



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# NAO-Influence on Temperature Trends in Norway and Canada for the last 50 Years

**Mats Nordhagen**

Master of Science in Physics and Mathematics

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Supervisor: Robert Edward Hibbins, IFY

Norwegian University of Science and Technology  
Department of Physics



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Student  
Mats Nordhagen

Supervisor  
Prof. Robert Hibbins

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## Preface

This paper is the final master report of the course TFY4900 - Physics at NTNU. The course aims to teach students to plan and use scientific methods to acquire deep knowledge within the area of the master thesis, and learn to systematic obtain information [1]. This report goes into atmospheric physics, and studies the correlation between the NAO and winter/summer surface temperatures in Norway and East Canada/West Greenland.

**The motivation for this work was to: investigate the extent to which the winter and summer surface temperatures in Norway and East Canada/West Greenland are driven by the NAO.**

A special thanks goes to professor Robert Hibbins for help and guidance with this project.

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# 1. Abstract

## 1.1 Abstract in English

The North Atlantic Oscillation (NAO), with its effect on the direction of the westerly winds over the Atlantic Ocean, has a large effect on weather in Europe, especially in Scandinavia. But also the North-West Atlantic weather is dependent on the NAO. As we assume opposite NAO-dependence on winter temperatures in Norway and East Canada, looking at temperature series from these two areas are interesting. By then looking at the summer temperatures for the same weather stations, one can compare if the NAO has the opposite effect as it has during winter, or if we see the same NAO-dependence throughout a calendar year.

Through gathering temperature series for the last 50 years for some weather stations in Norway and in East Canada/West Greenland and time series of the NAO-index (NAOI), a comparison of correlation coefficients between winter/summer and Norway/Canada could be done. With the data, a linear regression of temperature as a function of time could be done, to see how winter/summer temperatures have changed over the last 50 years. By using the time series of NAOI, there were done calculations to how much the temperature was expected to change due to NAO. Looking at the actual temperature gradients for the last 50 years, comparing them to the NAO-driven temperature gradients, and the non-NAO temperature gradient that can be calculated from the other two gradients, it can be seen where NAO has a big impact on temperature, and where other factors are much more important. With both summer and winter temperature series, for both Norway and the North-West Atlantic, similarities and differences on NAO-influence between both geographical areas and seasons could be found.

The results show that the increase in winter temperatures in Norway for the last 50 years to some degree are caused by increase in NAO. The NAO drives the summer temperatures in Norway down. This is however not due to negative correlation between NAO and summer temperatures, but because the NAO in summertime actually has decreased the last 50 years. For winter temperatures in Canada, the picture is more unclear, with both correlation coefficients and NAO-driven temperature gradients varying between positive and negative values. For the summer temperatures in Canada the NAO-driven temperature gradients are mainly positive. Comparing mean non NAO-driven winter time temperature gradients between Norway and Canada shows that while the gradients are close in magnitude, they are not significantly equal. The same goes for mean non NAO-driven summer temperature gradients.

## 1.2 Sammendrag på norsk

Den Nordatlantiske oscillasjonen (NAO), med dens effekt på vestavindens retning over Atlanterhavet, har en stor effekt på været i Europa, spesielt i Skandinavia. Men også det nordvest-Atlantiske været avhenger av NAO. Siden vi antar motsatt NAO-avhengighet på vintertemperaturer i Norge og Øst-Canada, er det interessant å se på temperaturserier fra disse to områdene. Ved å se på sommertemperaturene for de samme værstasjonene, kan man sammenligne om NAO har motsatt effekt sammenlignet med vinteren, eller om NAO-avhengigheten er den samme gjennom et kalenderår.

Gjennom å samle temperaturserier for de siste 50 årene for noen værstasjoner i Norge og i Øst-Canada/Vest-Grønland og tidsserier av NAO-indexen (NAOI), kan man sammenligne korrelasjonskoeffisienter mellom vinter/sommer og Norge/Canada. Man kan gjøre lineær regresjoner av temperaturdataene, for å se hvordan vinter-/sommertemperaturer har variert de siste 50 årene. Ved så å bruke NAOI-data, kan man gjøre beregninger for å se hvor mye man forventer at temperaturseriene skal utvikle seg. Ved å se på temperaturgradientene de siste 50 år, sammenligne dem med de NAO-drevede temperaturgradientene og de ikke-NAO-drevede temperaturgradientene som kan beregnes fra de to andre gradientene, så kan man se hvor NAO har en stor påvirkning på temperatur, og hvor andre faktorer er mye viktigere.

Resultatene viser at økningen i vintertemperaturer i Norge de siste 50 årene i noen grad er på grunn av NAO. Men sommertemperaturene i Norge blir drevet ned av NAO. Dette er ikke på grunn av negativ korrelasjon mellom NAO og sommertemperaturene, men fordi NAO på sommertid faktisk har sunket de siste 50 årene. Bildet er mer uklart for vintertemperaturer i Canada, der både korrelasjonskoeffisienter og NAO-drevede temperaturgradienter varierer mellom positive og negative verdier. For sommertemperaturene i Canada er de NAO-drevede temperaturgradientene stort sett positive. Sammenligner man ikke-NAO-drevede vintertemperaturgradienter mellom Norge og Canada, ser man at mens gradientene er nære hverandre i størrelse, er de ikke signifikant like store. Det samme gjelder for sommertemperaturgradientene.

## 2. Introduction

A lot of previous research has studied how winter temperatures in Norway or Scandinavia and the North-West Atlantic changes with the NAO [2]. While many of these use gridded data sets and look at regions of Norway, Canada or Greenland, this study picks out individual weather station with an at least 90 % temperature data set, and looks at winter/summer temperatures and NAO correlation, including linear regressions of the temperature series, at each of these points. In other words, this study looks at temperature time series over Norway and Canada/Greenland with high spatial and temporal resolution. Several of other studies also use running time series, where mean values are used to describe a period of time, before evolving this year by year. This study however, aims to find one correlation coefficient and temperature gradient for a weather station in the 50 years of time that is studied.

The reason Norway is chosen to look at is that it is a place where we can expect high positive correlation coefficients between temperature and NAO wintertime. This is due to warm westerly winds coming over to the Atlantic, and being pushed more and more North and towards Scandinavia the higher the NAOI is. The effect NAO has on Norwegian weather is biggest during winter, but the NAO is an important driver of variability in the atmosphere throughout the whole year [3].

Another reason to look at Norwegian winters is that the temperatures vary around  $0^{\circ}\text{C}$ , the freezing temperature of water. Since Norwegian electricity generation consists by a huge amount of reservoir storage hydropower [4], the difference between a warm and cold winter will therefore have a lot to say for Norwegian electricity generation, and also on consumption of electrical energy for heating.

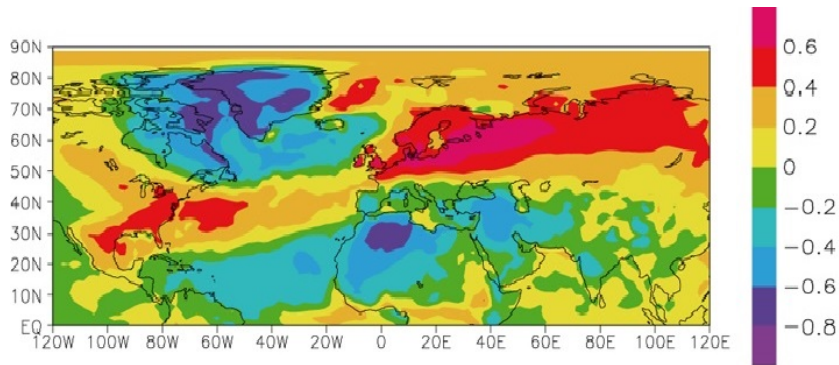


Figure 1: Correlation coefficients between winter time temperatures and NAO over the Northern hemisphere [5].

To contrast the influence NAO has on Norwegian winter temperatures, looking across the Atlantic Ocean to Canada is interesting. Looking at Figure 1 we see big negative correlation coefficients between NAO and winter temperatures in the area around the East coast of Canada and West coast of Greenland. As we expect NAO to drive temperature up in Norway during winter, we would expect the opposite here.

Also summer temperatures will be studied for both areas, to see which differences and similarities there are between seasons. In addition to see how much NAO drives the temperatures in these areas, it will also be interesting to see how much that is *not* driven by



NAO, but by other factors. In times where climate changes are heavily discussed, are the non-NAO driven temperature gradients similar in Norway and Canada wintertime? And what about for summer temperatures? If this is found to be the case, one could assume that there are global factors that drives temperatures that are similar for both Norway and Canada, and that the differences in temperature gradients are just due to NAO.

Research in some of the same areas as this was done in the fall 2014 in the course TFY4510 - Physics, Specialization Project at NTNU. This was just done on Norwegian daily mean temperatures in winter for the last 10 winters, and on stations with temperature series without any gaps. In addition to this, winter was here defined to be January, February and March, while in this master's project December, January and February will be the winter months.

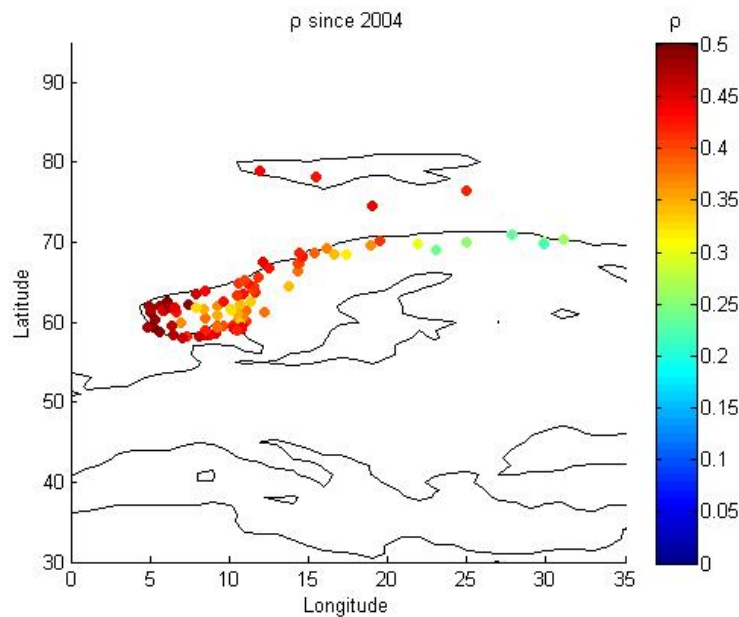


Figure 2: Correlation coefficients between winter temperatures and NAOI over Norway.

As seen in Figure 2 there are positive correlation coefficients,  $\rho$ , between mean winter temperatures in Norway and NAOI as expected. Coefficients as big as 0.5 can be seen along the South-West coast, meaning that 25 % of the variance in winter temperature time series for these stations, can be explained by NAO. The correlation coefficients fall off as we move North and/or East (in other words, away from the South-West coast).

This report looks at both winter and summer temperature series, and in both Norway and in the North-West Atlantic (East-coast Canada and West-coast Greenland), for some chosen ground-based meteorological stations. It does not only focus on the correlation, but also how a linear fit to these temperature series will look, and how much of the change in temperature can be explained by NAO and how much that must be due to other factors.

### 3. Theory

The North Atlantic Oscillation (NAO) is due to a pressure difference between a high pressure center over the Azores and a low pressure center above Iceland, often referred to as the Azores High and the Icelandic Low.

This creates a pressure gradient. The warm moist air coming over the North Atlantic Ocean will experience a force

$$F_p \propto -\nabla p$$

where  $\nabla p$  is the pressure gradient. The air will then be pushed north, how much depends on the size of the pressure gradient.

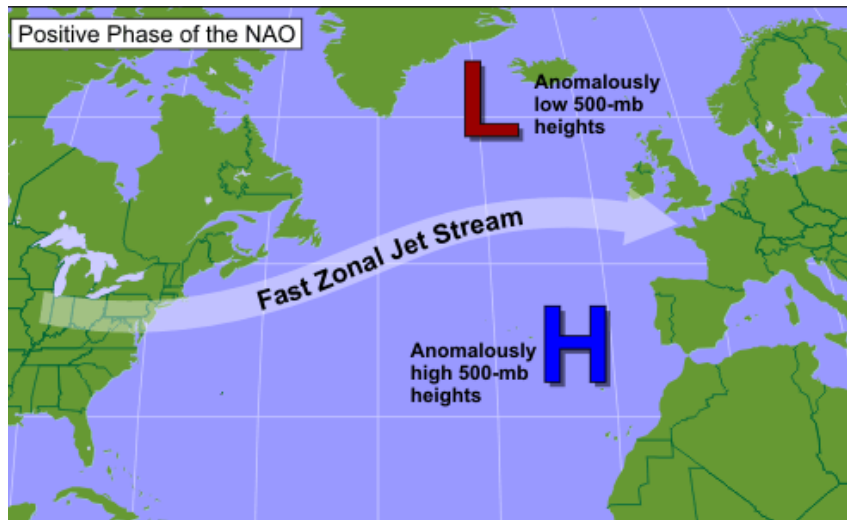


Figure 3: Westerly winds coming in against Europe between Azores High and Icelandic Low [6].

We see from Figure 3 that the higher the pressure difference is, the more the warm moist jet stream air is pushed past Western Europe and up to Scandinavia. Because of this we see positive correlation between winter temperatures in Norway and the strength of this pressure difference. The NAO index (NAOI) is created to give numerical values of the pressure differences. There are different ways to define and calculate these index values. The Hurrell winter station-based index of NAO is calculated by taking SLP (sea pressure level) differences between Lisbon, Portugal and Reykjavik, Iceland, subtracting the long term mean from the pressure difference, and then normalizing by dividing by the long term standard deviation [7]. An alternative way to calculate the NAOI is by using principal component analysis (PCA). Its calculations is done similarly, but the SLP's are found by using Empirical Orthogonal Function, a time series of SLP anomalies over the Atlantic sector [8]. As Figure 4 shows, the two measurements give quite similar NAOI, at least looking long-term.

As we see in Figure 4 typical values is between -2 and +2. Values higher than 0 is called a positive phase, while values lower than 0 is called a negative phase. We see that the NAO tends to be stuck in a phase for several years. Because of this, we might know which phase we will be in an upcoming winter, and therefore be able to say something about whether the winter will be warm or cold.

