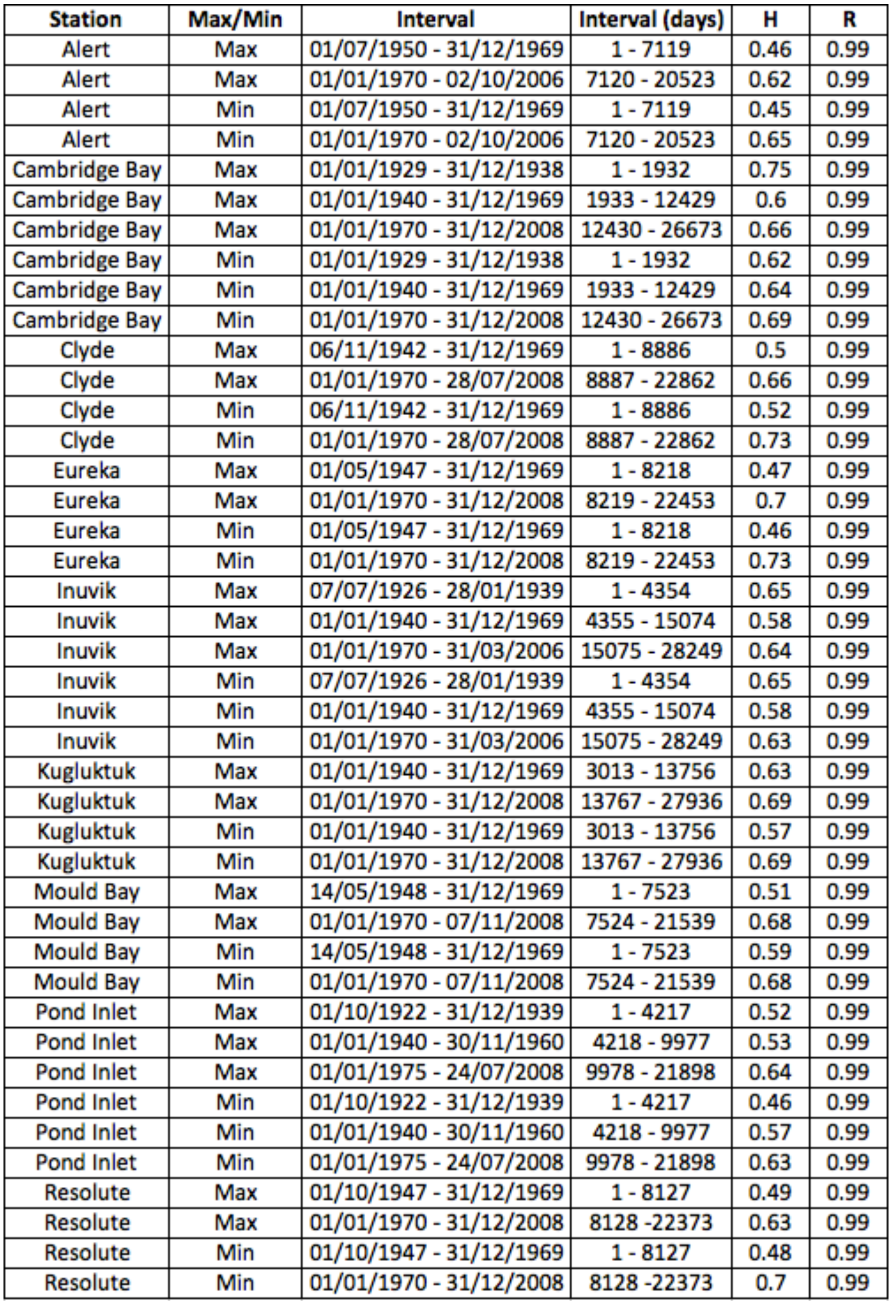
- Inuvik: Data missing from Mar. 1, 1939 – Dec. 31, 1939

Table 2: Summary of results for the analysis of the whole time series (maximum and minimum surface temperature data sets for each weather station). Criteria shown include: H (Hurst exponent), and R (correlation coefficient for the height-height correlation analysis).



Station	Max/Min	H	R	Mean Temp.(C)	Max Value (C)	Min Value (C)	Range (C)	Std. Dev.
Alert	Max	0.61	0.99	-14.4	24	-45.6	69.6	14.1
Alert	Min	0.64	0.99	-21.1	11.7	-50	61.7	14.7
Cambridge Bay	Max	0.66	0.99	-11.1	28.9	-47.2	76.1	16.1
Cambridge Bay	Min	0.69	0.99	-18.3	15	-52.8	67.8	16.4
Clyde	Max	0.60	0.99	-8.9	22.2	-43.7	65.9	13.2
Clyde	Min	0.69	0.99	-16.8	12.8	-50.2	63	14.4
Eureka	Max	0.68	0.99	-16.1	28.8	-52.1	80.9	17.2
Eureka	Min	0.72	0.99	-22.8	11.3	-55.3	66.6	17.7
Inuvik	Max	0.66	0.99	-4.36	33.9	-46.7	80.6	17.3
Inuvik	Min	0.68	0.99	-13.6	26.8	-55.3	82.1	16.7
Kugluktuk	Max	0.65	0.99	-6.7	34.9	-46.9	81.8	15.8
Kugluktuk	Min	0.65	0.99	-14.9	18.2	-50	68.2	15.7
Mould Bay	Max	0.67	0.99	-13.9	22.7	-50.4	73.1	14.4
Mould Bay	Min	0.67	0.99	-20.5	21.4	-53.9	75.3	15.4
Pond Inlet	Max	0.60	0.99	-10.8	25.7	-48.1	73.8	15.3
Pond Inlet	Min	0.66	0.99	-17.9	11.5	-53.9	65.4	15.7
Resolute	Max	0.60	0.99	-13.1	31.1	-45.5	76.5	14.1
Resolute	Min	0.69	0.99	-19.4	11.7	-52.2	63.9	14.9

Table 3: Summary of results for the analysis of the segmented time series. Criteria shown include: the segment interval (dates), the time interval of the segment in days, H (Hurst exponent), and R (correlation coefficient for the height-height correlation analysis).



Station	Max/Min	Interval	Interval (days)	H	R
Alert	Max	01/07/1950 - 31/12/1969	1 - 7119	0.46	0.99
Alert	Max	01/01/1970 - 02/10/2006	7120 - 20523	0.62	0.99
Alert	Min	01/07/1950 - 31/12/1969	1 - 7119	0.45	0.99
Alert	Min	01/01/1970 - 02/10/2006	7120 - 20523	0.65	0.99
Cambridge Bay	Max	01/01/1929 - 31/12/1938	1 - 1932	0.75	0.99
Cambridge Bay	Max	01/01/1940 - 31/12/1969	1933 - 12429	0.6	0.99
Cambridge Bay	Max	01/01/1970 - 31/12/2008	12430 - 26673	0.66	0.99
Cambridge Bay	Min	01/01/1929 - 31/12/1938	1 - 1932	0.62	0.99
Cambridge Bay	Min	01/01/1940 - 31/12/1969	1933 - 12429	0.64	0.99
Cambridge Bay	Min	01/01/1970 - 31/12/2008	12430 - 26673	0.69	0.99
Clyde	Max	06/11/1942 - 31/12/1969	1 - 8886	0.5	0.99
Clyde	Max	01/01/1970 - 28/07/2008	8887 - 22862	0.66	0.99
Clyde	Min	06/11/1942 - 31/12/1969	1 - 8886	0.52	0.99
Clyde	Min	01/01/1970 - 28/07/2008	8887 - 22862	0.73	0.99
Eureka	Max	01/05/1947 - 31/12/1969	1 - 8218	0.47	0.99
Eureka	Max	01/01/1970 - 31/12/2008	8219 - 22453	0.7	0.99
Eureka	Min	01/05/1947 - 31/12/1969	1 - 8218	0.46	0.99
Eureka	Min	01/01/1970 - 31/12/2008	8219 - 22453	0.73	0.99
Inuvik	Max	07/07/1926 - 28/01/1939	1 - 4354	0.65	0.99
Inuvik	Max	01/01/1940 - 31/12/1969	4355 - 15074	0.58	0.99
Inuvik	Max	01/01/1970 - 31/03/2006	15075 - 28249	0.64	0.99
Inuvik	Min	07/07/1926 - 28/01/1939	1 - 4354	0.65	0.99
Inuvik	Min	01/01/1940 - 31/12/1969	4355 - 15074	0.58	0.99
Inuvik	Min	01/01/1970 - 31/03/2006	15075 - 28249	0.63	0.99
Kugluktuk	Max	01/01/1940 - 31/12/1969	3013 - 13756	0.63	0.99
Kugluktuk	Max	01/01/1970 - 31/12/2008	13767 - 27936	0.69	0.99
Kugluktuk	Min	01/01/1940 - 31/12/1969	3013 - 13756	0.57	0.99
Kugluktuk	Min	01/01/1970 - 31/12/2008	13767 - 27936	0.69	0.99
Mould Bay	Max	14/05/1948 - 31/12/1969	1 - 7523	0.51	0.99
Mould Bay	Max	01/01/1970 - 07/11/2008	7524 - 21539	0.68	0.99
Mould Bay	Min	14/05/1948 - 31/12/1969	1 - 7523	0.59	0.99
Mould Bay	Min	01/01/1970 - 07/11/2008	7524 - 21539	0.68	0.99
Pond Inlet	Max	01/10/1922 - 31/12/1939	1 - 4217	0.52	0.99
Pond Inlet	Max	01/01/1940 - 30/11/1960	4218 - 9977	0.53	0.99
Pond Inlet	Max	01/01/1975 - 24/07/2008	9978 - 21898	0.64	0.99
Pond Inlet	Min	01/10/1922 - 31/12/1939	1 - 4217	0.46	0.99
Pond Inlet	Min	01/01/1940 - 30/11/1960	4218 - 9977	0.57	0.99
Pond Inlet	Min	01/01/1975 - 24/07/2008	9978 - 21898	0.63	0.99
Resolute	Max	01/10/1947 - 31/12/1969	1 - 8127	0.49	0.99
Resolute	Max	01/01/1970 - 31/12/2008	8128 -22373	0.63	0.99
Resolute	Min	01/10/1947 - 31/12/1969	1 - 8127	0.48	0.99
Resolute	Min	01/01/1970 - 31/12/2008	8128 -22373	0.7	0.99

Table 4: Summary of results for the analysis of the segmented time series (maximum and minimum surface temperature data sets for each weather station). Criteria shown include: mean, maximum, and minimum temperatures, temperature range, and standard deviation.