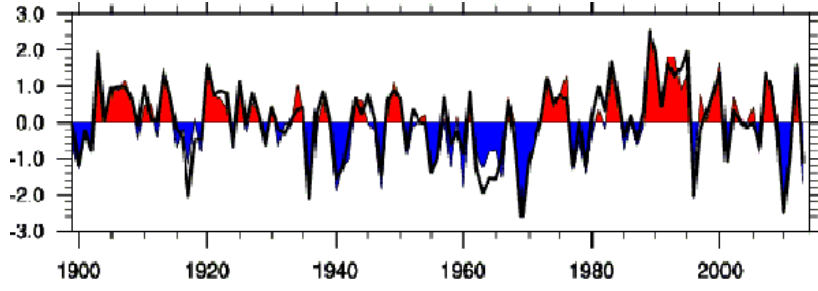


Figure 4: The NAO index from 1900 to present [7]. The black line is the station-based NAOI, while the colors shows the PCA timeseries.

The linear correlation coefficient,  $\rho$  is a statistical parameter that varies between -1 and 1. It measures the strength and direction of a linear relationship between two variables [9]. A positive correlation coefficient indicates positive correlation, while a negative correlation coefficient means a negative correlation between the variables. Two independent data sets will have a correlation coefficient of 0.

There are two temperature gradients we want to find through regressing. The first one is the actual temperature change the last 50 years, in other words a direct linear regression of temperature as a function of time. We then get a linear relationship like this:

$$T_r = A_r + B_r \cdot t$$

where  $T_r$  is the temperature,  $A_r$  is a constant,  $B_r$  is the temperature gradient and  $t$  is time (in years).

The other temperature gradient is calculated. This is done by using two linear regressions; one to find temperature as a function of NAO, and one to find NAO as a function of time.

$$T = a + b \cdot NAOI \quad (1)$$

$$NAOI = c + d \cdot t \quad (2)$$

where  $a, b, c$  and  $d$  are linear regression coefficients,  $T$  is temperature,  $NAOI$  is the NAO index and  $t$  is time (in years). A function for temperature as a function of time can then be found by combining these two equations:

$$T_c = A_c + B_c \cdot t \quad (3)$$

where  $A = (a + bc)$  and  $B = bd$ . The errors in  $A$  and  $B$  is found by using propagation of uncertainty:

$$\sigma_A = \sqrt{\sigma_a^2 + (bc)^2 \cdot \left( \left( \frac{\sigma_b}{b} \right)^2 + \left( \frac{\sigma_c}{c} \right)^2 \right)}$$

$$\sigma_B = B \cdot \sqrt{\left( \frac{\sigma_b}{b} \right)^2 + \left( \frac{\sigma_d}{d} \right)^2}$$

where  $\sigma_i$  is the standard deviation of coefficient  $i$ .

Now we have the two temperature gradients  $B_r$  and  $B_c$ . The former is the actual temperature gradient. The latter is calculated through NAO and says how much the

temperature is expected to change due to changes in NAO, and it is thereby the NAO-driven temperature gradient. The non-NAO-driven temperature gradient is the part of  $B_r$  that is not NAO-driven, hence

$$B_o = B_r - B_c$$

where  $B_o$  is the non-NAO-driven temperature gradient, in other words the part of the actual temperature gradient that is caused by other factors than NAO. Its standard deviation will be

$$\sigma_o = \sqrt{\sigma_r^2 + \sigma_c^2}$$

To compare  $B_o$  between Norway and Canada and between summer and winter, we will need a mean value for  $B_o$  with its correct error. To do this, weighted arithmetic mean is used, to make the gradients with small standard deviations weigh more than those with big standard deviations:

$$\langle B_o \rangle = \frac{\sum_{i=1}^n \frac{B_{o,i}}{\sigma_o^2}}{\sum_{i=1}^n \frac{1}{\sigma_o^2}} \quad (4)$$

As an error for this mean we use standard error of mean, which is calculated as follows:

$$\Delta B_o = \left( \sum_{i=1}^n \frac{1}{\sigma_o^2} \right)^{-\frac{1}{2}} \quad (5)$$

## 4. Method

The data series for the NAOI was downloaded from National Weather Service [10]. To include 50 winters and 50 summers, NAO-data are needed from 01.12.1964 up to 31.08.2014, as we define winter to be December, January and February, and summer to be June, July and August. There is one datapoint (the NAO-index) per day. In this (close to) 50 year time series of NAOI-data, two datapoints are missing. These were simply calculated by taking the mean of the previous and next day's NAOI. As winters are 90 days long, 91 days in leap years, there are 4512 data points for 50 years of winter. Summers are 92 days long, so there are 4600 data points for the 50 summers.

The Norwegian weather data were downloaded from Norwegian Meteorological Institute [11]. These are data sets from ground-based meteorological stations. Temperature data for the same time period as for the NAO-data were gathered. These data sets also include meta data such as longitude, latitude and altitude. They include minimum, maximum and mean temperatures for each day, and we use the mean temperature data point for our research. 16 stations were picked out. The same stations as a previous research were used [12], both because they are well spread geographically across Norway, and also to compare number and thereby easily spot a mistake or an error. That research used 18 stations, but as two of them had huge holes in the data series, here only 16 are used, all with over 90 % data coverage.

The Canada/Greenland weather data were downloaded from National Centers for Environmental Information [13]. Longitude, latitude and altitude of the stations were given here as well, but there were only minimum and maximum temperatures for each day, and no mean temperature. We simply take the mean of the minimum and maximum temperature, and use these mean values as data points. The stations here were picked by trying to have them a bit spread geographically. They also needed minimum 90 % data coverage to be accepted.

All computations, calculations and plotting are done in Matlab (version R2010a), and the program's built-in functions are used for calculations of correlation coefficients, regression coefficients and high-pass filtering.

With these data sets, NAO time series and temperature time series, we first look at winter. Picking out only winter temperatures from the temperature series and only NAOI for the winter days, we can find the temperature gradients. Through regressions we have the linear relationships we see in Equation (1) and (2) in the Theory-section, and use these numbers to calculate our  $T_c$ . The actual temperature gradient,  $T_r$ , is found by simply making a linear regression between temperature and time. The same procedure is followed for the summer temperatures.

Before making the linear regression we see in Equation (2) between NAO and temperature, a high-pass filtering was done on both time series. This was done to get rid of low frequency trends in the temperature and NAO time series. It was clear from the linear regressions that for instance for Norwegian winter temperatures, both NAO and temperature have increased the last 50 years, making their correlation a little stronger than it actually is with the raw data.  $F_{stop} = \frac{1}{90} days^{-1}$  was chosen as the frequency limit where lower frequency are cut off. This frequency was chosen because 90 days is a quarter of a year, and thereby the length of a winter/summer. This removes seasonal effects, and also

takes away any lower frequency cycles, like solar cycles etc.  $F_{pass} = \frac{1}{50} days^{-1}$  was chosen as the frequency where higher frequencies pass through the filter unchanged. The reason this can't be set closer to  $F_{stop}$  is to avoid overshooting around the frequency  $\frac{1}{90} days^{-1}$ . The sample frequency was 1 day. Since almost none of the temperature series were 100 % complete, there were some holes in the data series. For the filtering to be correct (1 data point means 1 day), these holes needed to be filled. This was done by linearly interpolating temperature data between the previous and next existing data point. These linearly interpolated data points were removed after the filtering was done. The correlation coefficients between NAOI and temperature are taken from the high-pass filtered data series.

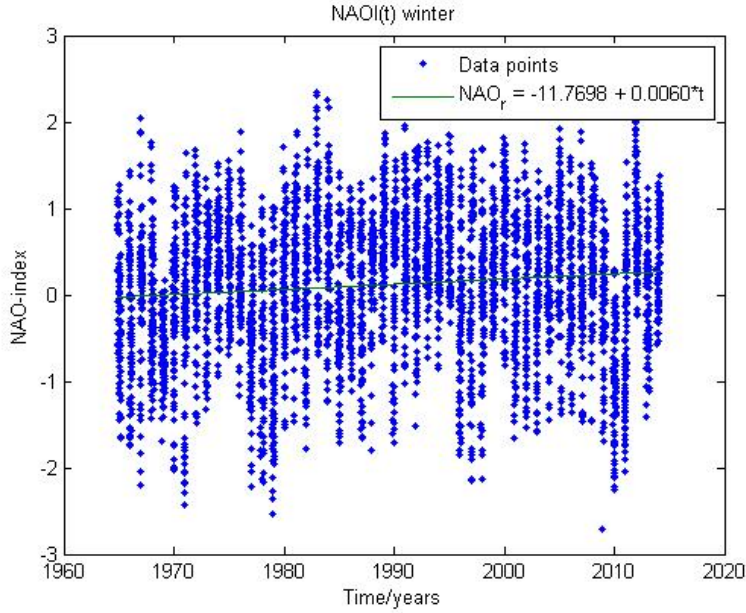


Figure 5: NAO-index for winter since December 1964 to February 2014.

Figure 5 and Figure 6 shows how the NAO changes through a high-pass filter. Figure 5 shows the actual NAO development for winter dates the last 50 years, which is (see Equation (2)):

$$NAO_f = -11.7698 + 0.006 \cdot t$$

with standard deviations  $\sigma_c = 1.6495$  and  $\sigma_d = 0008$  with unit of time years. We see a positive gradient, also including the standard deviation. But in Figure 6, the NAO-data are filtered, and we have the linear relationship:

$$NAO_r = 1.6260 - 0.0008 \cdot t$$

with standard deviations  $\sigma_c = 1.1294$  and  $\sigma_d = 0.0006$  with unit of time years. The gradient itself is almost an order of magnitude smaller than for the actual NAO-data gradient, and including the standard deviation, it is basically zero. This means we have removed the upward trend for the winter-time NAO, and only the day-to-day change is what we are left with. With the same procedure done on temperature data, we only measure the day-to-day response in temperature to the change in NAO.

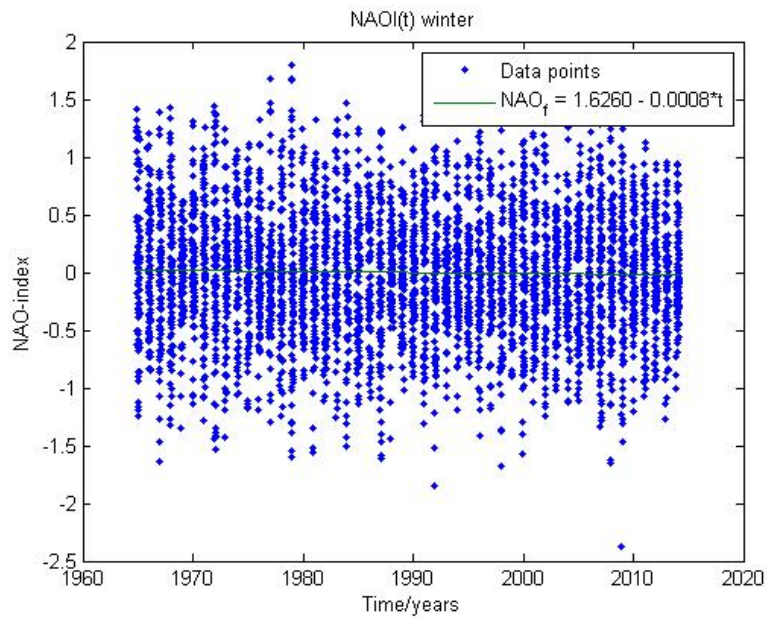


Figure 6: High-pass filtered NAO-index for winter since December 1964 to February 2014.

It looks like the figures have blue vertical lines with gaps between them. The blue dots that form vertical lines are the actual temperature datas, 90 dots in each of them (91 in the leap years), that cover a winter, about a quarter of a year. That is why we see 50 lines; and the gap between them is the rest of the year. We will see the same later in temperature plots.

## 5. Results

### 5.1 Linear regression for NAO for winter and summer

In the Method-section, see Figure 5 , we have already seen what the winter-time NAO looks like: the linear relationship  $NAO_f = -11.7698 + 0.006 \cdot t$  with standard deviations  $\sigma_c = 1.6495$  and  $\sigma_d = 0008$ . Looking at Figure 4, the positive trend might be what would be expected; it looks like the NAOI has increased from the middle of 1964 up to today.

But looking at the NAO-time series for summer, it turns out that summer-time NAOI actually has decreased the last 50 years.

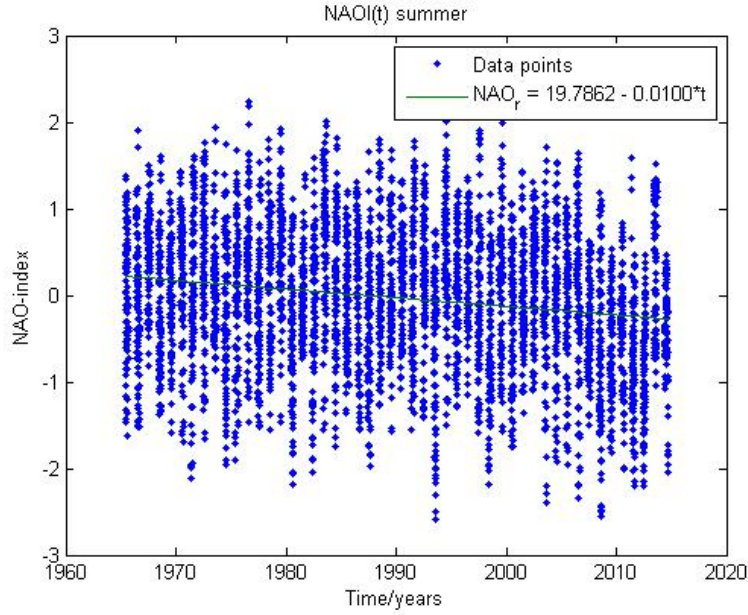


Figure 7: NAO-index for summer since June 1965 to August 2014.

We see in Figure 7 that NAO during summer has decreased, following this linear relationship:

$$NAO_r = 19.7862 - 0.0100 \cdot t$$

with standard deviations  $\sigma_c = 1.6284$  and  $\sigma_d = 0008$  with unit of time years.

As mentioned, when making linear regressions on temperature as a function of NAO, both time series are filtered. The NAO time series for summer is seen in Figure 8

With the linear relationship:

$$NAO_r = 0.5925 - 0.0003 \cdot t$$

with standard deviations  $\sigma_c = 1.2620$  and  $\sigma_d = 0.0006$  with unit of time years. Taking the standard deviations into account, we see again that the high-pass filtered NAO data gradient is basically 0, as it should be.



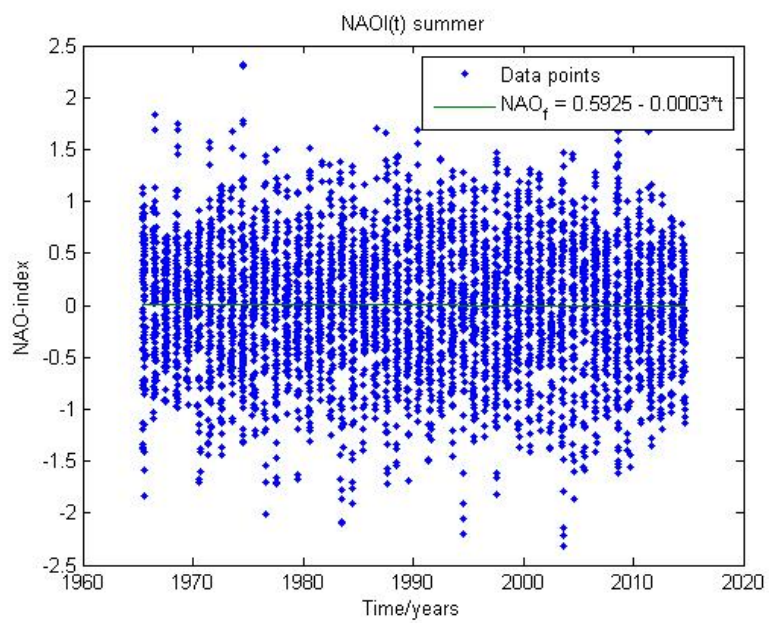


Figure 8: High-pass filtered NAO-index for summer since June 1965 to August 2014.

## 5.2 Winter temperatures in Norway

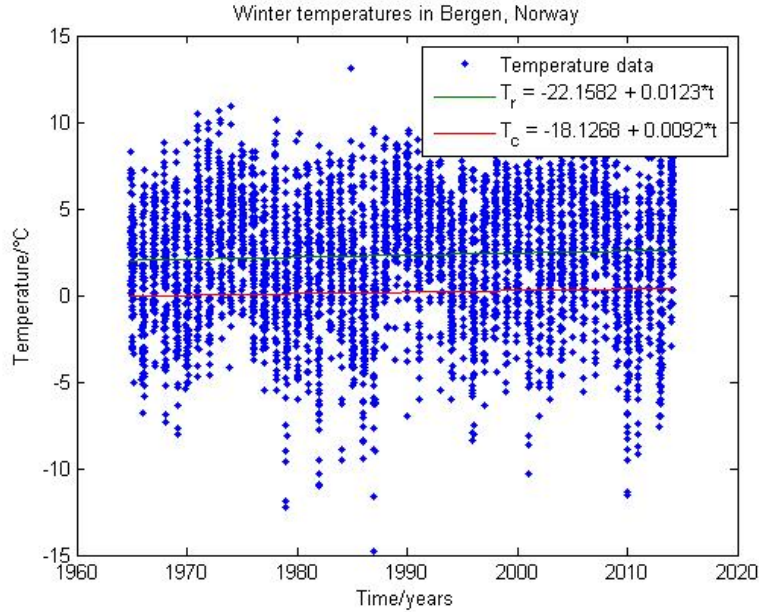


Figure 9: Winter temperatures in Bergen, Norway between December 1964 and February 2014, with both linear relationships for both the actual temperature development,  $T_r$ , and NAO-driven temperature change,  $T_c$ .

Figure 9 shows a typical winter temperature plot for a Norwegian weather station. We see a positive temperature gradient for the last 50 winters,  $B_r = 0.0123$  °C/year, and a positive NAO-driven temperature gradient,  $B_r = 0.0092$  °C/year. This means that a big portion, actually 75 %, of the increase in winter temperatures in Bergen the last 50 years can be explained by the NAO.

Table 1 shows that all of the winter temperature gradients of the Norwegian weather stations are positive, varying between 0.01 and 0.13 °C/year. All of the NAO-driven temperature gradients are also positive, meaning that parts of the total temperature increase are explained by NAO.

Figure 10 shows the temperature gradients plotted. The sum of the two is the total temperature gradient. It should be mentioned that the weather station Jan Mayen here has been moved east, to have it a bit closer to the rest of the stations. The correct longitude for Jan Mayen is -8.6690.

The correlation coefficients we see in Table 1 are in Figure 11 plotted in a colormap of Norway. The blue correlation coefficients are the lowest, red the highest.

Using Equation (4) and Equation (5) to calculate the mean and its error of the non-NAO-driven temperature gradient, we get:

$$\langle B_o \rangle = 0.0321 \pm 0.0011$$

In the Discussion-section, we will use this number for comparison with  $\langle B_o \rangle$  in Canada.

Station	Location	$\rho$	$B_r$	$B_c$	$B_o$
	City		$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$
50540	Bergen	0.2958	0.0123	0.0092	0.0031
27500	Færder	0.2877	0.0397	0.0091	0.0366
99950	Jan Mayen	0.0702	0.1054	0.0032	0.1022
54130	Lærdal	0.2946	0.0356	0.0134	0.0222
42160	Lista	0.2925	0.0359	0.0096	0.0263
24870	Nesbyen	0.2056	0.0638	0.0128	0.0510
62490	Ona	0.2297	0.0237	0.0057	0.0180
18700	Oslo	0.2579	0.0517	0.0106	0.0411
10400	Røros	0.1472	0.0493	0.0111	0.0382
85380	Skrova	0.1654	0.0354	0.0048	0.0306
99860	Svalbard	0.2254	0.1296	0.0157	0.1139
36200	Torungen	0.2871	0.0443	0.0094	0.0349
90450	Tromsø	0.1393	0.0367	0.0053	0.0314
47300	Utsira	0.2872	0.0246	0.0068	0.0178
98550	Vardø	0.0789	0.0479	0.0027	0.0452
17850	Ås	0.2709	0.0533	0.0125	0.0408

Table 1: Weather stations with parameters.  $\rho$  is the correlation coefficient between temperature and NAOI (both high-pass filtered),  $B_r$  is the gradient of the  $T_r$ -regressions curve, while  $B_c$  is the gradient of the  $T_c$ -regressions curve, calculated from Equation (3), and  $B_o = B_r - B_c$  is the non-NAO-driven temperature gradient.

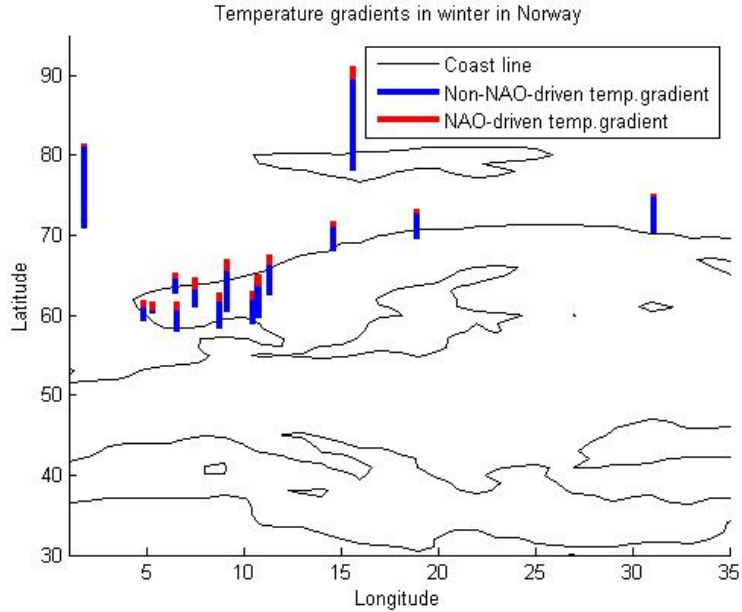


Figure 10: Temperature gradients in winter-time Norway the last 50 years. The blue bar is the non-NAO-driven temperature gradient,  $B_o$ , the red one is the NAO-driven temperature gradient,  $B_c$ . The bars are scaled so that 1 latitude equals  $0.01\text{ }^{\circ}\text{C}/\text{year}$ . The red bar starts off where the blue bar ends, meaning that their sum is the whole length of the total blue and red bar, and that it equals  $B_r$ , the total temperature gradient. The meteorological stations' location are at the start (bottom) of the blue bar.

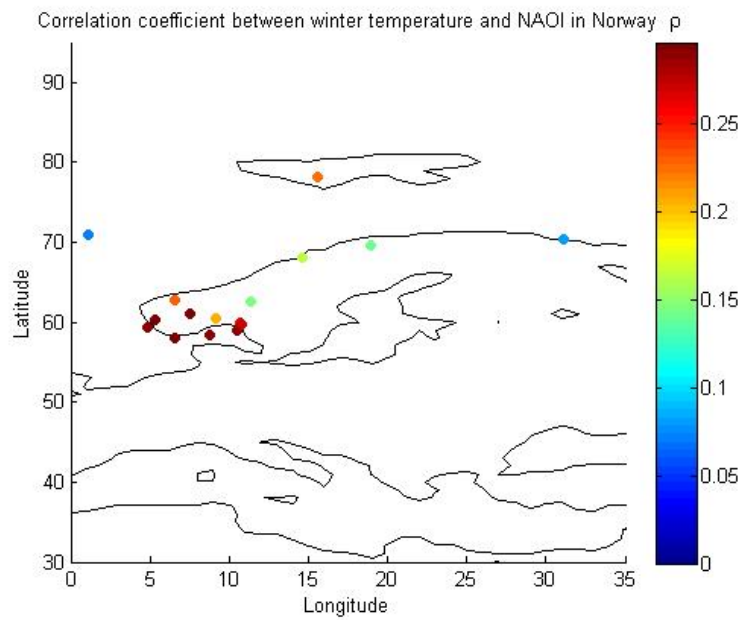


Figure 11: Correlation coefficients between winter temperatures in Norway and NAO the last 50 years.

### 5.3 Winter temperatures in Canada

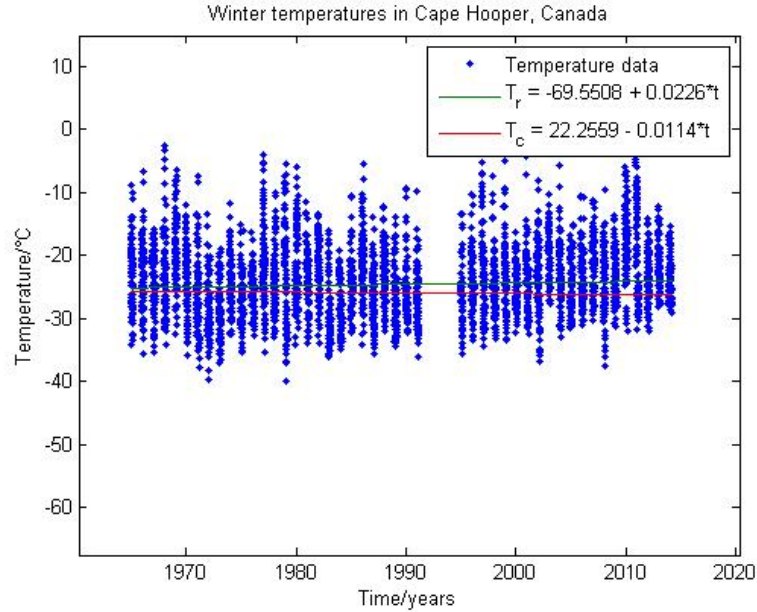


Figure 12: Winter temperatures in Cape Hooper, Canada between December 1964 and February 2014, with both linear relationships for both the actual temperature development,  $T_r$ , and NAO-driven temperature change,  $T_c$ .

Figure 11 shows a plot of the winter temperatures at weather station in Canada. We see that the total temperature has increased, whereas the NAO-driven temperature gradient first of all would expect a higher temperature, but also shows that NAO effects have pulled the temperature down over the last 50 years.

Table 2 shows us that the picture is much more unclear in Canada/Greenland than it was in Norway. While  $B_r$  is positive,  $B_c$  varies a lot from station to station, both in size and whether it's positive or negative. Figure 13 plots the temperature gradients, and might help visualize.

The correlation coefficients we see in Table 2 are in Figure 14 plotted in a colormap of Canada. The blue correlation coefficients are the lowest, red the highest, but we see that the colorbar is adjusted so that the same colors can't be compared in Figure 11 and Figure 14. Another thing to mention is that the longitudes in the Canada-plots are 360 degrees bigger than the normal way to refer to longitudes, due to the properties of the mapping device.

Using Equation (4) and Equation (5) to calculate the mean and its error of the non-NAO-driven temperature gradient, we get:

$$\langle B_o \rangle = 0.0488 \pm 0.0029$$

Station	Location	$\rho$	$B_r$	$B_c$	$B_o$
	City		$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$
CA002400660	Cape Hooper, Canada	-0.2571	0.0226	-0.0114	0.0340
CA002401030	Dewar Lakes, Canada	-0.3021	0.0474	-0.0177	0.0651
CA002400570	Fox Five, Canada	0.0092	0.0150	0.0220	-0.0070
GLE00100992	Ilulissat, Greenland	0.0034	0.0473	0.0148	0.0325
CA002402592	Iqaluit, Canada	-0.0006	0.0412	-0.0013	0.0425
CA002400305	Alert, Canada	0.0310	0.0495	0.0874	-0.0379
CA007113534	Kuuujuaq, Canada	-0.0172	0.0410	-0.0282	0.0692
CA002301000	Coral Harbour, Canada	-0.1617	0.0403	-0.0104	0.0507
CA002401200	Eureka, Canada	-0.1779	0.0467	-0.0106	0.0573
GLE00147061	Sisimiut, Greenland	0.0101	0.1304	0.0836	0.0468
CA002300500	Baker Lake, Canada	-0.0201	0.0777	-0.0469	0.1246
CA002400600	Cambridge Bay, Canada	-0.0267	0.0634	-0.0015	0.0649
CA007103283	Inukjuak, Canada	-0.0019	0.0256	0.0063	0.0319
CA006085700	North Bay, Canada	0.0902	0.0514	0.0059	0.0455
CA008501100	Cartwright, Canada	-0.1997	0.0205	-0.0123	0.0328
CA008501900	Goose, Canada	-0.1442	0.0266	-0.0096	0.0362

Table 2: Weather stations with parameters.  $\rho$  is the correlation coefficient between temperature and NAOI (both high-pass filtered),  $B_r$  is the gradient of the  $T_r$ -regressions curve, while  $B_c$  is the gradient of the  $T_c$ -regressions curve, calculated from Equation (3), and  $B_o = B_r - B_c$  is the non-NAO-driven temperature gradient.