Station	Max/Min	Interval	Interval (days)	Mean Temp. (C)	Max Value (C)	Min Value (C)	Range (C)	Std. Dev.
Alert	Max	01/07/1950 - 31/12/1969	1 - 7119	-14.3	20	-45	65	14.2
Alert	Max	01/01/1970 - 02/10/2006	7120 - 20523	-14.5	24	-45.6	69.6	14.1
Alert	Min	01/07/1950 - 31/12/1969	1 - 7119	-21.2	11.7	-48.9	60.6	14.8
Alert	Min	01/01/1970 - 02/10/2006	7120 - 20523	-21.1	11.5	-50	61.5	14.6
Cambridge Bay	Max	01/01/1929 - 31/12/1938	1 - 1932	-11.4	28.9	-45	73.9	16.3
Cambridge Bay	Max	01/01/1940 - 31/12/1969	1933 - 12429	-11.5	23.9	-46.7	70.6	16.1
Cambridge Bay	Max	01/01/1970 - 31/12/2008	12430 - 26673	-10.7	26.9	-47.2	74.1	16
Cambridge Bay	Min	01/01/1929 - 31/12/1938	1 - 1932	-20.1	13.9	-52.8	66.7	16.8
Cambridge Bay	Min	01/01/1940 - 31/12/1969	1933 - 12429	-19	15	-50.6	65.6	16.4
Cambridge Bay	Min	01/01/1970 - 31/12/2008	12430 - 26673	-18	13	-49.5	62.5	16.3
Clyde	Max	06/11/1942 - 31/12/1969	1 - 8886	-8.7	22.2	-41.4	63.6	13.2
Clyde	Max	01/01/1970 - 28/07/2008	8887 - 22862	-9	21.7	-43.7	65.4	13.3
Clyde	Min	06/11/1942 - 31/12/1969	1 - 8886	-16.7	9	-48.2	57.2	14.3
Clyde	Min	01/01/1970 - 28/07/2008	8887 - 22862	-16.9	12.8	-50.2	63	14.5
Eureka	Max	01/05/1947 - 31/12/1969	1 - 8218	-16.3	19.4	-50.4	69.8	17.2
Eureka	Max	01/01/1970 - 31/12/2008	8219 - 22453	-15.9	28.8	-52.1	80.9	17.2
Eureka	Min	01/05/1947 - 31/12/1969	1 - 8218	-23.1	9.1	-54.4	63.5	17.9
Eureka	Min	01/01/1970 - 31/12/2008	8219 - 22453	-22.5	11.3	-55.3	66.6	17.6
Inuvik	Max	07/07/1926 - 28/01/1939	1 - 4354	-5.25	33.9	-46.7	80.6	17.1
Inuvik	Max	01/01/1940 - 31/12/1969	4355 - 15074	-4.6	31.7	-46.7	78.4	17.2
Inuvik	Max	01/01/1970 - 31/03/2006	15075 - 28249	-3.88	32.8	-45	77.8	17.3
Inuvik	Min	07/07/1926 - 28/01/1939	1 - 4354	-15.1	18.2	-49.2	67.4	16.8
Inuvik	Min	01/01/1940 - 31/12/1969	4355 - 15074	-13.9	19.4	-55.3	74.7	16.9
Inuvik	Min	01/01/1970 - 31/03/2006	15075 - 28249	-12.9	26.8	-54	80.8	16.5
Kugluktuk	Max	01/01/1940 - 31/12/1969	3013 - 13756	-7	33.7	-46.9	80.6	15.8
Kugluktuk	Max	01/01/1970 - 31/12/2008	13767 - 27936	-6.3	34.9	-43.5	78.4	15.8
Kugluktuk	Min	01/01/1940 - 31/12/1969	3013 - 13756	-15.3	16.7	-50	66.7	15.8
Kugluktuk	Min	01/01/1970 - 31/12/2008	13767 - 27936	-14.5	18.2	-47.8	66	15.6
Mould Bay	Max	14/05/1948 - 31/12/1969	1 - 7523	-14.1	15.6	-48.9	64.5	14.5
Mould Bay	Max	01/01/1970 - 07/11/2008	7524 - 21539	-13.9	22.7	-50.4	73.1	14.3
Mould Bay	Min	14/05/1948 - 31/12/1969	1 - 7523	-20.7	8.3	-53.9	62.2	15.6
Mould Bay	Min	01/01/1970 - 07/11/2008	7524 - 21539	-20.4	21.4	-53.9	75.3	15.3
Pond Inlet	Max	01/10/1922 - 31/12/1939	1 - 4217	-11.4	20	-43.3	63.3	15.3
Pond Inlet	Max	01/01/1940 - 30/11/1960	4218 - 9977	-9.7	19.4	-46.7	66.1	15
Pond Inlet	Max	01/01/1975 - 24/07/2008	9978 - 21898	-11.1	25.7	-48.1	73.8	15.5
Pond Inlet	Min	01/10/1922 - 31/12/1939	1 - 4217	-18.1	10	-48.9	58.9	16
Pond Inlet	Min	01/01/1940 - 30/11/1960	4218 - 9977	-17.1	8.3	-53.3	61.6	15.8
Pond Inlet	Min	01/01/1975 - 24/07/2008	9978 - 21898	-18.4	11.5	-53.9	65.4	15.6
Resolute	Max	01/10/1947 - 31/12/1969	1 - 8127	-13.4	18.3	-45.1	63.2	14.2
Resolute	Max	01/01/1970 - 31/12/2008	8128 -22373	-13	31.1	-45.4	76.5	14
Resolute	Min	01/10/1947 - 31/12/1969	1 - 8127	-19.9	11.7	-52.2	63.9	15.2
Resolute	Min	01/01/1970 - 31/12/2008	8128 -22373	-19.1	9.9	-52	61.9	14.7

4.2 Samples of maximum daily temperatures from each station

The following sets of figures are the samples of maximum daily surface temperatures taken from each weather station. The days selected are days 1000 – 1999 from each time series. Because the date in which data started being accumulated varies between stations, the actual dates also vary (defined in each figure description).

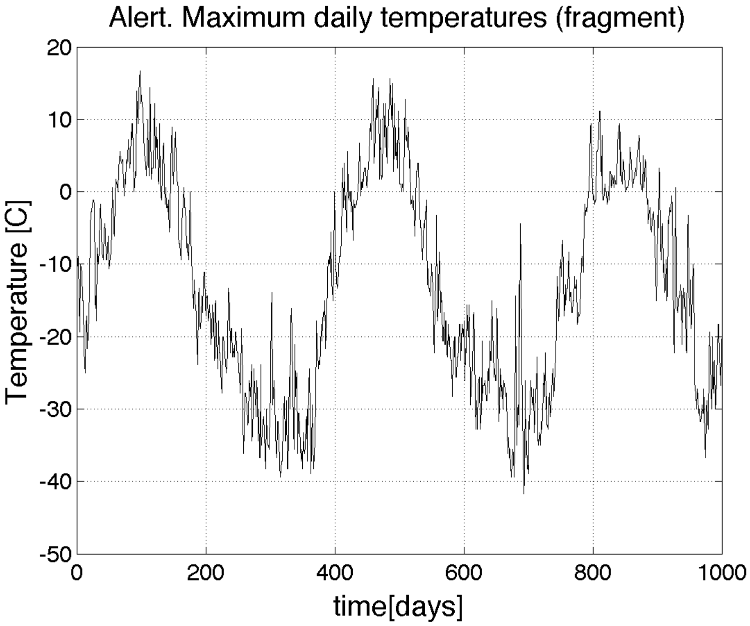


Figure 2: A sample of maximum daily surface temperatures at the Alert weather station. This sample includes day 1000 to 1999 of the data set: from January 7, 1950 to October 2, 1952.

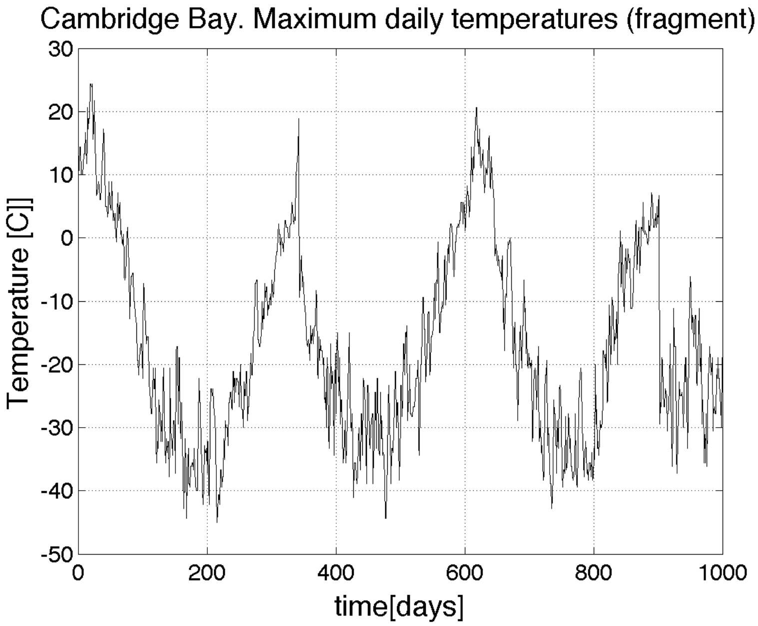


Figure 3: A sample of maximum daily surface temperatures at the Cambridge Bay weather station. This sample includes day 1000 to 1999 of the data set: from January 1, 1929 to September 27, 1931.

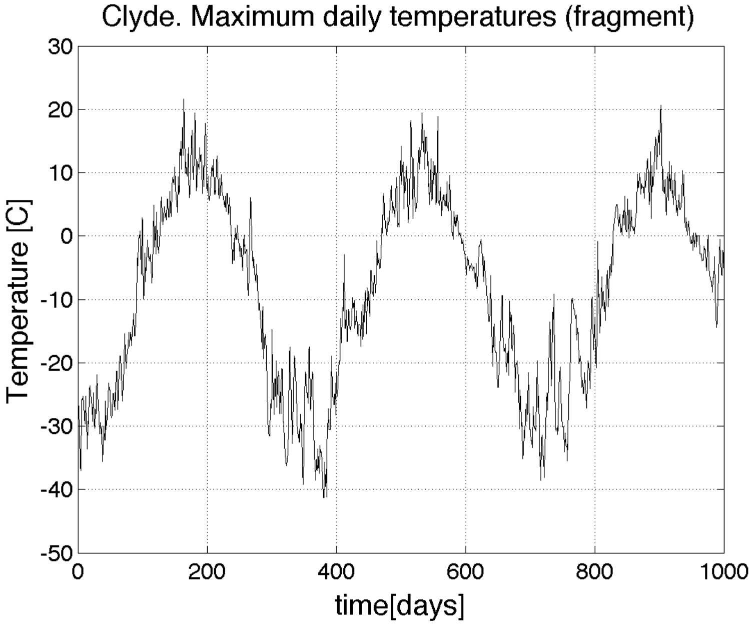


Figure 4: A sample of maximum daily surface temperatures at the Clyde weather station. This sample includes day 1000 to 1999 of the data set: from November 6, 1942 to March 6, 1945.

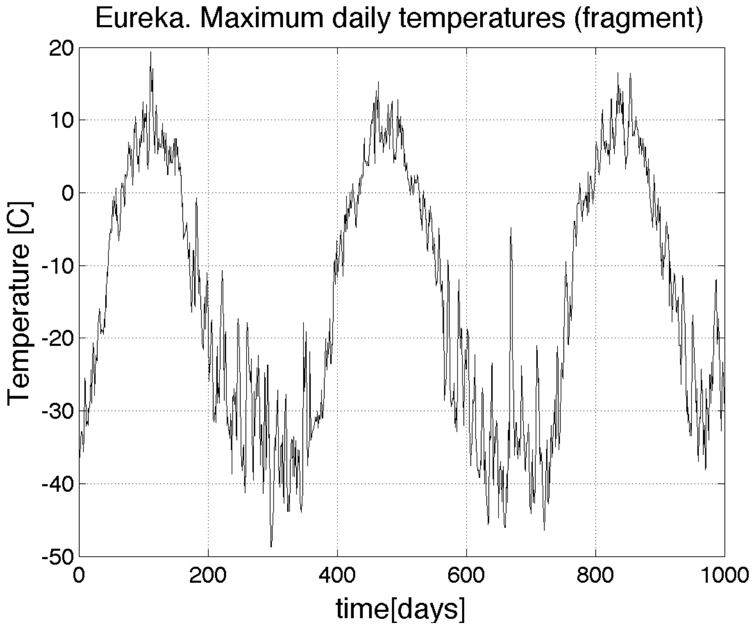


Figure 5: A sample of maximum daily surface temperatures at the Eureka weather station. This sample includes day 1000 to 1999 of the data set: from January 5, 1947 to September 30, 1949.