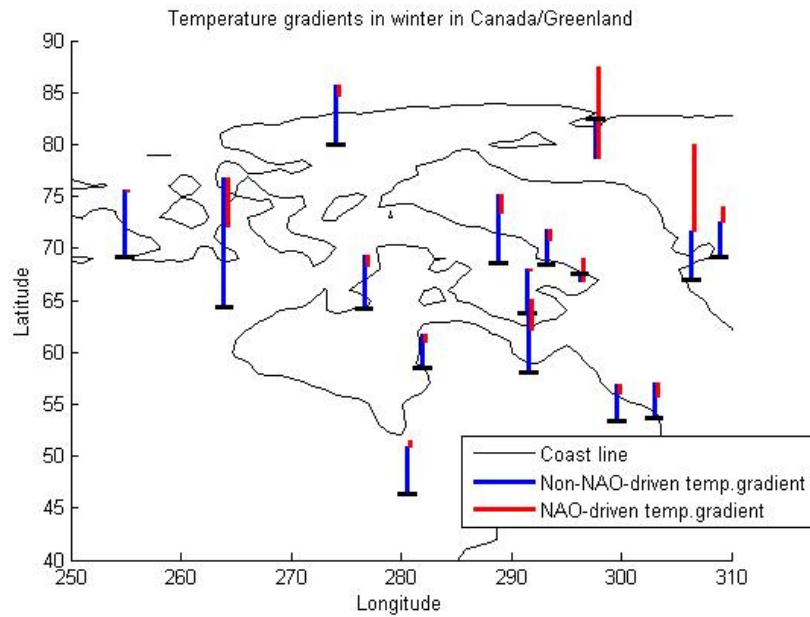


Figure 13: Temperature gradients in winter-time Canada/Greenland the last 50 years. The blue bar is the non-NAO-driven temperature gradient,  $B_o$ , the red one is the NAO-driven temperature gradient,  $B_c$ . The bars are scaled so that 1 latitude equals  $0.01\text{ }^\circ\text{C}/\text{year}$ . The red bar starts off where the blue bar ends, meaning that their sum is the whole length of the total blue and red bar, and that it equals  $B_r$ , the total temperature gradient. Since it varies a bit whether the blue bar is positive or negative, a black horizontal line is put at the location of the weather station. The red bars are moved a bit to the right, so that we are able to see those going down.

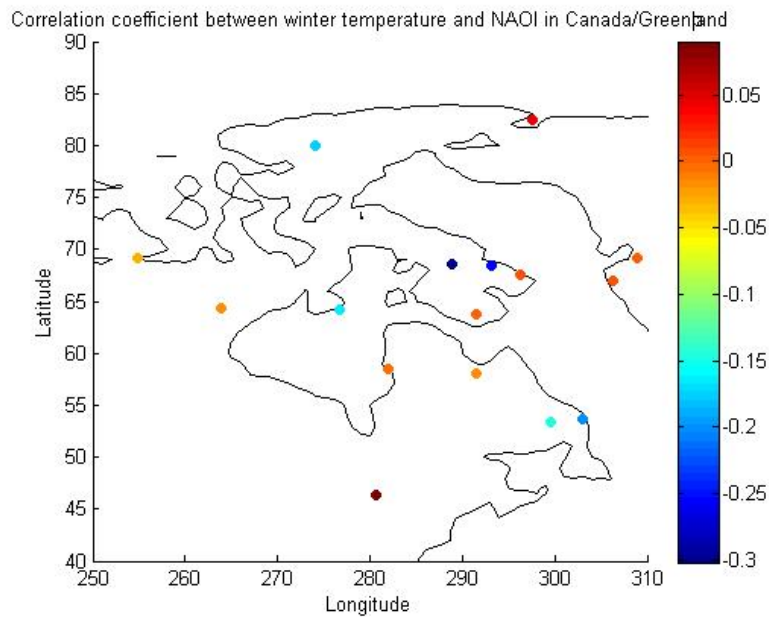


Figure 14: Correlation coefficients between winter temperatures in Canada/Greenland and NAO the last 50 years.

## 5.4 Summer temperatures in Norway

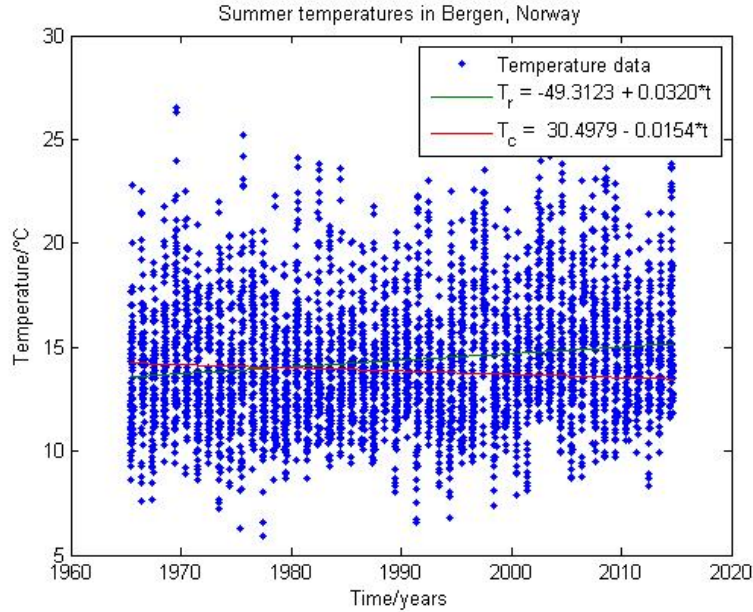


Figure 15: Summer temperatures in Bergen, Norway between June 1965 and August 2014, with both linear relationships for both the actual temperature development,  $T_r$ , and NAO-driven temperature change,  $T_c$ .

In Figure 15 we see the temperature-plot for Bergen in summer. The  $B_r$  is positive, as we see in Table 3 that it is for all of the stations, but the  $B_c$  is negative, again as it is for all. The reason for this is that even though most correlation coefficients are positive, NAO has decreased during summer as seen in Figure 7. This way the NAO-driven temperature gradient will come out negative.

We see in Table 3 that most correlation coefficients are positive, and those that are negative are very small. This results in negative  $B_c$ .

Using Equation (4) and Equation (5) to calculate the mean and its error of the non-NAO-driven temperature gradient, we get:

$$\langle B_o \rangle = 0.0412 \pm 0.0008$$



Station	Location	$\rho$	$B_r$	$B_c$	$B_o$
	City		$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$
50540	Bergen	-0.0279	0.0320	-0.0154	0.0474
27500	Færder	0.0787	0.0197	-0.0152	0.0349
99950	Jan Mayen	0.1193	0.0463	-0.0054	0.0517
54130	Lærdal	-0.0147	0.0222	-0.0223	0.0445
42160	Lista	0.0166	0.0307	-0.0160	0.0467
24870	Nesbyen	0.0936	0.0188	-0.0214	0.0402
62490	Ona	0.0591	0.0272	-0.0094	0.0366
18700	Oslo	0.1117	0.0203	-0.0177	0.0380
10400	Røros	0.0997	0.0142	-0.0186	0.0328
85380	Skrova	-0.0035	0.0285	-0.0081	0.0366
99860	Svalbard	0.1049	0.0258	-0.0262	0.0520
36200	Torungen	0.0629	0.0292	-0.0157	0.0449
90450	Tromsø	0.1118	0.0184	-0.0089	0.0273
47300	Utsira	-0.0060	0.0328	-0.0113	0.0441
98550	Vardø	0.2087	0.0282	-0.0045	0.0327
17850	Ås	0.1187	0.0132	-0.0209	0.0341

Table 3: Weather stations with parameters.  $\rho$  is the correlation coefficient between temperature and NAOI (both high-pass filtered),  $B_r$  is the gradient of the  $T_r$ -regressions curve, while  $B_c$  is the gradient of the  $T_c$ -regressions curve, calculated from Equation (3), and  $B_o = B_r - B_c$  is the non-NAO-driven temperature gradient.

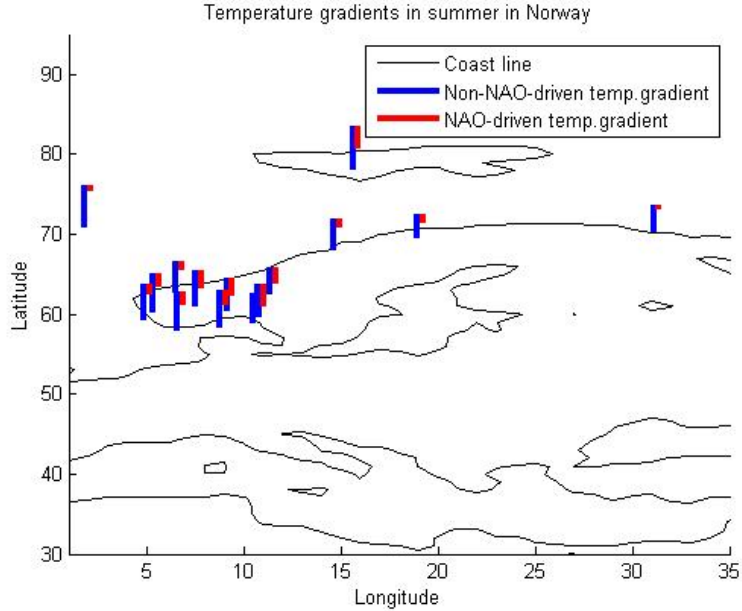


Figure 16: Temperature gradients in summer-time Norway the last 50 years. The blue bar is the non-NAO-driven temperature gradient,  $B_o$ , the red one is the NAO-driven temperature gradient,  $B_c$ . The bars are scaled so that 1 latitude equals  $0.01\text{ }^{\circ}\text{C}/\text{year}$ . The red bar starts off where the blue bar ends, meaning that their sum is the whole length of the total blue and red bar, and that it equals  $B_r$ , the total temperature gradient. The red bars are moved a bit to the right, so that we are able to see those that are going down.

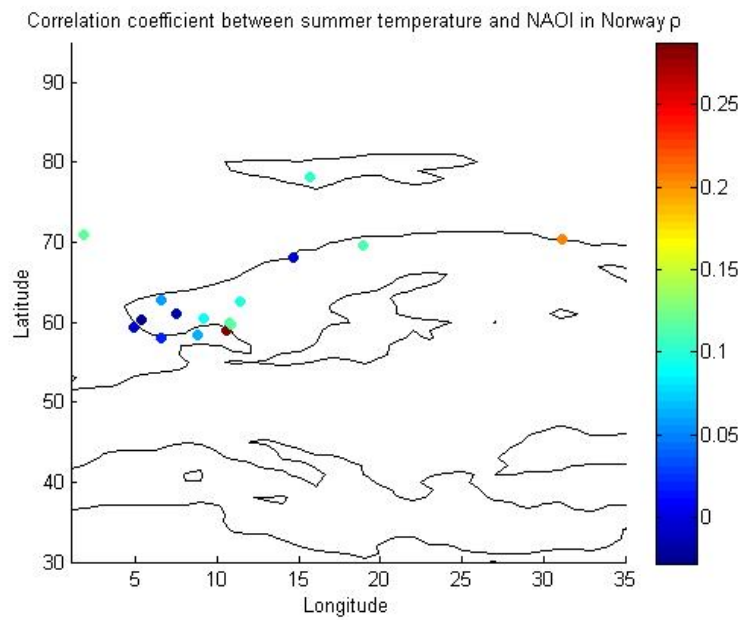


Figure 17: Correlation coefficients between summer temperatures in Norway and NAO the last 50 years.

## 5.5 Summer temperatures in Canada

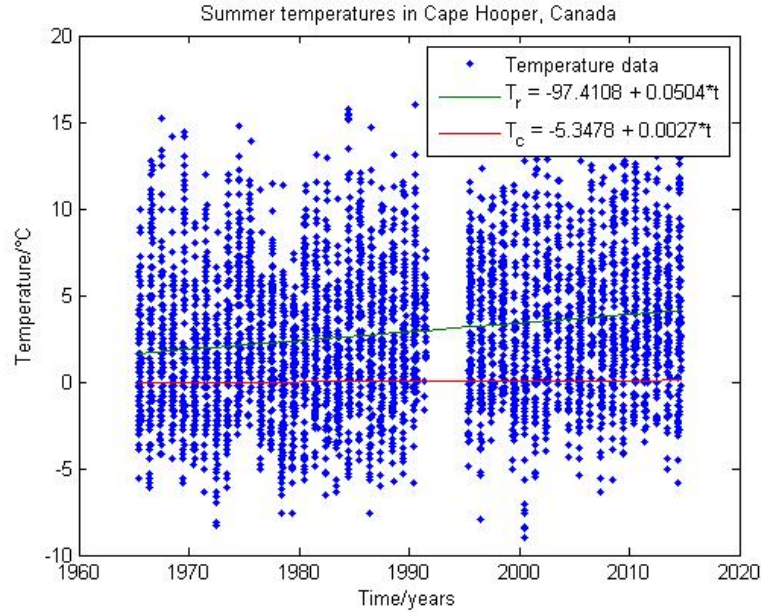


Figure 18: Summer temperatures in Cape Hooper, Canada between June 1965 and August 2014, with both linear relationships for both the actual temperature development,  $T_r$ , and NAO-driven temperature change,  $T_c$ .

In Figure 18 we see one of the Canada-stations for summer temperatures.  $B_r$  is always positive. Since most of the correlation coefficients are negative (see Table 4), and the NAOI in summer has decreased the last 50 years, most of the  $B_c$  end up positive.

Table 4 shows us that the actual temperature has increased, and that most of the NAO-driven temperature gradients also are positive due to negative correlation coefficients.

Using Equation (4) and Equation (5) to calculate the mean and its error of the non-NAO-driven temperature gradient, we get:

$$\langle B_o \rangle = 0.0387 \pm 0.0010$$

Station	Location	$\rho$	$B_r$	$B_c$	$B_o$
	City		$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$	$^{\circ}\text{C}/\text{year}$
CA002400660	Cape Hooper, Canada	-0.0531	0.0504	0.0027	0.0477
CA002401030	Dewar Lakes, Canada	-0.2637	0.0467	0.0107	0.0360
CA002400570	Fox Five, Canada	-0.1132	0.0649	0.0056	0.0593
GLE00100992	Ilulissat, Greenland	-0.2163	0.0321	0.0075	0.0246
CA002402592	Iqaluit, Canada	-0.0107	0.0241	0.0003	0.0238
CA002400305	Alert, Canada	-0.2741	0.0179	0.0114	0.0065
CA007113534	Kuuujuaq, Canada	0.0047	0.0532	-0.0003	0.0535
CA002301000	Coral Harbour, Canada	-0.0645	0.0430	0.0022	0.0408
CA002401200	Eureka, Canada	-0.3345	0.0370	0.0104	0.0266
GLE00147061	Sisimiut, Greenland	-0.2394	0.0724	0.0084	0.0640
CA002300500	Baker Lake, Canada	-0.0386	0.0314	0.0016	0.0298
CA002400600	Cambridge Bay, Canada	-0.1944	0.0394	0.0074	0.0320
CA007103283	Inukjuak, Canada	-0.2036	0.0648	0.0091	0.0557
CA006085700	North Bay, Canada	0.0294	0.0395	-0.0015	0.0410
CA008501100	Cartwright, Canada	0.1570	0.0394	-0.0095	0.0489
CA008501900	Goose, Canada	0.1282	0.0390	-0.0076	0.0466

Table 4: Weather stations with parameters.  $\rho$  is the correlation coefficient between temperature and NAOI (both high-pass filtered),  $B_r$  is the gradient of the  $T_r$ -regressions curve, while  $B_c$  is the gradient of the  $T_c$ -regressions curve, calculated from Equation (3), and  $B_o = B_r - B_c$  is the non-NAO-driven temperature gradient.

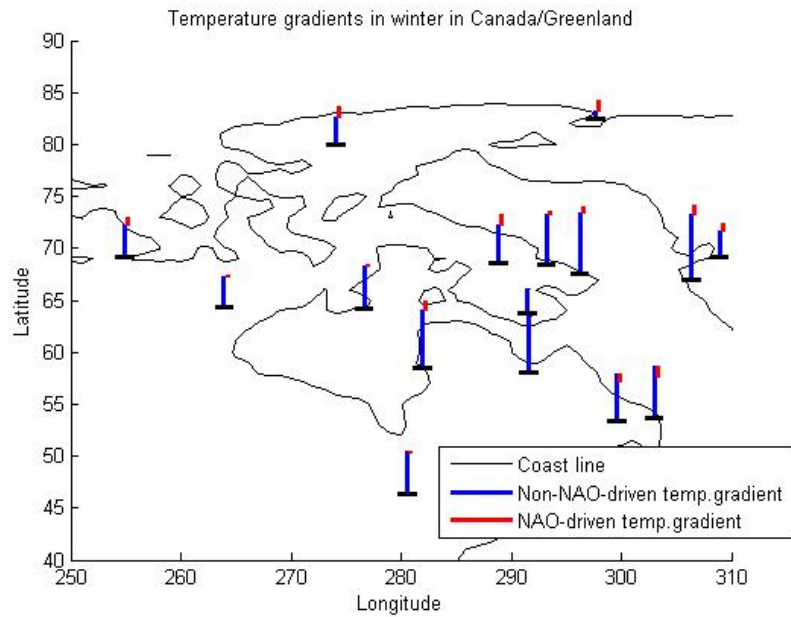


Figure 19: Temperature gradients in summer-time Canada/Greenland the last 50 years. The blue bar is the non-NAO-driven temperature gradient,  $B_o$ , the red one is the NAO-driven temperature gradient,  $B_c$ . The bars are scaled so that 1 latitude equals  $0.01\text{ }^\circ\text{C}/\text{year}$ . The red bar starts off where the blue bar ends, meaning that their sum is the whole length of the total blue and red bar, and that it equals  $B_r$ , the total temperature gradient. A black horizontal line is put at the location of the weather station. The red bars are moved a bit to the right, so that we are able to see those going down.

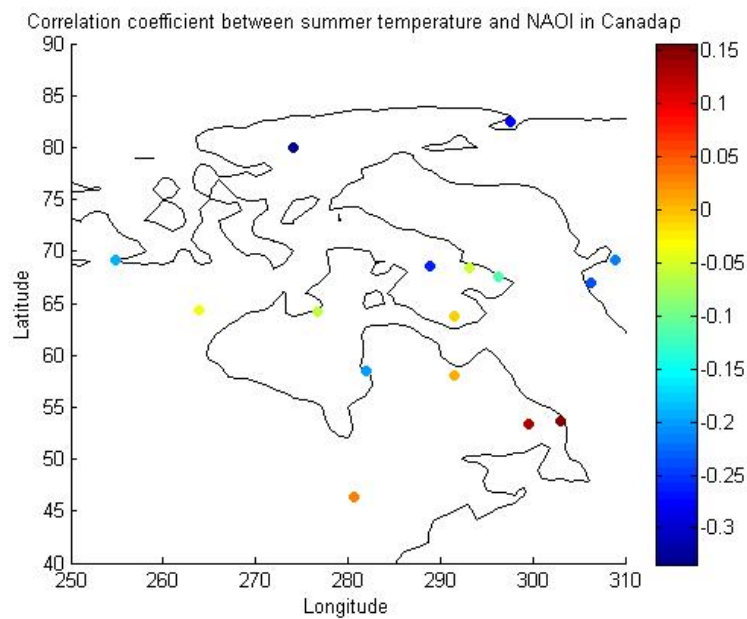


Figure 20: Correlation coefficients between summer temperatures in Canada/Greenland and NAOI the last 50 years.

## 6. Discussion

### 6.1 Linear regression for NAO for winter and summer

Looking at Figure 4, it does seem like the NAOI has increased during the last 50 years. And for winter the NAOI-development has increased, seen in Figure 5. That this gradient is positive, means that positive correlation coefficients will lead to positive NAO-driven temperature gradients, and the opposite for negative correlation coefficients.

Though for summer, we see the opposite. Figure 7 shows that the NAO-gradient for the last 50 summers is negative, with an absolute value bigger than for winter. A negative NAO-gradient, will make the positive  $\rho$  lead to negative  $B_c$  and vice versa. We must keep this in mind when looking at the temperature gradients.

### 6.2 Winter temperatures in Norway

We see from Table 1 what all  $B_r$  are positive. All  $B_c$  are positive, but smaller than  $B_r$ . This makes all of the  $B_o$  positive too. As mentioned earlier, we do expect NAO to drive Norwegian winter temperatures up, and this shows us that it does do that. It varies to what extent it does, from the 16 stations we look at here, the  $B_c$  gradients are between 3 % and 75 % of  $B_r$ . In Figure 10 we see that the islands Jan Mayen and Svalbard have the greatest total temperature gradient, but the NAO ( $B_c$ -red bars) are not the reason for this. It seems like other factors are responsible for the huge temperature increase there the last 50 years.

Figure 11 visualizes what we see in Table 1, that the correlation coefficients between winter temperatures and NAOI are positive. They seem to be highest to the south-west, and decrease as we go north and east (seen even clearer in Figure 2, but they are not calculated the exact same way). This is not so strange, as the south-west coast of Norway is where the weather coming over the Atlantic Ocean will hit first and have biggest effect.

### 6.3 Winter temperatures in Canada

In Table 2 we see that all  $B_r$ -gradients are positive. The NAO-driven temperature gradients  $B_c$  however, vary between positive and negative. This is a bit surprising, judging by Figure 1. In this figure, it looks like the correlation between NAO and winter temperature should be negative and strong. In Figure 13 it is shown that all  $B_o$  is positive, except for one. The eastmost points have huge NAO-driven temperature gradients, even though the correlation coefficients between temperature and NAO are small (positive) values.

Figure 14 shows us that the most positive correlation coefficients are east of the Baffin Bay that lies between Canada and Greenland (in addition to the southernmost weather station).

### 6.4 Summer temperatures in Norway

When we go from winter to summer, we need to keep in mind that the NAO has decreased in the 50-year period we are looking at. So since there are mostly positive correlation coefficients between Norwegian summer temperatures and NAOI (the negative ones are very small), we end up with only negative  $B_c$ . The total temperature gradients are as always positive. In Figure 16 we see that the  $B_o$  are bigger (in absolute value) than the  $B_c$  at each point (which it need to be for  $B_r$  to be positive). The  $B_c$  varies between 10

and 60 % of the  $B_o$ . So it is clear that NAO plays an important role in Norwegian summer temperatures, but in negative direction.

Figure 17 visualizes what we see in Table 3, that though most  $\rho$  are positive, most of them are small. The strongest one is actually for up to the north-east, which is the opposite of what we see for winter in Figure 11. One might think that  $\rho$  should be negative during summer, because the temperatures are hotter, so that when westerly winds comes across the Atlantic Ocean, they will drive the temperature down. But it seems like other weather drivers, for instance from the Arctic areas, keeps the Norwegian summer temperatures so low, that the weather coming over the Atlantic Ocean actually drives the temperature up.

## 6.5 Summer temperatures in Canada

From Table 4 we see that most correlation coefficients between Canadian summer temperatures and NAOI are negative. Since NAOI has decreased in summer-time, most of the  $B_c$  then end up being positive. Though they are very small. The smallest is as small as 0.5 % of the  $B_r$ , meaning that the NAO basically has no effect on the temperature there. Looking at Figure 19 this is easier to see. Other effects than NAO dominates the temperature changes here, except for at the northernmost point, where the total temperature hasn't changed much.

In Figure 20 we see that most of the  $\rho$  are negative, with highest absolute values to the north and east.

## 6.6 Comparing non-NAO-driven temperature gradients

As mentioned earlier, comparing the non-NAO-driven temperature gradients could be interesting. By doing that we can see whether or not the other weather drivers (other than NAO) give the same temperature gradient in Norway as they do at the other side of the Atlantic Ocean in Canada/Greenland. The gradients were calculated in the Results-section.

We first look at the gradients for winter time:

$$\langle B_{o,nor} \rangle = 0.0321 \pm 0.0011$$

$$\langle B_{o,can} \rangle = 0.0488 \pm 0.0029$$

The indices 'nor' and 'can' is short for Norway and Canada respectively. We see that they are not equal. The Canadian gradient is about 1.5 times bigger than for Norway.

We then look at the gradients for summer time:

$$\langle B_{o,nor} \rangle = 0.0412 \pm 0.0008$$

$$\langle B_{o,can} \rangle = 0.0387 \pm 0.0010$$

These gradients are not equal, but much closer. Since the non-NAO-driven temperature gradients not are equal, the other weather drivers (other than NAO) on the Northern hemisphere affect the temperatures in Norway and in East-Canada/West-Greenland differently, though the difference is small during summer. To give the numbers more significance, more than 16 weather stations per country should be taking into consideration.

## 7. Conclusion

The winter-time temperatures in Norway are positively correlated to the NAOI, and for multiple of the places studied, the NAO is the biggest weather driver. For Canada/Greenland the picture is more unclear, as it varies whether the NAO drives the temperature up or down. The summer-time temperatures in Norway are also positively correlated to the NAOI, but since the summer-time NAOI has decreased the last 50 years, the NAO-driven temperature gradients are negative. At the Canada/Greenland-weather stations, the NAO seems to have a very small effect.

The non-NAO-driven temperature gradients during winter are not equal between Norway and Canada/Greenland. The same goes for the gradients in summer, but here they are much closer in absolute values.



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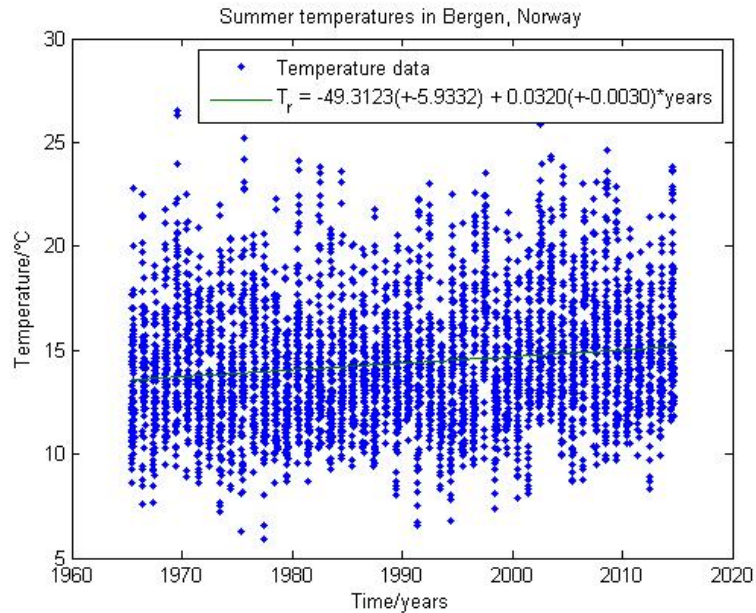
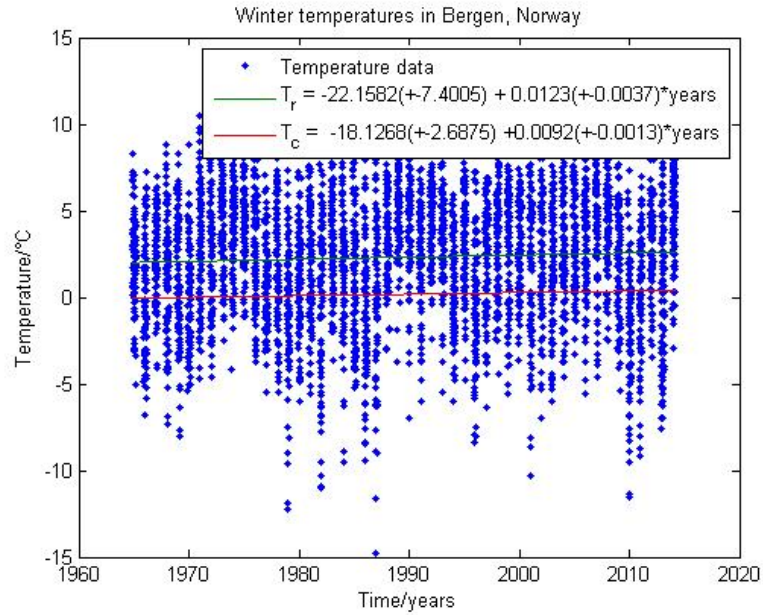
## Appendix I - Longitudes and latitudes