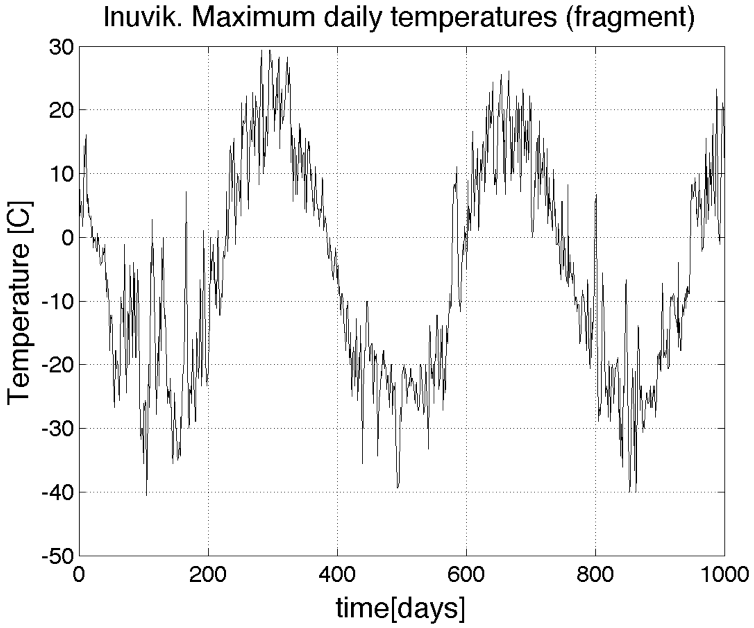


Figure 6: A sample of maximum daily surface temperatures at the Inuvik weather station. This sample includes day 1000 to 1999 of the data set: from July 7, 1926 to April 1, 1929.

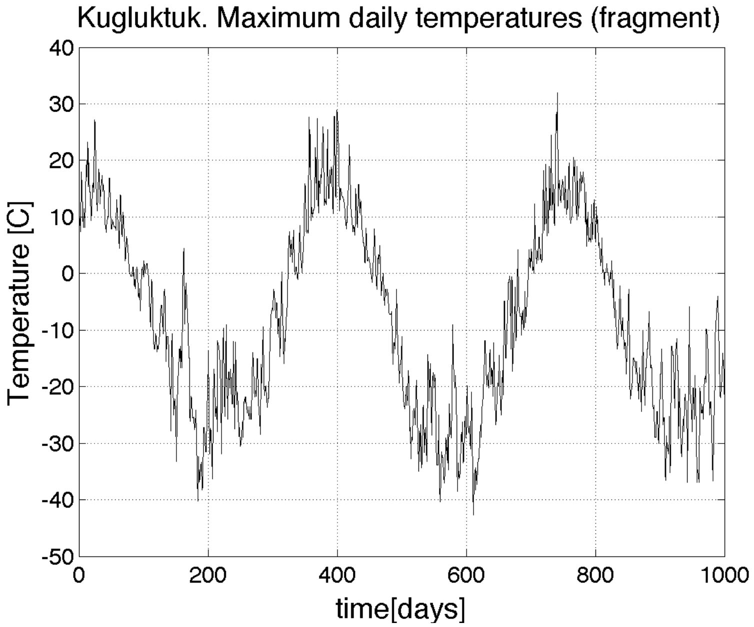


Figure 7: A sample of maximum daily surface temperatures at the Kugluktuk weather station. This sample includes day 1000 to 1999 of the data set: from January 1, 1940 to September 26, 1942.

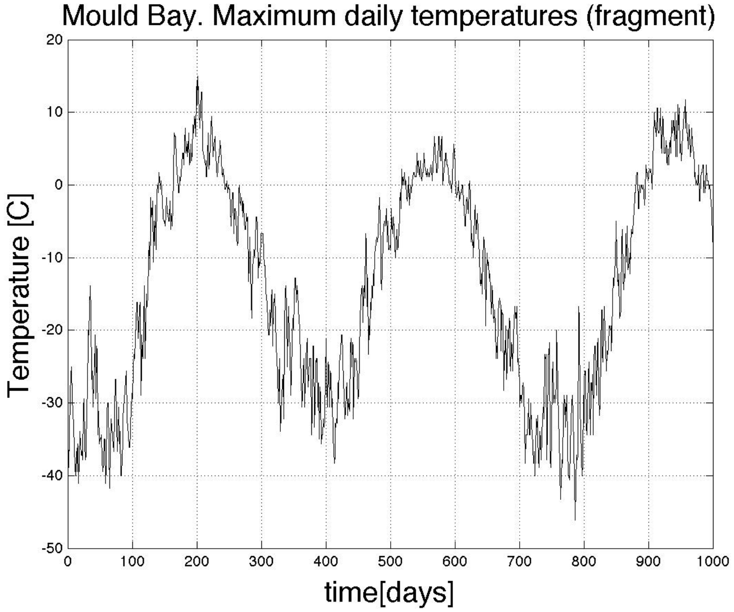


Figure 8: A sample of maximum daily surface temperatures at the Mould Bay weather station. This sample includes day 1000 to 1999 of the data set: from May 14, 1948 and February 7, 1951.

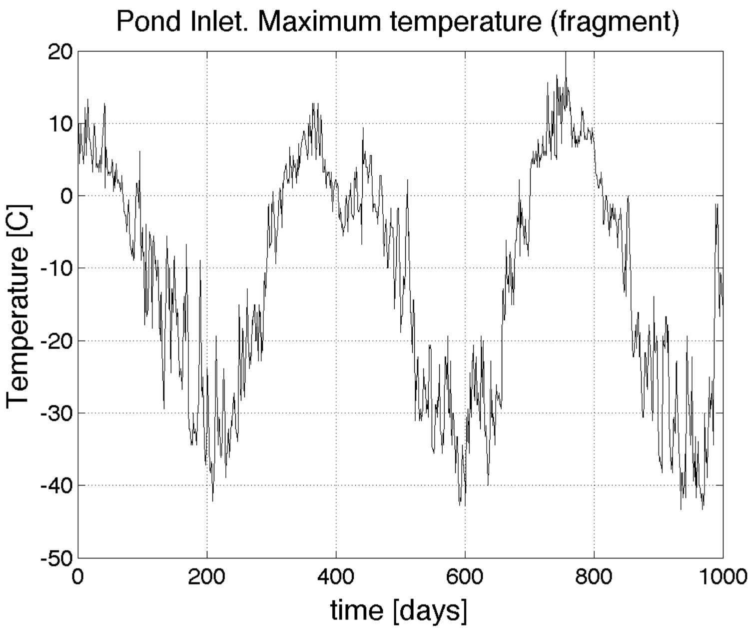


Figure 9: A sample of maximum daily surface temperatures at the Pond Inlet weather station. This sample includes day 1000 to 1999 of the data set: from October 1, 1922 to June 26, 1925.

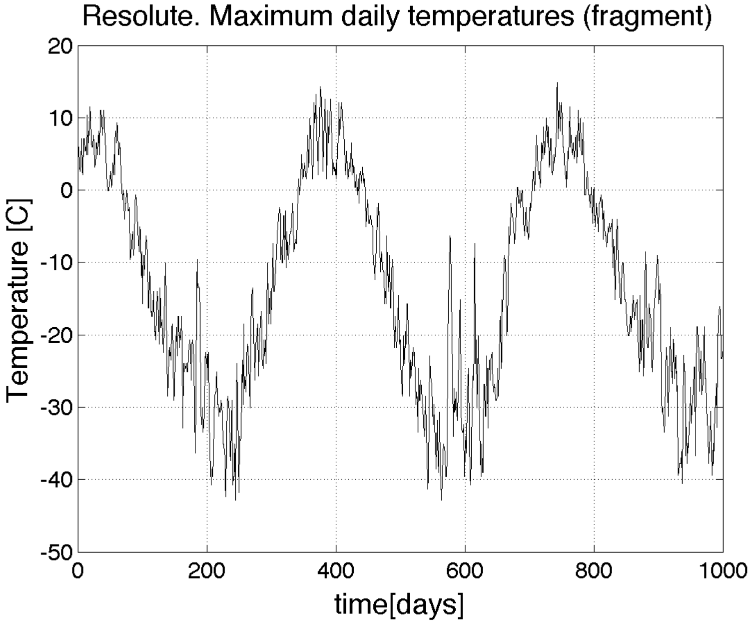


Figure 10: A sample of maximum daily surface temperatures at the Resolute weather station. This sample includes day 1000 to 1999 of the data set: from October 1, 1947 to June 26, 1950.

Figures 2 – 10 show 1000-day samples of maximum daily surface temperature records for each weather station. One reason for showing these samples was to give a sense of the seasonal fluctuations found at each location. The primary reason was to demonstrate the pattern of self-similarity of surface temperatures at different temporal scales. Approximate self-similarity can be noted at scales as small as several days, or over seasons, with the constant shift in temperature direction that occurs bi-annually. Though approximate self-similarity is found in all of the samples, the patterns are different from each other, and it is probable that these patterns change at different temporal scales. The point of using the height-height correlation analysis to find the Hurst exponents of each time series is to quantitatively describe each pattern in terms of persistency, and to see how these patterns change over time.

4.3 Examples of time series (minimum temperatures)

The following are examples of time series from three minimum daily surface temperature data sets (whole time series). The three stations used as examples are Alert, Resolute, and Kugluktuk. These specific stations are chosen for their varying spatial location (Alert being the northernmost weather stations, Resolute being at a approximately central location, and Kugluktuk being the furthest south). For each example, a sample time series (day 1000 – 1999), seasonally detrended time series, and traced time series, are shown (three figures each).

4.3.1 Examples of time series (minimum temperatures): Alert, NU

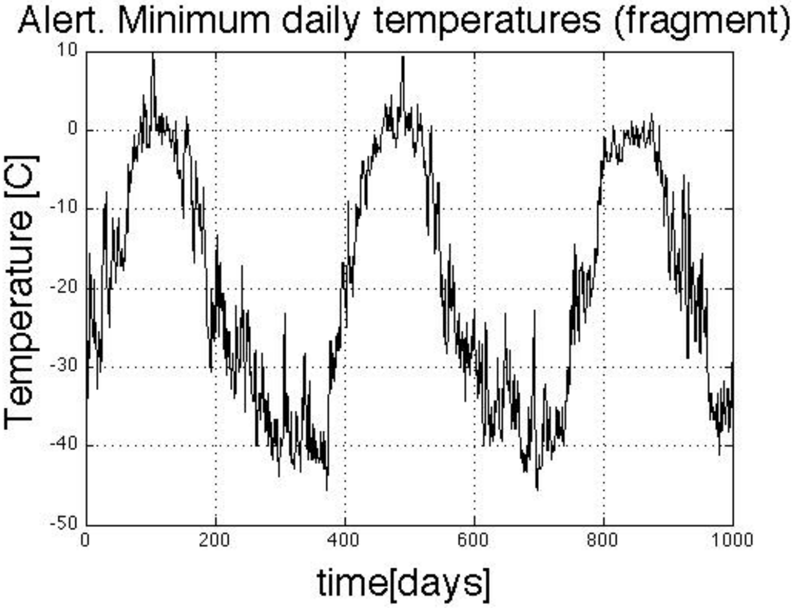


Figure 11: A sample of minimum daily surface temperatures at the Alert weather station. This sample includes day 1000 to 1999 of the data set: from January 7, 1950 to October 2, 1952.

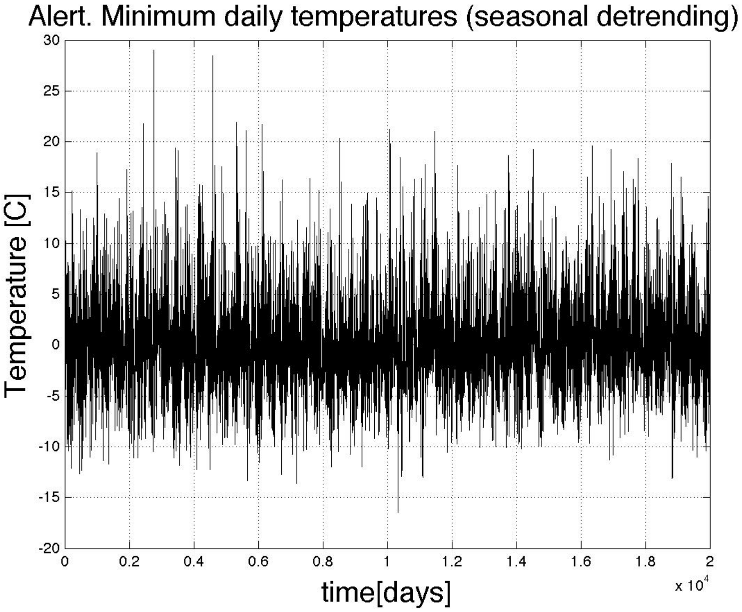


Figure 12: Detrended minimum daily surface temperatures at the Alert weather station.

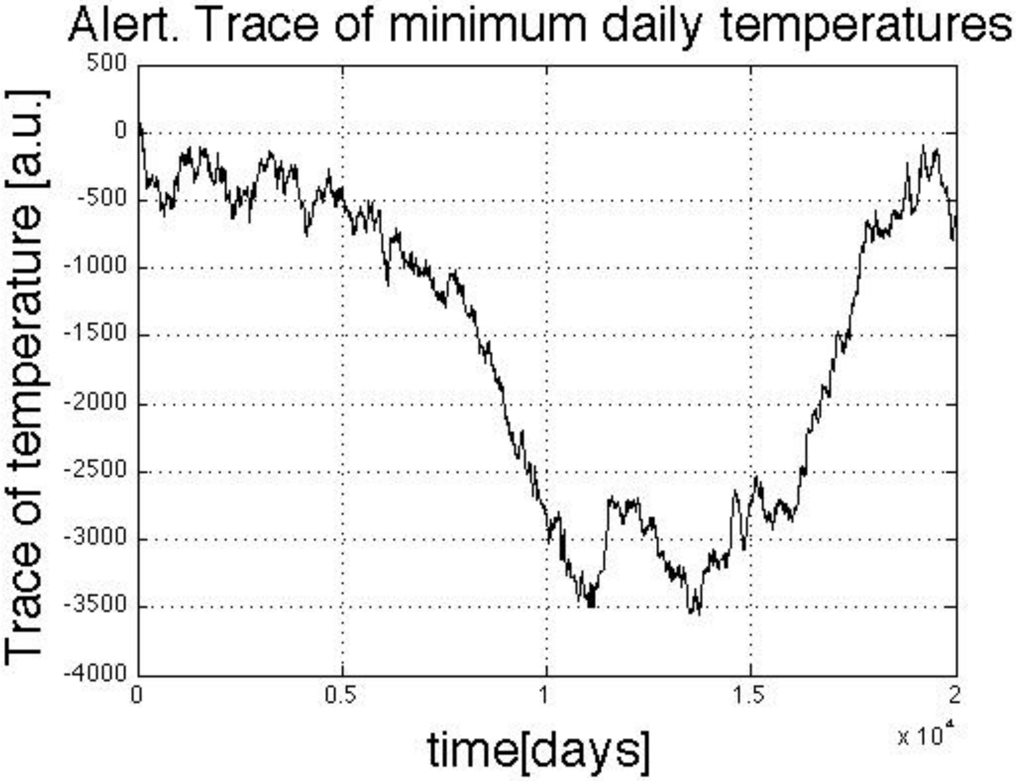


Figure 13: Trace of minimum daily surface temperatures at Alert.

4.3.2 Examples of time series (minimum temperatures): Resolute, NU

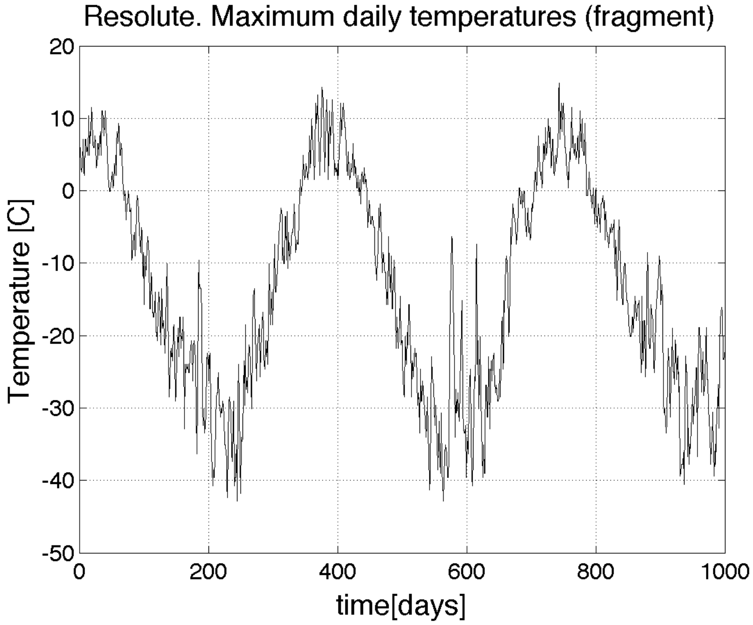


Figure 14: A sample of minimum daily surface temperatures at the Resolute weather station. This sample includes day 1000 to 1999 of the data set: from October 1, 1947 to June 26, 1950.

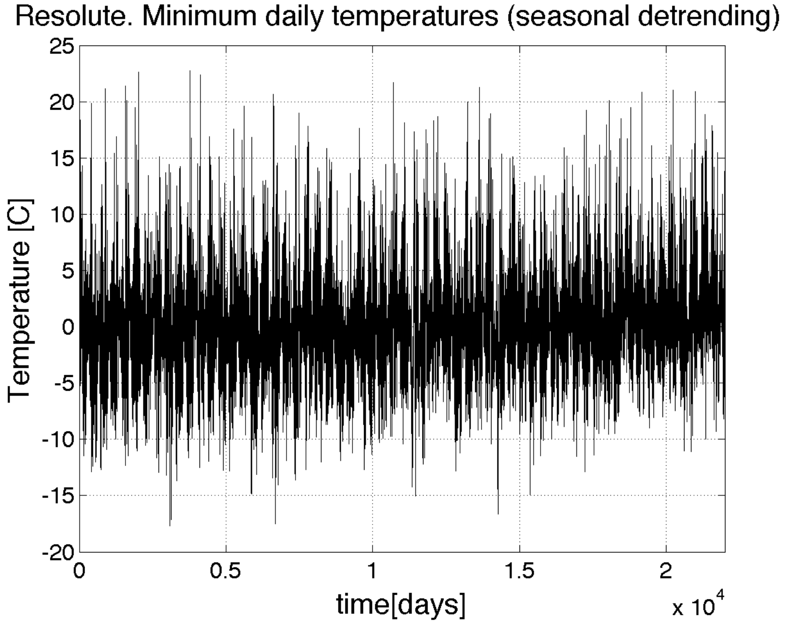


Figure 15: Detrended minimum daily surface temperatures at the Resolute station.

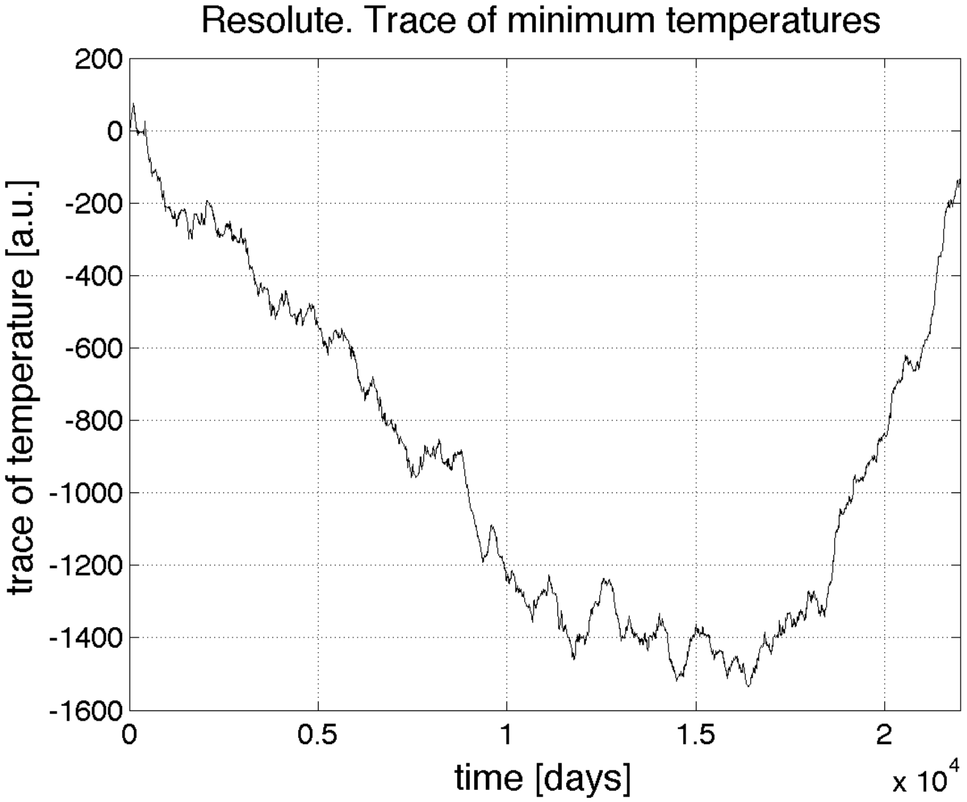


Figure 16: Trace of minimum daily surface temperatures at Resolute.

4.3.3 Examples of time series (minimum temperatures): Kugluktuk, NU

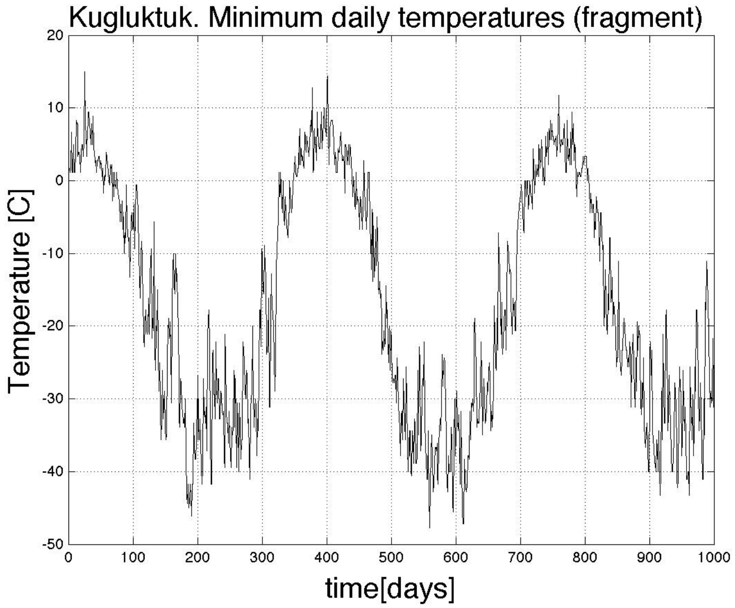


Figure 17: A sample of minimum daily surface temperatures at the Kugluktuk weather station. This sample includes day 1000 to 1999 of the data set: from January 1, 1940 to September 26, 1942.