Station	Location	Longitude	Latitude
50540	Bergen	5.33	60.38
27500	Færder	10.52	59.02
99950	Jan Mayen	-8.66	70.93
54130	Lærdal	7.51	61.06
42160	Lista	6.56	58.10
24870	Nesbyen	9.13	60.56
62490	Ona	6.53	62.85
18700	Oslo	10.72	59.94
10400	Røros	11.37	62.57
85380	Skrova	14.64	68.15
99860	Svalbard	15.62	78.22
36200	Torungen	8.78	58.39
90450	Tromsø	18.93	69.65
47300	Utsira	4.87	59.30
98550	Vardø	31.09	70.37
17850	Ås	10.78	59.66
CA002400660	Cape Hooper, Canada	-66.81	68.46
CA002401030	Dewar Lakes, Canada	-71.16	68.65
CA002400570	Fox Five, Canada	-63.78	67.53
GLE00100992	Ilulissat, Greenland	-51.1	69.22
CA002402592	Iqaluit, Canada	-68.55	63.75
CA002400305	Alert, Canada	-62.33	82.5
CA007113534	Kuujuaq, Canada	-68.41	58.1
CA002301000	Coral Harbour, Canada	-83.36	64.2
CA002401200	Eureka, Canada	-85.93	79.98
GLE00147061	Sisimiut, Greenland	-53.66	66.91
CA002300500	Baker Lake, Canada	-96.08	64.3
CA002400600	Cambridge Bay, Canada	-105.13	69.1
CA007103283	Inukjuak, Canada	-78.08	58.46
CA006085700	North Bay, Canada	-79.41	46.36
CA008501100	Cartwright, Canada	-57.03	53.71
CA008501900	Goose, Canada	-60.41	53.31

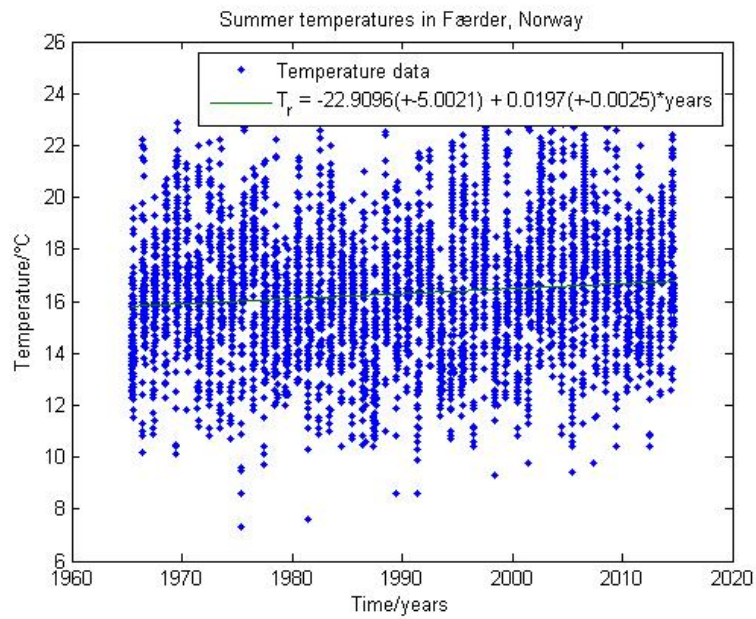
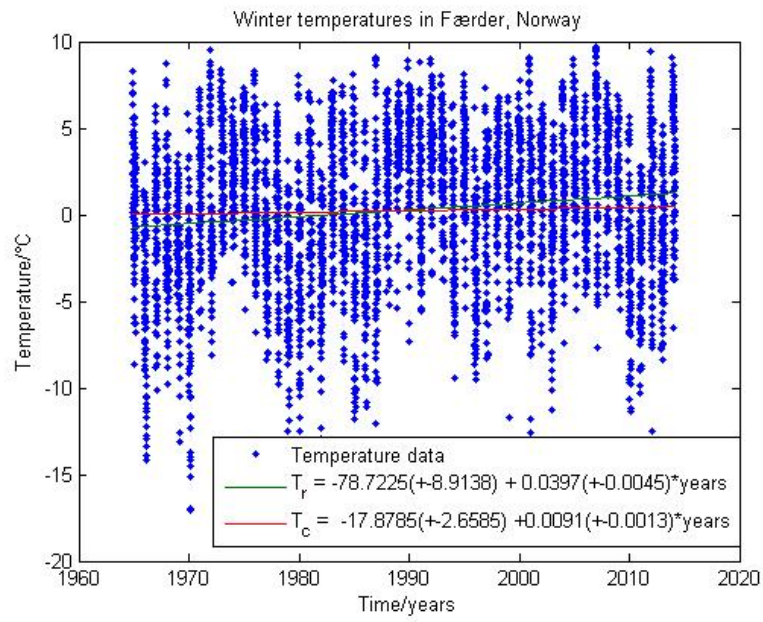
Table 5: Weather stations in Norway and Canada/Greenland and their longitudes and latitudes.

## Appendix II - Temperature plots

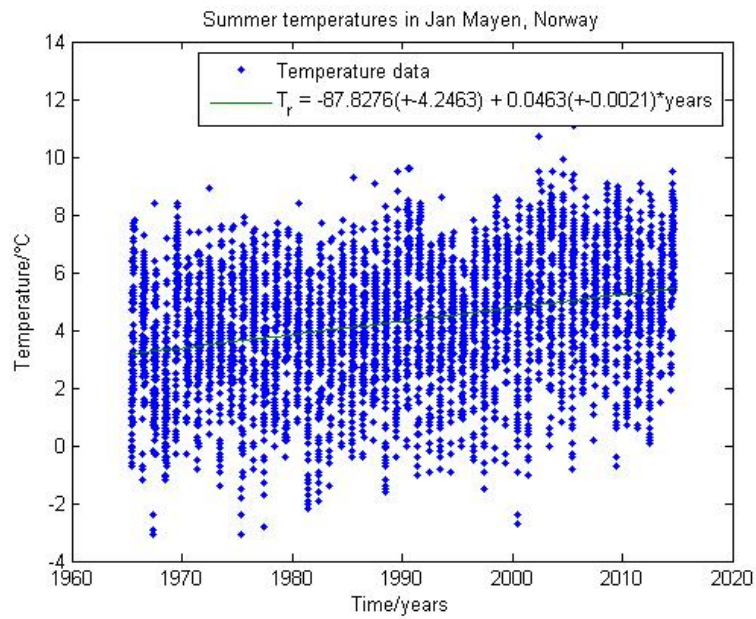
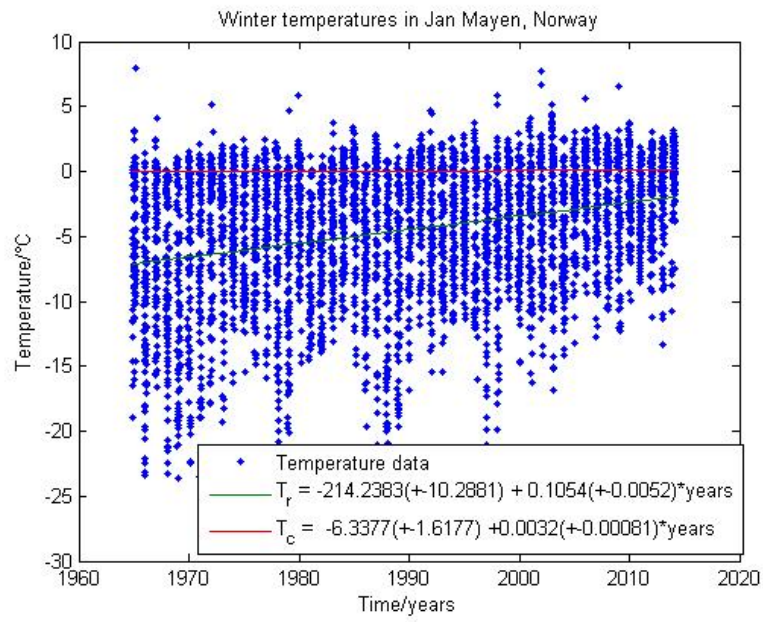
Temperature plots with  $T_r$  and  $T_c$ . Their standard deviations in parenthesis. For winter-time Norway,  $T_c$  are in the plot, in the rest, their values are written under the plot.



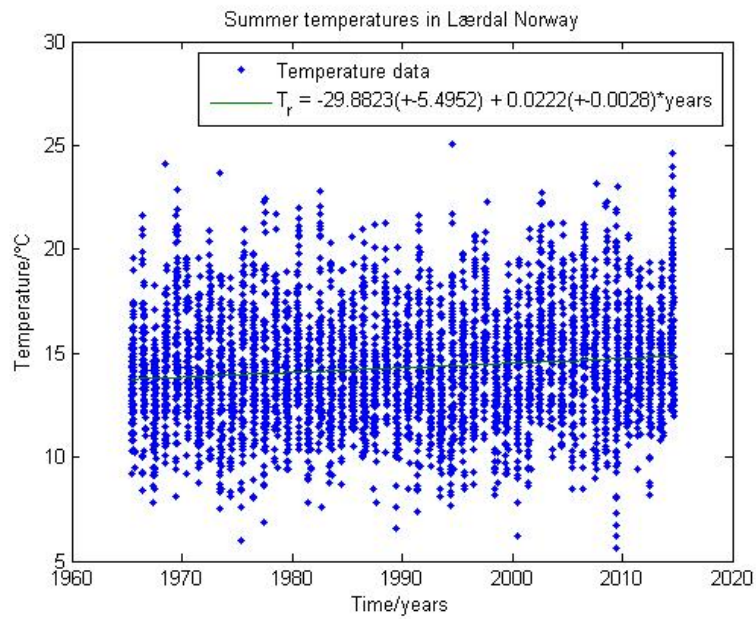
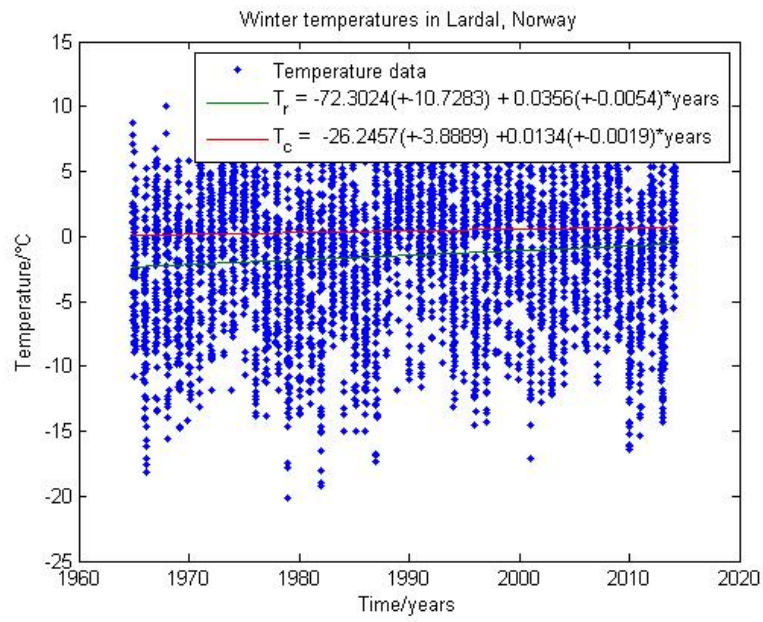
$$T_c = 30.4979(+ - 2.9064) - 0.0154(+ - -0.0014) \cdot \text{years}$$



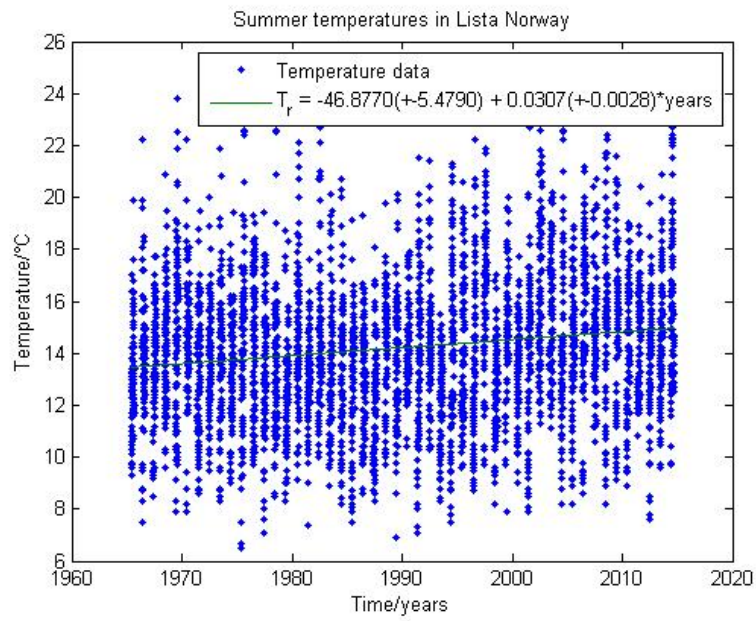
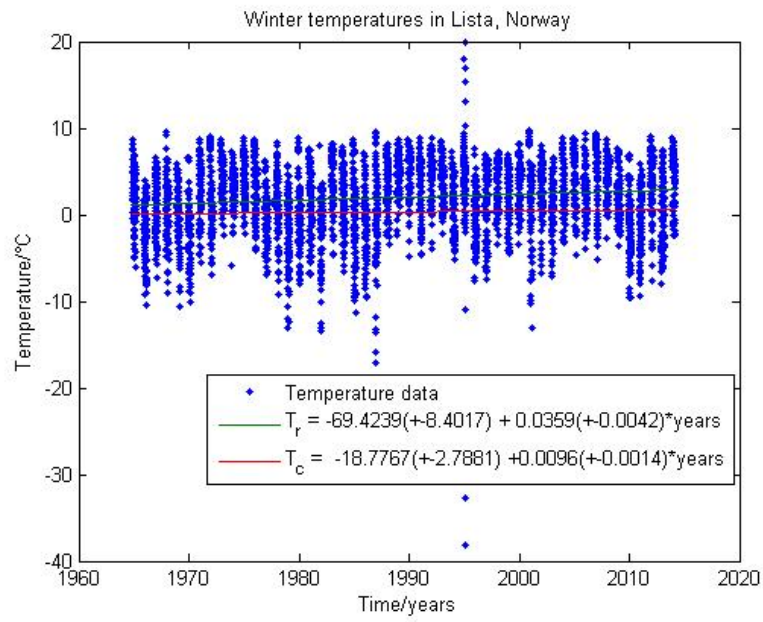
$$T_c = 30.0646(+ - 2.8883) - 0.0152(+ - -0.0014) \cdot \text{years}$$