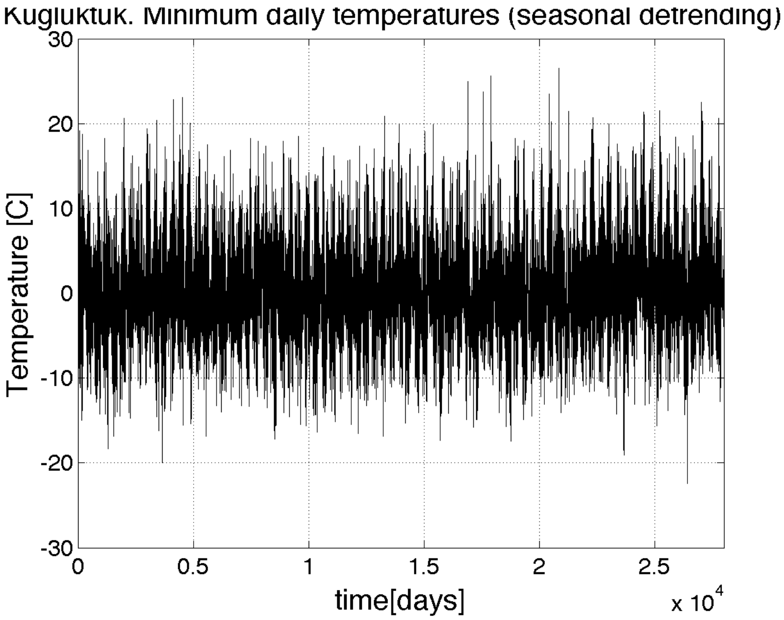


Figure 18: Detrended minimum daily surface temperatures at the Kugluktuk station.

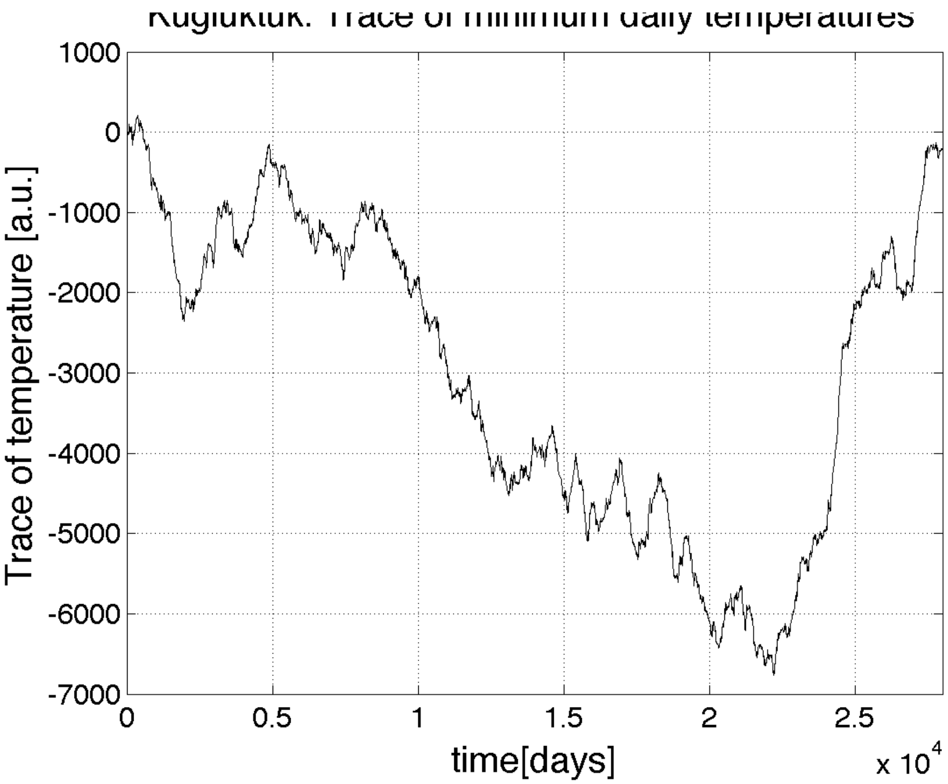


Figure 19: Trace of minimum daily surface temperatures at Kugluktuk.

Figures 11, 14, 17 demonstrate 1000-day samples of minimum daily surface temperature records for Alert, Resolute, and Kugluktuk. These figures are shown for similar reasons as to the 1000-day samples of maximum daily surface temperatures shown in Section 5.2: to demonstrate self-similarity, and show seasonal fluctuations for these three stations.

Figures 12, 15, 18 demonstrate examples of the seasonally detrended time series (methodology explained in Section 4.2.1). By seasonally detrending each time series, the seasonal fluctuations are removed. This is done so that the height-height correlation for pattern persistence analyzes the change in pattern of each daily temperature for each individual day of the year, rather than the yearly changes found by natural seasonal fluctuations. In this way, daily temperature variability was highlighted, rather than seasonal patterns. Creating a seasonally detrended time series was the first procedure performed on each time series before calculating the Hurst exponent.

Figures 13, 16, 19 demonstrate examples of traced time series. The trace of each time series was created by using a cumulative sum method (Section 4.2.1). By developing the trace, the time series is ‘smoothed’, eliminating the noise of daily temperature fluctuations while emphasizing long-term trends. By eliminating the high degree of fluctuations over short temporal scales, the large scale patterns are remained, and it is the quantitative analysis of these larger patterns that is of interest in terms of analyzing climate variability (climate studies being interest in long-term weather patterns).

These three weather stations all have a time series length that can be divided into two segments for analysis: they contain a period of cooling and warming described by Chylek et al., 2007. These periods are clearly visible in the figures depicting the traced time series (Fig. 13, 16, 19).

4.5 Height-height correlation examples

The following three figures are examples of the height-height correlation analysis performed on each time series in order to determine the Hurst exponent. The three examples are the same as in the previous section (Alert, Resolute, Kugluktuk). The analyses shown here were performed on the whole data sets of maximum daily surface temperatures.

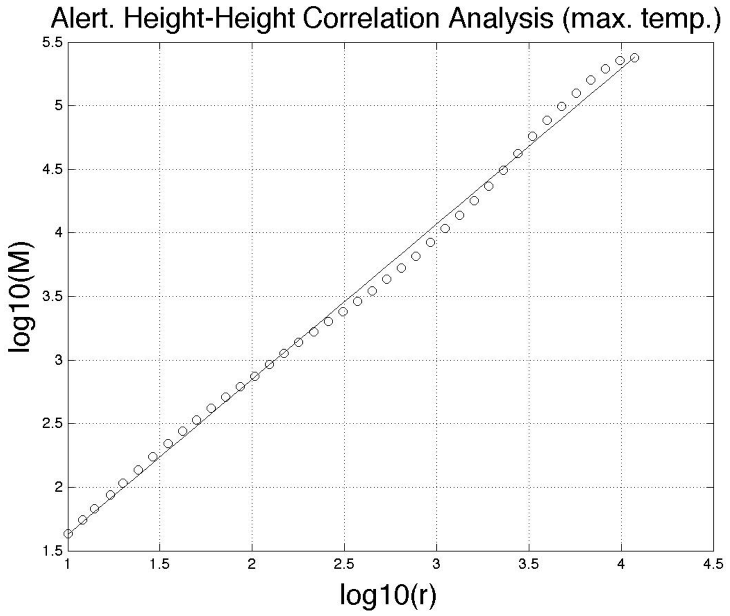


Figure 20: Height-height correlation analysis for Alert (maximum data set). $H = 0.61$, R = 0.99.

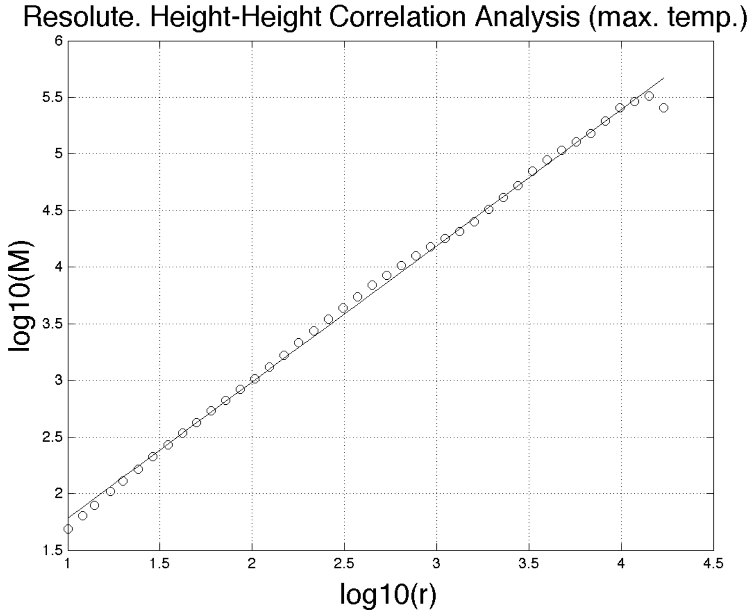


Figure 21: Height-height correlation analysis for Resolute (maximum data set). *H* = 0.60, R = 0.99.

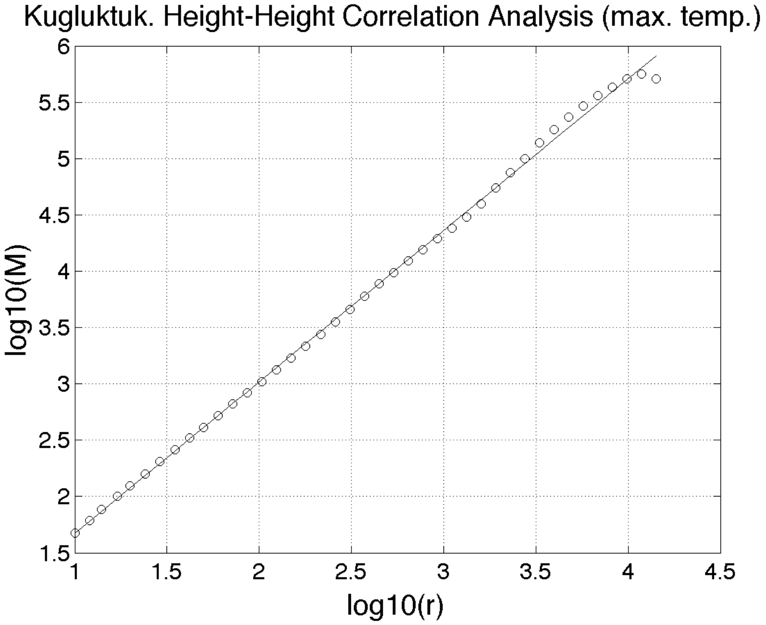


Figure 22: Height-height correlation analysis for Kugluktuk (maximum data set). *H* = 0.65, R = 0.99.

The approximately straight line formed when the logarithmic relationship of scale size *r* and the average of squared differences for each point pair h(x) and h(x+r) (Section 4.2.1) shows the approximate self-similarity of surface temperatures over time. When the linear correlation is plotted, one-half the slope of the line is equal the Hurst exponent of the time series. Here, each station has an *H* value of: $0.6 < x < 0.65$, quantitatively showing that each time series has pattern persistence.

4.6 Interval time series

The following graphs depict how maximum daily surface temperatures changed over the intervals in this analysis. As mentioned, the intervals are divided in two or three, based on Chylek et al., 2007: 1) Beginning of time series – 1940, 1940 – 1970, 1970 – end of time series. Based on these criteria, some time series were divided into two intervals, and others into three intervals.

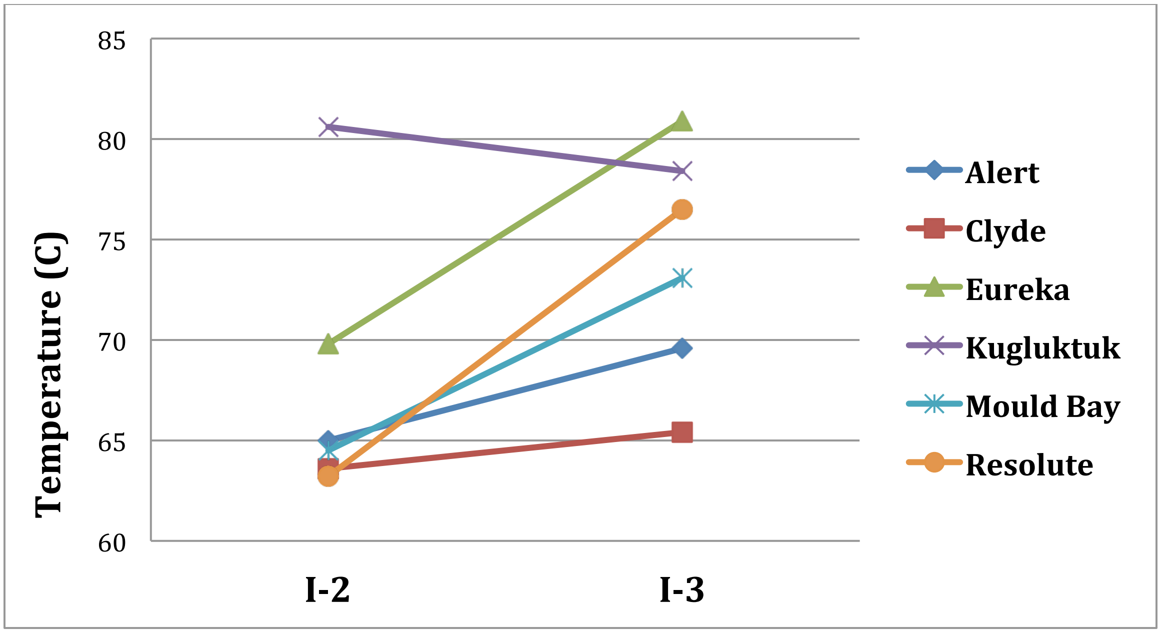


Figure 23: Comparative view of change in temperature ranges for the stations with two intervals (approximately (1) 1940 – 1970 & (2) 1970 – 2005). Taken from maximum daily temperature data sets. For specific intervals dates, see: Table 4.

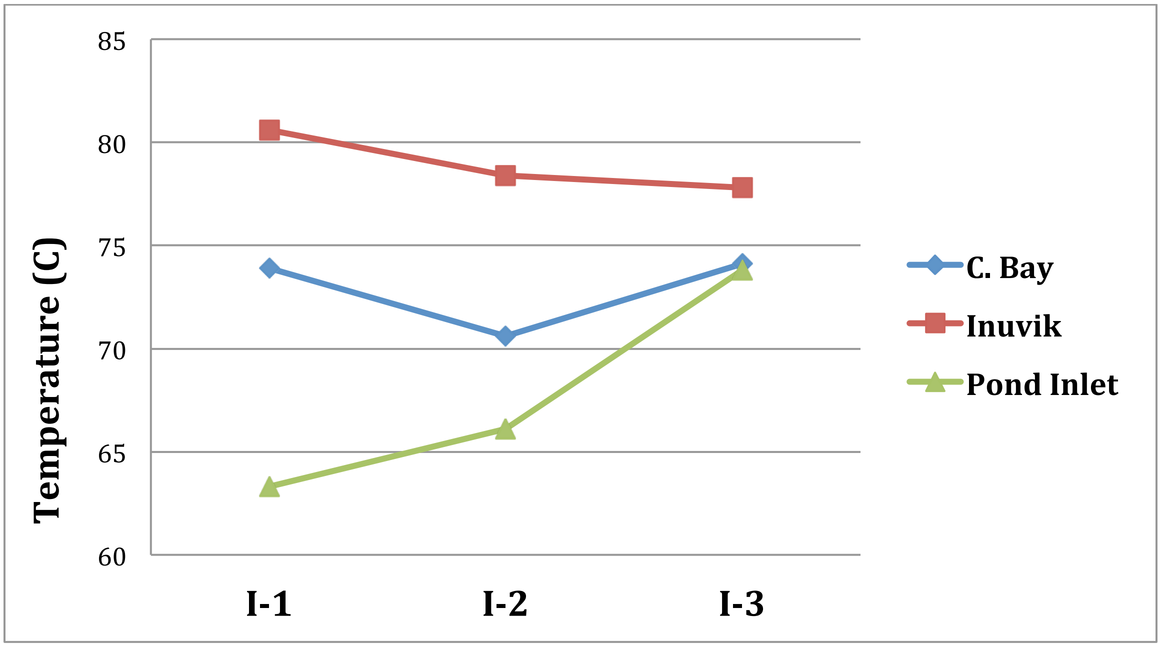


Figure 24: Comparative view of change in temperature ranges for the stations with three intervals (approximately (1) 1920 – 1940, (2) 1940 – 1970 & (3) 1970 – 2005). Taken from maximum daily temperature data sets. For specific intervals dates, see: Table 4.

The change in maximum daily temperature range for each station was positive for seven out of nine stations. The two stations that had decreases in range were Kugluktuk and Inuvik, which are the two southernmost stations of this analysis. The increase in range shows that the difference between maximum daily temperature values and minimum daily temperature values has increased over this time period.

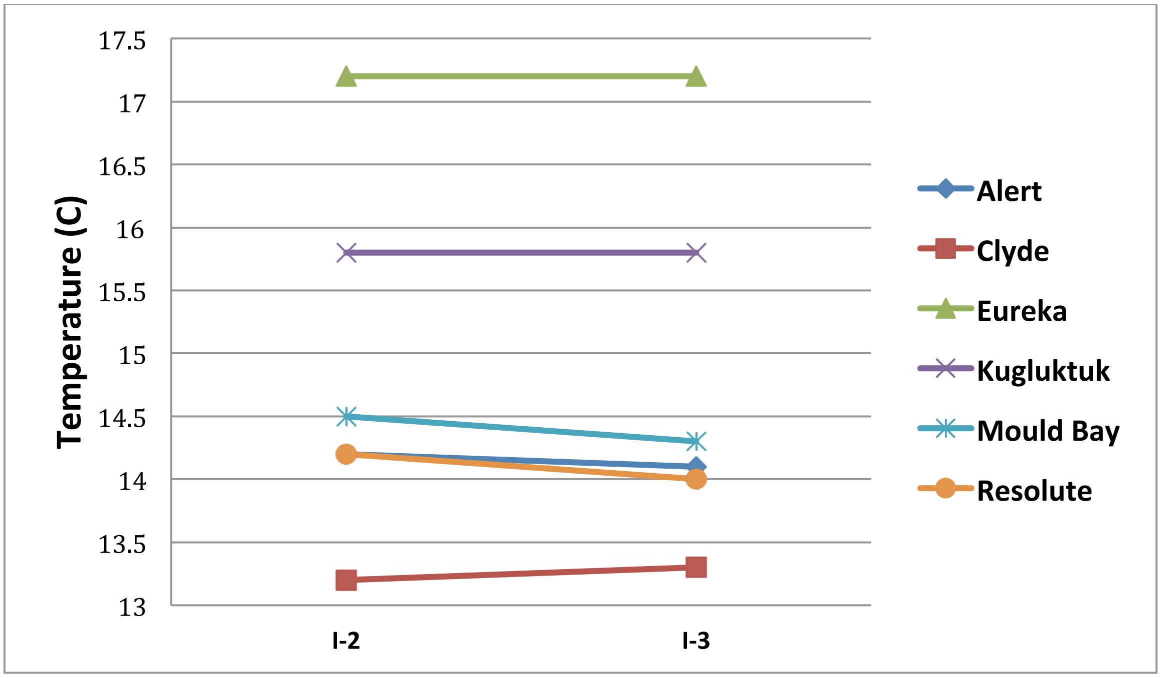


Figure 25: Comparative view of change in standard deviation for the stations with two intervals (approximately (1) 1940 – 1970 & (2) 1970 – 2005). Taken from maximum daily temperature data sets. For specific intervals dates, see: Table 4.

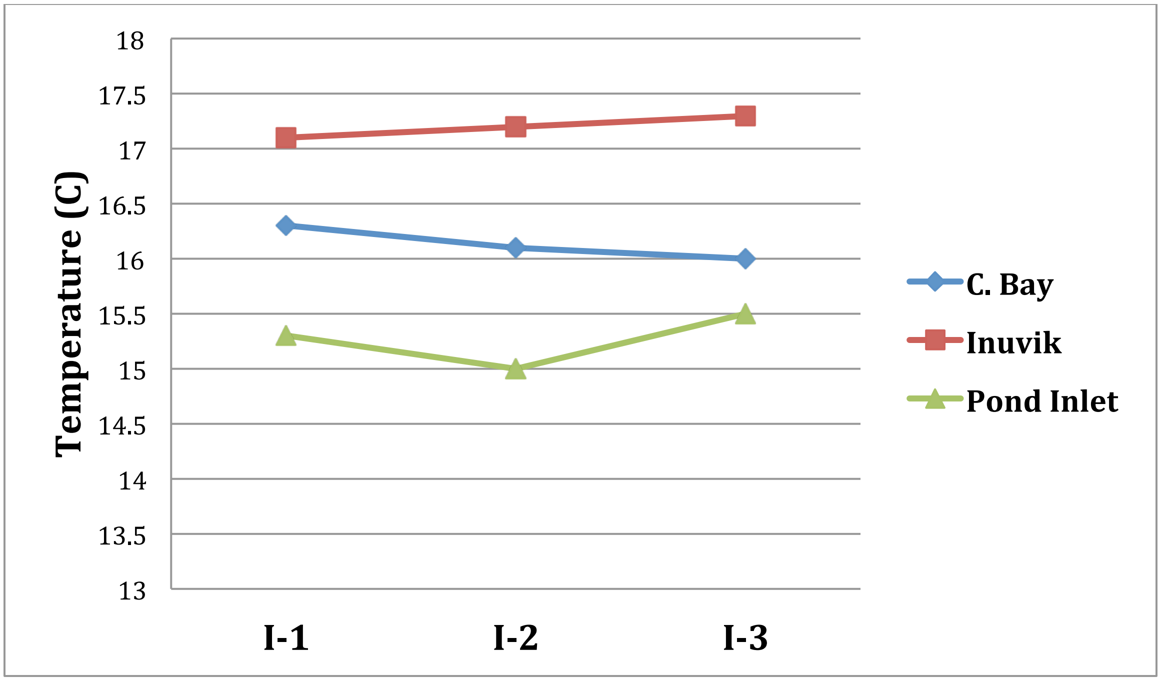


Figure 26: Comparative view of change in standard deviation for the stations with three intervals (approximately (1) 1920 – 1940, (2) 1940 – 1970 & (3) 1970 – 2005). Taken from maximum daily temperature data sets. For specific intervals dates, see: Table 4.

With the exception of Clyde and Inuvik, standard deviation of maximum temperatures remained approximately equal or decreased slightly over the last time interval (Figures 25 and 26). The change in standard deviation is only greater than 0.2°C at one station: Pond Inlet (increase of 0.5°C, from 15.0°C to 15.5°C). This finding indicates that daily surface temperatures deviations from the mean are not changing substantially. In this sense, the results show that variability does not appear to be increasing.