$$T_c = T_c = 10.7404(+ - 2.4317) - 0.0054(+ - -0.0012) \cdot \text{years}$$

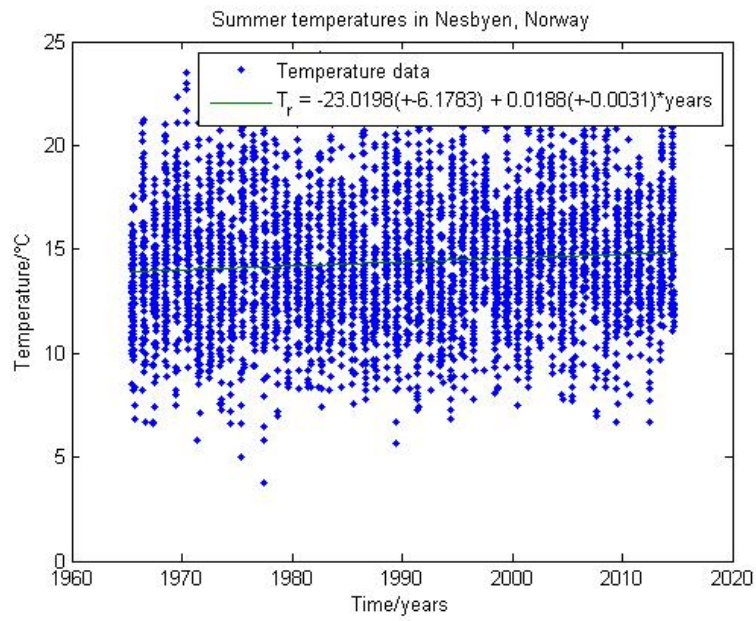
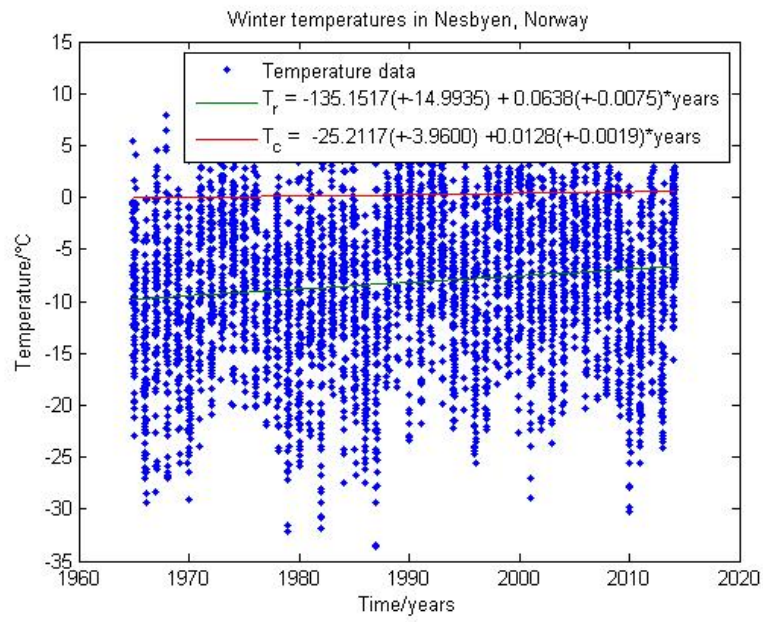


$$T_c = 44.0863(+ - 4.2081) - 0.0223(+ - -0.0021) \cdot \text{years}$$

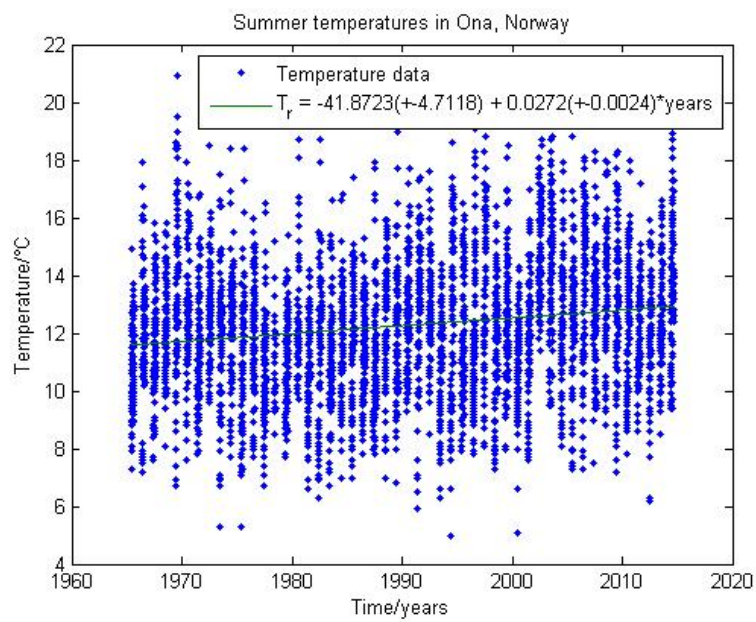
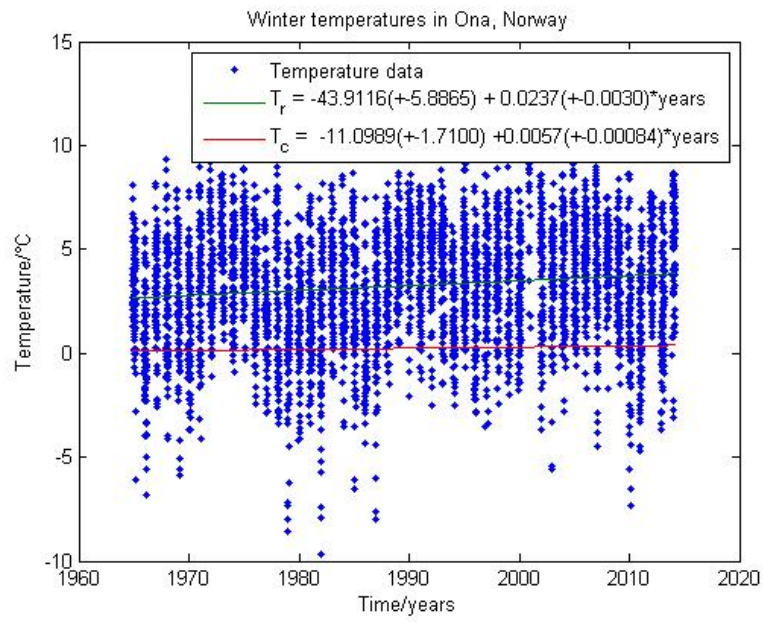


$$T_c = 31.5961(+ - 3.0213) - 0.0160(+ - -0.0015) \cdot \text{years}$$

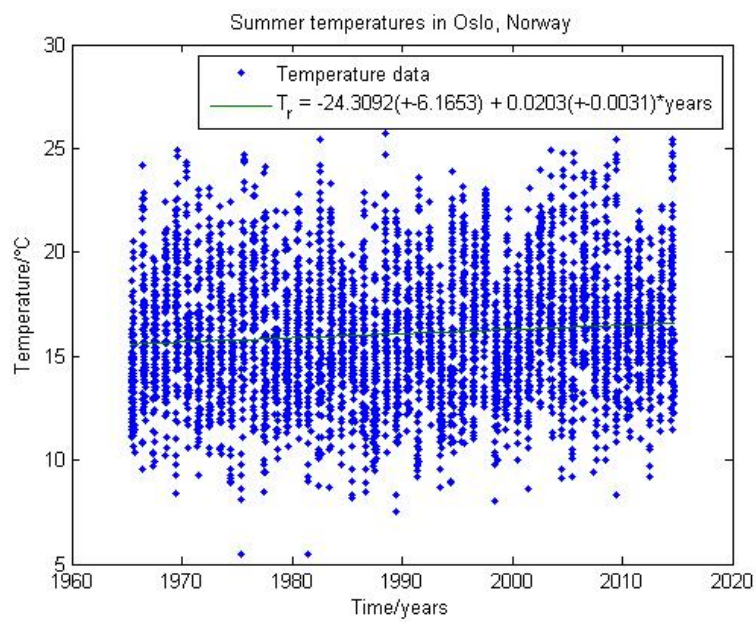
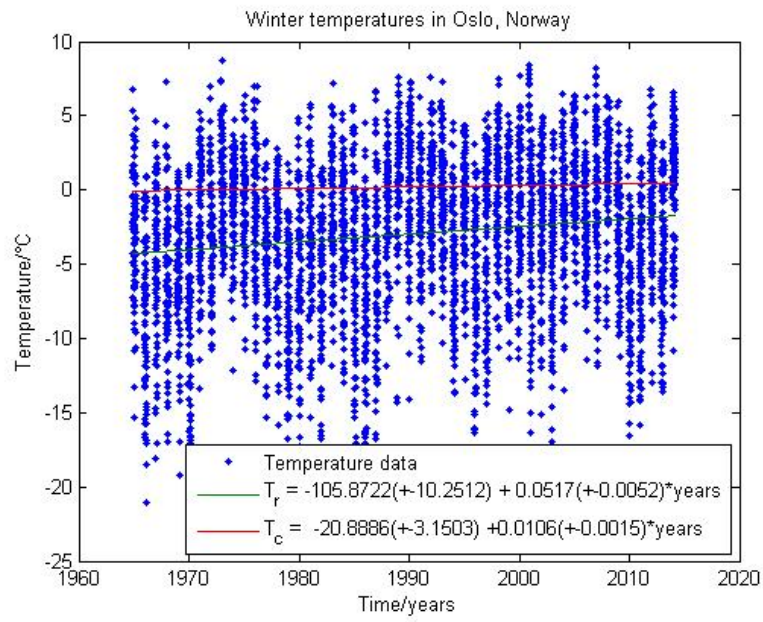




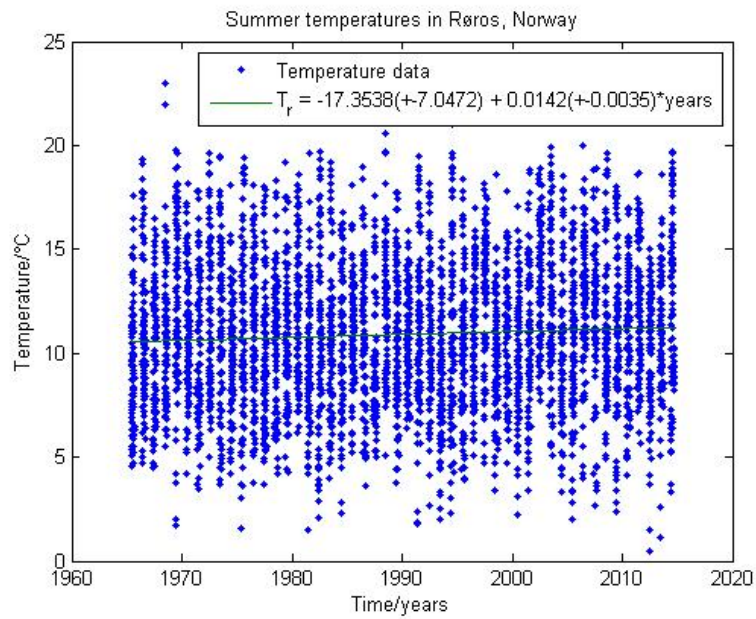
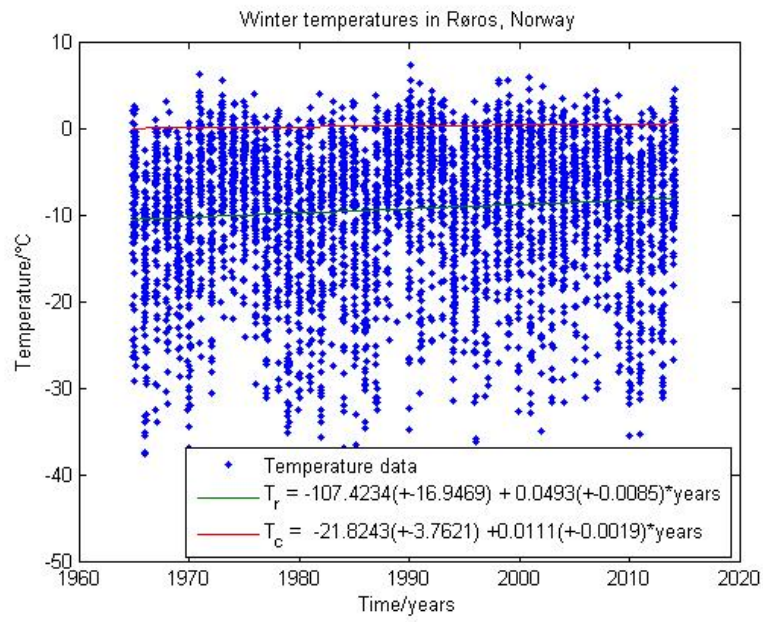
$$T_c = 42.3086(+ - 4.6087) - 0.0214(+ - -0.0023) \cdot \text{years}$$