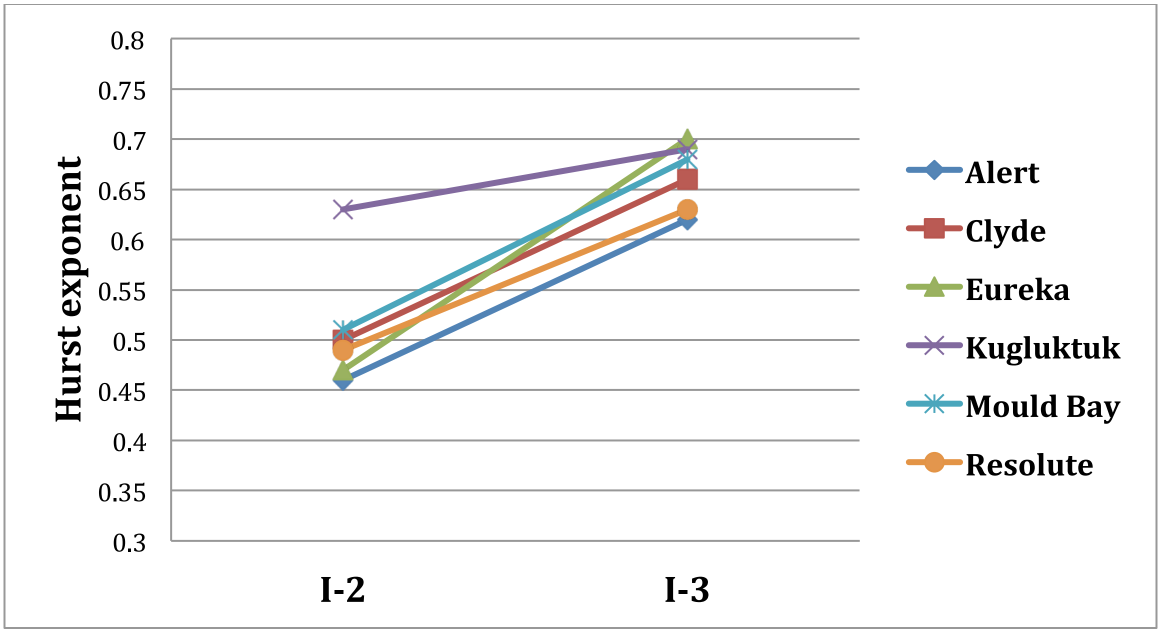


Figure 27: Comparative view of change in Hurst exponents for the stations with two intervals (approximately (1) 1940 – 1970 & (2) 1970 – 2005). Taken from maximum daily temperature data sets. For specific intervals dates, see: Table 3.

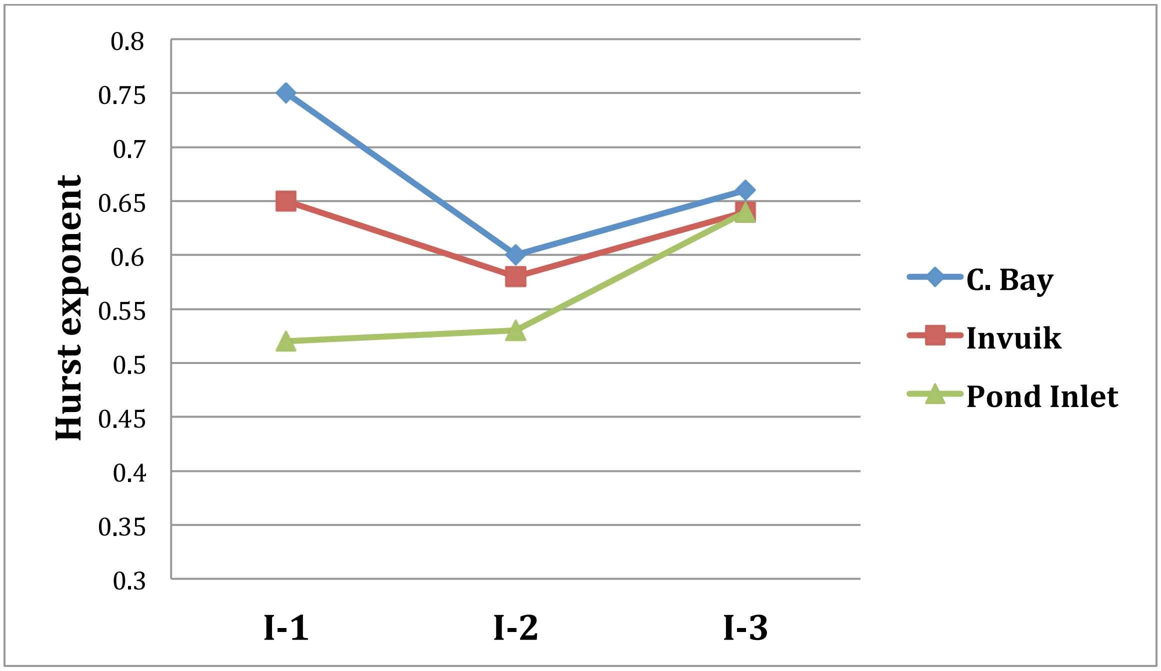


Figure 28: Comparative view of change in Hurst exponents for the stations with three intervals (approximately (1) 1920 – 1940, (2) 1940 – 1970 & (3) 1970 – 2005). Taken from maximum daily temperature data sets. For specific intervals dates, see: Table 3.

The Hurst exponents increased over the last interval at all weather stations (Figures 27 and 28). The Hurst exponents for the last warming period (I-3) are each $0.60 < H < 0.75$, indicating the maximum daily surface temperatures show pattern persistence during that interval. Since H increased in all cases, pattern persistence quantitatively increased over the last two intervals. The cooling period (I-2) showed the least pattern persistence at all weather stations. H was less than 0.50 during the cooling period (I-2) at Alert, Eureka, and Resolute, indicating that surface temperatures patterns were anti-persistent during that period. For the three weather stations divided into three intervals (Fig. 28), H was higher during the first warming period (I-1) than the second (I-3).

Table 5. Depiction of whether mean temperature, maximum daily temperature, and minimum daily temperature increased (arrow-up), decreased (arrow-down), or remained equal (equal sign) for maximum daily temperature datasets over the last two intervals (1940 – 1970 and 1970 – 2005).

Station	Mean Temp. (C)	Max Value (C)	Min Value (C)
Alert	↓	↑	↓
Cambridge Bay	↑	↑	↓
Clyde	↓	↓	↓
Eureka	↑	↑	↓
Inuvik	↓	↑	↓
Kugluktuk	↑	↑	↑
Mould Bay	↑	↑	↓
Pond Inlet	↓	↑	↓
Resolute	↑	↑	↓

Mean surface temperatures from the nine maximum daily temperature time series increase at five weather stations (Cambridge Bay, Eureka, Kugluktuk, Mould Bay, Resolute), and decreased at four weather stations (Alert, Clyde, Inuvik, Pond Inlet). While these results do not give an indication whether temperatures are changing, maximum temperatures are increasing and minimum temperatures are decreasing at the majority of the stations.

Table 6. Depiction of whether Hurst exponent, standard deviation, and temperature range increased (arrow-up), decreased (arrow-down), or remained equal (equal sign) for maximum daily temperature datasets over the last two intervals (1940 – 1970 and 1970 – 2005).

Station	H	Std. Dev.	Range (C)
Alert	↑	↓	↑
Cambridge Bay	↑	↓	↑
Clyde	↑	↑	↑
Eureka	↑	=	↑
Inuvik	↑	↑	↓
Kugluktuk	↑	=	↓
Mould Bay	↑	↓	↑
Pond Inlet	↑	↑	↑
Resolute	↑	↓	↑

The criteria portrayed in Table 6 are indicators of climate variability. Hurst exponents increased over the last interval at all weather stations. Standard deviation changed for seven of nine weather stations, though the changes are relatively minor in each case (Figures 25 and 26). Temperature ranges increased at all weather stations except the two southernmost stations: Inuvik and Kugluktuk.

5.0 Discussion

The goal of this study was to analyze surface air temperature variability in Arctic Canada. The study involved analyzing Arctic Canadian weather stations that had daily maximum and minimum temperature time series exceeding 50 years. A multi-criterial approach was taken to analyze the time series of each station. In addition, the time series were segmented to gain a better understanding if temperature patterns changed over the time period of available recorded data. These segmented time series were based on the periods of temperature warming and cooling described by Chylek et al. (2009). The homogenized maximum and minimum daily surface temperature datasets were provided by Vincent et al. from Environment Canada (Vincent et al., 2002).

The periods of warming and cooling described by Chylek et al. (2009) coincide with the long-term patterns found by creating the traced time series (examples: Figs. 13, 16, 19). According to the traced time series, as well as Chylek et al. (2009), temperatures are increasing at a faster rate in the more recent period of warming than in the first (I-3 vs. I-1).

Mean temperatures increased at five of nine stations (Table 5). This result is not necessarily what would be expected, but whether temperatures are increasing and decreasing are not necessarily represented by this criteria in this analysis, since there are few means to compare, and the time period of each interval are large. One method which may have been more effective would be to create a linear regression on each interval, and take the slope of the regression to determine change in temperatures per day. With the results of the traced time series described above, it would be expected that the slope would be positive in the last time series.

The three criteria analyzed in relation to temperature variability were temperature range (the difference of maximum daily value and minimum daily value), standard deviation, and Hurst exponent.

At most weather stations, maximum daily temperature values increased, and minimum daily temperature values decreased, coinciding to the results of the analysis of temperature ranges (Table 5). Temperature range increased at seven of nine stations, with decreases at Inuvik and Kugluktuk (Table 6). This result gives an indication that temperature variability in terms of extreme temperature values are increasing. While this does not indicate that the distribution of extreme values is increasing (see: discussion of standard deviation below), but extreme values of the temporal periods of the time intervals used in this analysis increased. Greater extreme temperature values could still have local impacts on ecological systems, and human health (Marchand et al., 2006; O'Neill and Ebi, 2009).

Standard deviation decreased at four stations, increased at three stations, and remained the same at two stations (Table 6). The change in standard deviations was relatively small, with change greater than 0.2 only found once (increase of 0.5 at Pond Inlet). In terms of temperature variability, the small changes in standard deviation indicate that the proportional distribution of temperatures about the mean temperature of each time interval did not increase substantially.

The criteria discussed here do not take into account the succession of values of the time series. The sequence of values could be considered as important as the values themselves, as the values only take into consideration one dimension of the relationship. In order to gain a better understanding of how these values are arranged in terms of temporal scale and arrangement, and to therefore gain a better understanding of their patterns and potential pattern change, a multiscale analysis was also conducted. The multiscale analysis method chosen for this study was the height-height correlation method. Height-height correlation has been shown to be useful for determining pattern persistence in systems and patterns of self-affinity.

When plotted on a log-log graph, a straight line will represent a self-affine pattern. This was the case when the height-height correlation analysis was performed on the daily temperature time series. The lines were approximately straight, indicating self-similarity in temperature variability over many decades (Bassingthwaighte and Raymond, 1995). The approximately linear relationship found by performing the height-height correlation analysis in this study shows that temperature patterns at these weather stations are approximately self-similar (see: Figures 20 – 22). This self-similarity can be seen in the samples shown in Figures 2 – 10.

The results shown in Table 2 show that *H* was greater than 0.5 for all time series. The values range from 0.60 (Clyde – Max., and Pond Inlet – Max.) to 0.72 (Eureka – Min.). These results indicate the surface temperatures show pattern persistence over the whole period of each time series. In all cases, the *H* value determined for maximum temperature datasets is less than or equal to the *H* value of the minimum temperature datasets. A possible explanation for this finding is that there is likely less temperature variability and fluctuations at during hours without sunlight, and therefore a smoother, more persistent pattern of minimum daily temperatures.

The height-height correlation method was also applied to the segmented time series to determine if pattern persistence changed as temperatures trended from a period of cooling to the recent warming period. In the cases where datasets were divided into three segments (Cambridge Bay, Inuvik, Pond Inlet), *H* values are greatest during the last time period (approximately 1970 – end of the dataset: 2005 – 2008), lowest during the middle period (approximately 1940 – 1970), and higher than the middle period during the first time period (approximately 1920 – 1940).

The results of the height-height correlation analysis of segmented time series indicate that during the latest period of warming, these locations experienced greater pattern persistence of the entire time period, and experienced the least persistence during the cooling period of 1940 – 1970. Similarly, in the cases where datasets were divided into two segments (Alert, Clyde, Eureka, Kugluktuk, Mould Bay, Resolute), *H* values are greater in the last time period than the first.

During the cooling period, *H* values were at or near the 0.5. Even though temperatures were trending in a negative direction during this time, the pattern was irregular and even quantitatively anti-persistent in some cases (Table 2: Alert, Eureka, Pond Inlet, Resolute). Though temperatures were decreasing, the pattern was irregular and did not give an indication that it was going to continue in the same direction over time.

In contrast to the nature of the pattern during the cooling period, every time series of the last interval showed persistence (Table 2). As surface temperatures began trending in a positive direction again, fluctuations from this overall pattern became less frequent and smaller in scale. There is a greater likelihood for the pattern to continue in the same direction as the temporal scale increases in the future. This is in contrast to the high likelihood for pattern change found during the cooling period (Muteanu et al, 1995). These findings indicate that variability is decreasing in terms of the decreasing tendency for the pattern of temperatures to change direction at different time scales.

The results of the temperature range, standard deviation, and height-height correlation analysis seem to contradict one another (Table 6) in terms of temperature variability. Temperature range is most often increasing, indicating greater variability. Standard deviations showed little change, indicating little change in variability. Hurst exponents are increasing, showing less fluctuations and changes in direction in the pattern of temperatures at different temporal scales. These results do not actually contradict themselves, but need to be all taken into account to get the best understanding of how variability might be changing. Each criterion gives a unique indication of variability change in Arctic Canada.

The increasing temperature ranges found at most stations show that individual day with extreme temperatures are increasing. It would be more telling to find annual temperature range values and see if thesuccessions of values are trending in a positive direction as well, since at larger time scales the probability of having extreme temperature values increases as well.

Together, the results of the standard deviation and height-height correlation analysis indicate that even though temperatures are increasing in the Arctic, (Ford et al., 2006; Houghton et al., 1996; Kaufman et al., 2009; Overland et al., 2008; Pryzbylak, 2003) the proportion of temperatures deviating from the mean temperature for any day of the year is remaining approximately the same as temperature trend upwards. As temperature trends changed from the period of cooling (I-2) to the recent period of warming (I-3), though the distribution of temperatures showed slight change, the pattern of temperature values tending to reverse directions at different scales began ended, and the pattern became more persistent. With higher values of *H* found in the last interval, the pattern for temperatures to move together in a similar direction appears to be increasing, while in the recent past (I-2), the patterns showed little or no persistence. The pattern of temperatures over time appears ‘smoother’ in the last interval (Figs. 13, 16, 19), with temperature tending approximately in the same direction, while there was a clear tendency for temperature patterns to reverse themselves (anti-persistence) in the cooling interval.

7.0 Conclusions

The goal of this study was to analyze surface air temperature data in Arctic Canada in terms of potential change temperature variability. The study involved analyzing weather stations in Arctic Canada that had daily maximum and minimum temperature time series exceeding 50 years. The data sets were provided by Vincent et al. from Environment Canada (Vincent et al., 2002).

A multi-criterial analysis approach was taken to in order to gain a number of quantitative indications of how daily surface temperatures have changed in Arctic Canada, in light of recent concern over climate change. Monitoring temperature patterns in the polar regions is especially concerning since these regions are most vulnerable to climate change, and should experience the greatest changes in temperature patterns, and begin experiencing them before other regions (Ford et al., 2006; Overland et al., 2008; Kaufman et al., 2009).

Each time series showed pattern persistence over their entire time period, though the quantitatively determined (*H*) degree of persistence decreased from the first recorded period of warming (I-1: 1920 – 1940) to the period of cooling (I-2: 1940 – 1970) with only one exception: Pond Inlet. During this time period, most time series had *H* values near or below 0.5, indicating little to no pattern persistence, or in some cases, anti-persistence ($H > 0.5$). As temperatures began trending to the second warming period (I-3: 1970 – end of time series), temperature patterns again began to show pattern persistence. To conclude, these findings indicate the tendency for temperature patterns to change direction at different scales ended after the cooling period, and temperature patterns have begun to smooth and continue in the same direction with successive values.

Though standard deviations have not changed considerably over the last decade indicates that even though the overall pattern shows less fluctuations and tendency to change direction, the distribution of temperatures about the mean temperature for each day is not changing. Temperature ranges did increase, however, indicating that single extreme values might be increasing.

During the time period with available daily surface temperature data from the Arctic Canada, there have been three distinct periods of either warming or cooling. Temperature trends approximately reversed themselves twice. It would be more useful to revisit this analysis after a time period similar in length to those used in this study in order to determine if temperatures do continue to trend in a positive direction as is predicted (Chylek et al. 2009, Pryzbylak, 2003), and if the pattern persistency continues to increase. Will the tendency for temperatures to change direction and trend in a negative (cooling) direction) continue to lessen? While variability in temperatures away from daily means do not appear to be increasing, it will also be interesting to see if they do change in the next interval. With another interval of data, the conclusions of this analysis, in terms of temperature variability, will be much more telling in regards to what is happening in Arctic Canada in the face of global climate change. It would also be useful to apply a similar analysis on other Arctic regions to see if similar conclusions can be drawn.

REFERENCES:

Barry RG, Hare FK (1974) Arctic Climate. In JD Ives and RG Barry, eds., *Arctic and Alpine Environments,* London, Methuen, 17-54.

Bassingthwaighte JB, Raymond GM (1995) Evaluation of the dispersional analysis method for fractal time series. *Annals of Biomedical Engineering*. 23: 491-505.

Boé J, Hall A, Qu X (2009) September sea-ice cover in the Arctic Ocean projected to vanish by 2100. *Nature Geoscience*. 2: 341-343.

Chapman WL, Walsh JE (1993) Recent variations of sea ice and air temperature in high latitudes. *Bulletin of the American Meteroligical Society.* 74: 33-47.

Chylek P, Folland CK, Lesins G, Dubey MK, Wang M (2009) Arctic air temperature change amplification and the Arctic Multidecadal Oscillation. *Geophysical Research Letters*. 36: 1-5.

Ford JD, Smit B, Johanna W (2006) Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. *Global Environmental Change*. 16: 145-160.

Houghton JT, Jenkins GJ, Ephraums JJ (1990) Climate change: The IPCC scientific assessment. *Cambridge University Press*. p. 365.

Houghton JT, Meila Filho FG, Callander BA, Harris N, Kattenberg A, Maskell K (1996) Climate Change 1995: The Science of Climate Change (eds). Cambridge University: Cambridge. pp 572.

Kaufman DS, Schneider DP, McKay NP, Ammann CM, Bradley RS, Briffa KR, Miller GH, Otto-Bliesner BL, Overpeck JT, Binther BM. (2009) Recent warming reverses long-term Arctic cooling. *Science*. 325: 1236-1239.

Koerner RM (1979) Accumulation, Ablation, and Oxygen Isotope Variations on the Queen Elizabeth Islands Ice Caps, Canada. *Journal of Glaciology*. 22: 25-41.

Koscielny-Bunde E, Bunde A, Havlin S, Goldreich Y (1996) Analysis of daily temperature fluctuations. *Physica A*. 231: 393-396.

Lee YT, Chen C, Lin CY, Sung-Ching C (2012) Negative correlation between power-law scaling and Hurst exponents in long-range connective sandpile models and real seismicity. *Chaos, Solitons & Fractals.* 45: 125-130.

Malamud BD, Turcotte DL (1999) Self-affine Time Series: I. Generation and Analysis. *Advances in Geophysics*. 40: 1-90.

Marchand FL, Verlinden M, Kockelbergh F, Graae BJ, Beyens L, Nijs I (2006) Disentangling effects of an experimentally imposed extreme temperature event and naturally associated desiccation on Arctic tundra. *Functional Ecology*. 20: 917 – 928.

Maxwell JB (1980) The Climate of the Canadian Arctic Islands. Vol. 1. *Environment Canada*. Ottawa: Ministry of Supply and Services.

Maxwell JB (1982) The Climate of the Canadian Arctic Islands. Vol. 2. *Environment Canada*. Ottawa: Ministry of Supply and Services.

Munteanu F, Ioana C, Suteanu C, Cretu E (1995) Smoothing dimensions for time series characterization. *Fractals*. 3: 315-328.

O'Neill MS, Ebi KL (2009) Temperature Extremes and Health: Impacts of Climate Variability and Change in the United States. *Journal of Occupational & Environmental Medicine*. 51: 13 - 25.

Overland JE, Wang M, Salo S (2008) The recent Arctic warm period. *Tellus*. 60: 589.

Przybylak R (2000) Temporal and spatial variation of surface air temperature over the period of instrumental observations in the Arctic. *International Journal of Climatology.* 20:587-614

Pryzbylak, R (2003) The Climate of the Arctic. Kluwer Academic Publishers, Dordrecht, Boston.

Rouse WR, Carlson DW, Weick EJ (1992) Impacts of summer warming on the energy and water balance of wet tundra. *Climatic Change*. 22: 305-326.

Rybski D, Bunde A, Von Storch H (2008) Long-term memory in 1000-year simulated temperature records. *Journal of Geophysical Research*. 113 (D2)

Stroeve J, Holland MM, Meier W, Scambos T, Serreze M. (2007) Arctic sea ice decline, faster than forecast. *Geophysical Research Letters*. 34: 5.

Suteanu C (2011) Detrended fluctuation analysis of daily atmospheric surface temperature record in Atlantic Canada. *Canadian Geographer*. 55: 180-191.

Suteanu C, Ioana C (2007) Pattern identification in the dynamic fingerprint of seismically active zones. *Quaternary International*. 171-172: 45-51.

Suteanu C (2005) Complexity, science and the public: The geography of a new interpretation. *Theory, Culture & Society*. 22: 113-140.

Thomas MK (1975) Recent climatic fluctuations in Canada. *Climate Studies*. Atmospheric Environment Service, Toronto. pp 92.

Trinidad Segovia JE, Fernandez-Martinez M, Sanchez-Granero MA (2012) A note on geometric-based procedures to calculate the Hurst exponent. *Physica A*. 391: 2209-2214.

Vincent LA, Zhang X, Bonsal BR, Hogg WD (2002) Homogenization of daily temperatures over Canada. *Journal of Climate*. 15: 1322-1334.

Vowinckel W, Orvig, S (1966) Energy Balance of the Arctic: The Heat Budget over the Arctic Ocean. *Archives meteorology, géophysique, bioklimatique*. 14: 303-325.

Woo M-K, Ohmura A (1997) The Arctic Islands. In Bailey WG, Oke TR, Rouse WR (1997) The surface climates of Canada. McGill-Queen's University Press, Montreal and Kingston, pp 172-197.

Wuebbles DJ, Hayhoe K (2002) Atmospheric methane and global change. *Earth-Science Reviews*. 57: 177-210.