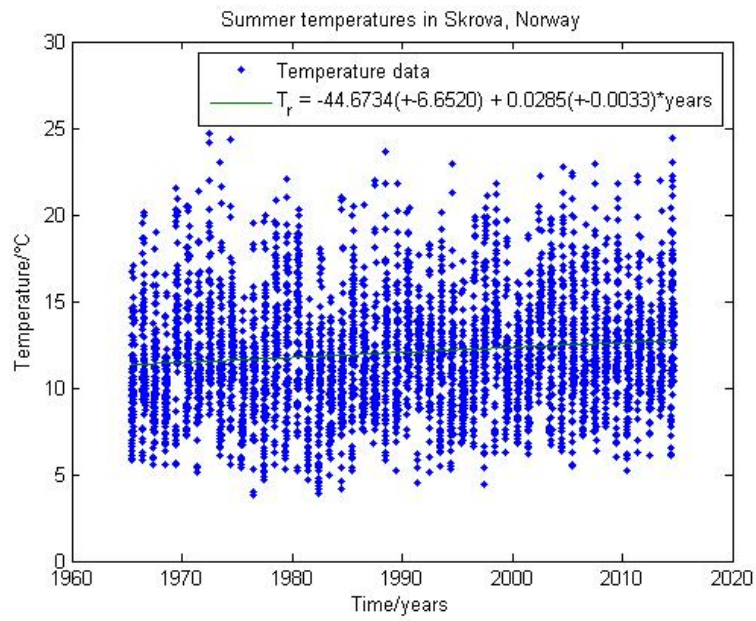
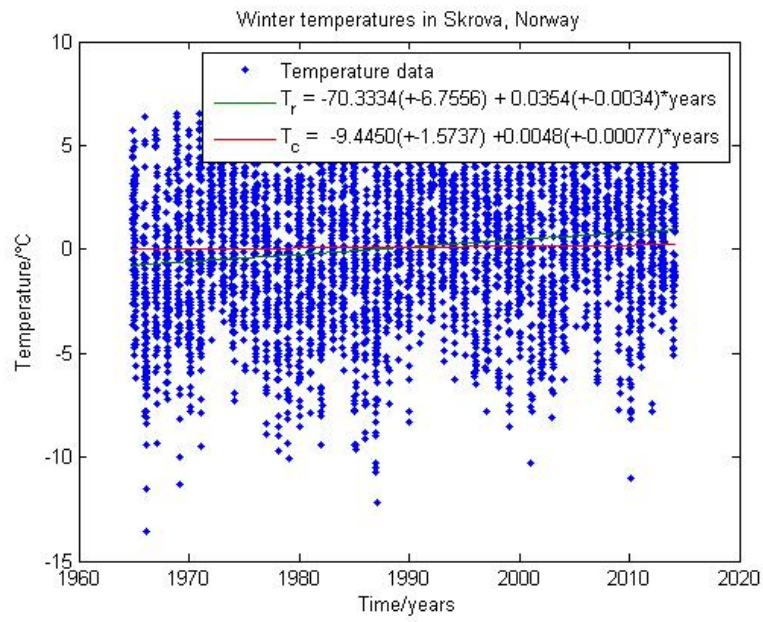
$$T_c = 18.6868(+ - 1.9424) - 0.0094(+ - -0.00096) * year \cdot years$$



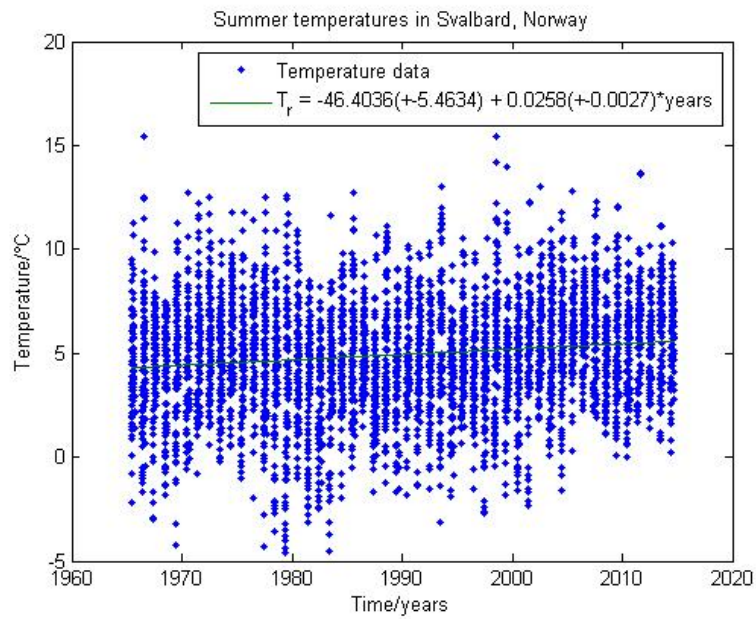
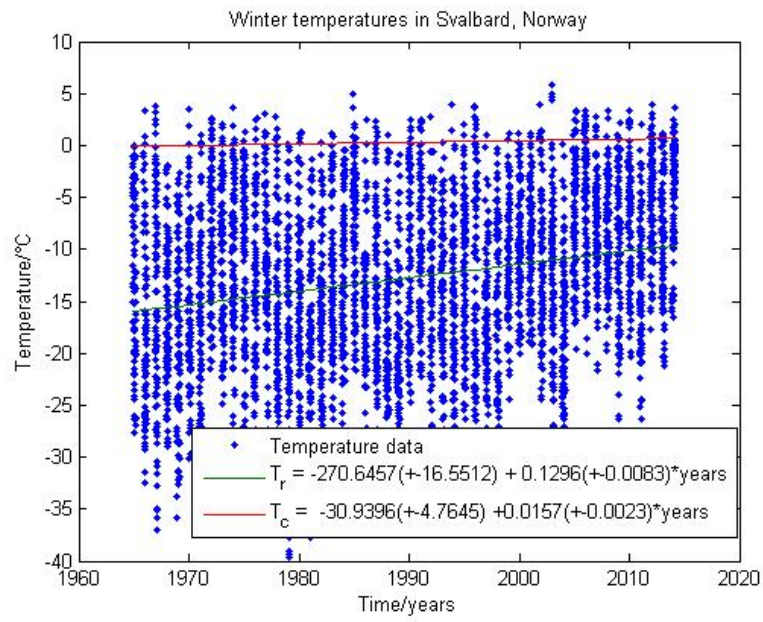
$$T_c = 35.0949(+ - 3.4908) - 0.0177(+ - -0.0017) \cdot \text{years}$$



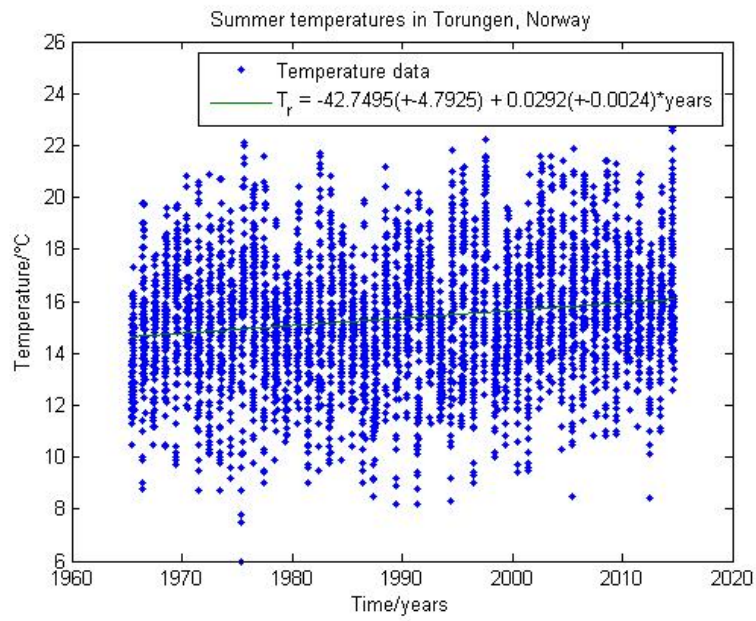
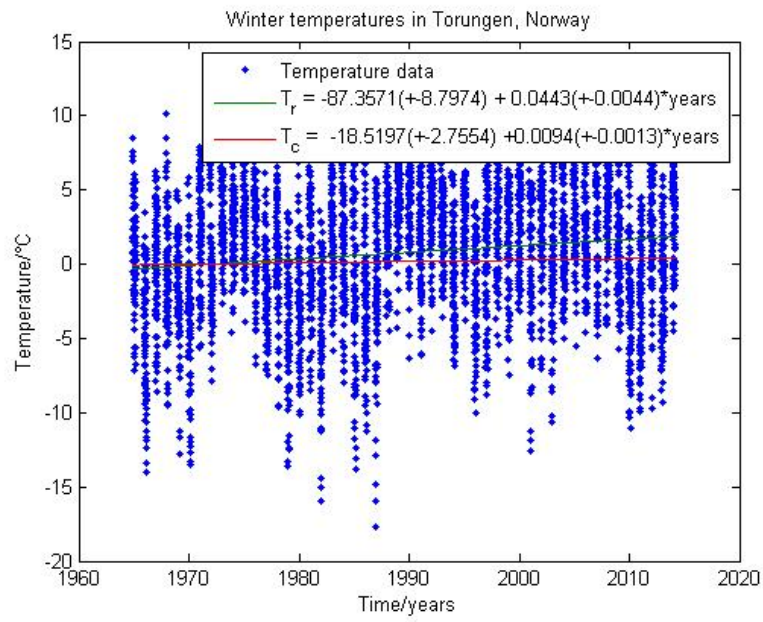
$$T_c = 36.7215(+ - 4.7580) - 0.0186(+ - -0.0024) \cdot \text{years}$$



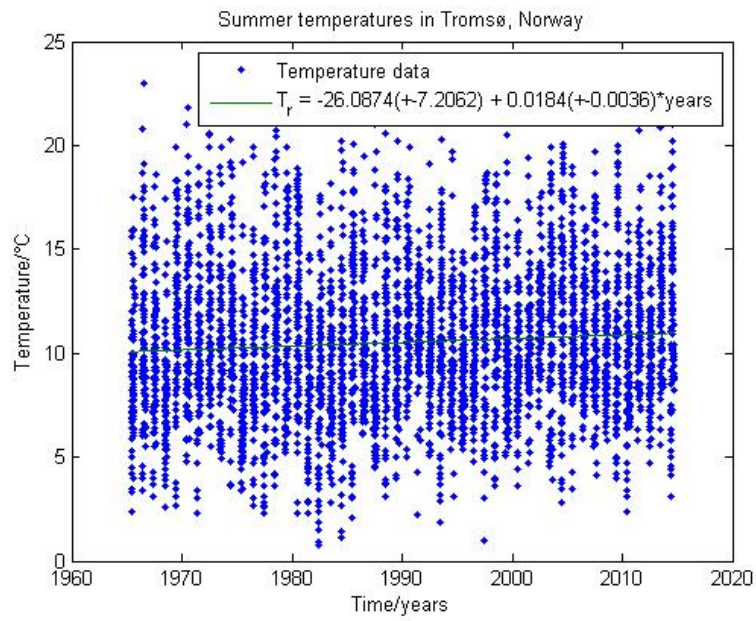
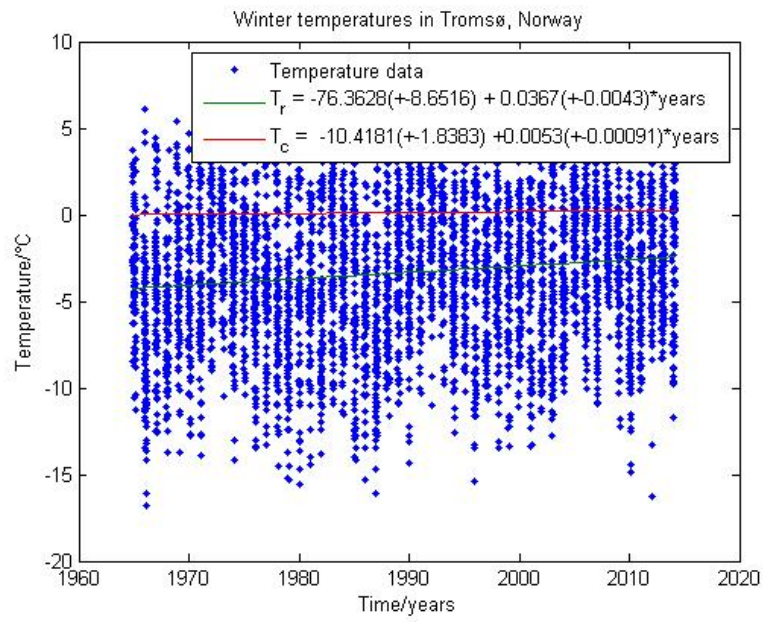
$$T_c = 15.9828(+ - 1.9300) - 0.0081(+ - -0.00096) \cdot \text{years}$$



$$T_c = 51.8760(+ - 5.4259) - 0.0262(+ - -0.0027) \cdot \text{years}$$

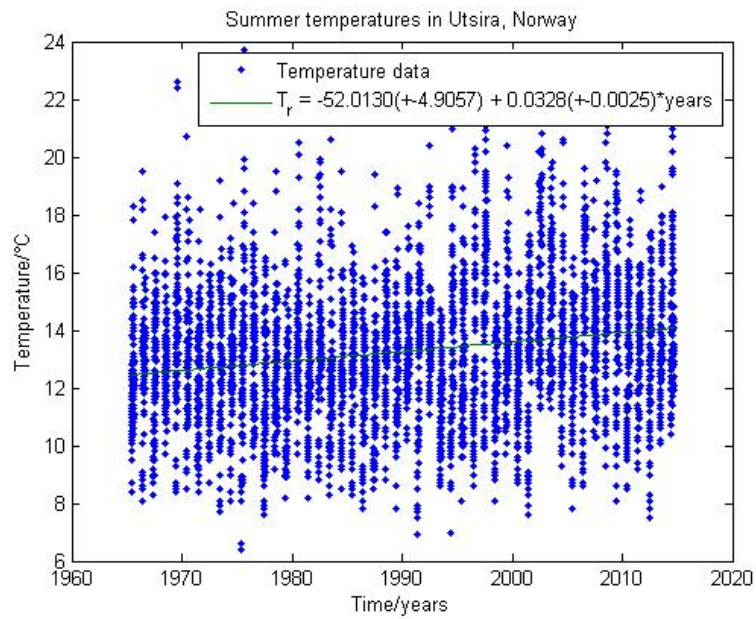
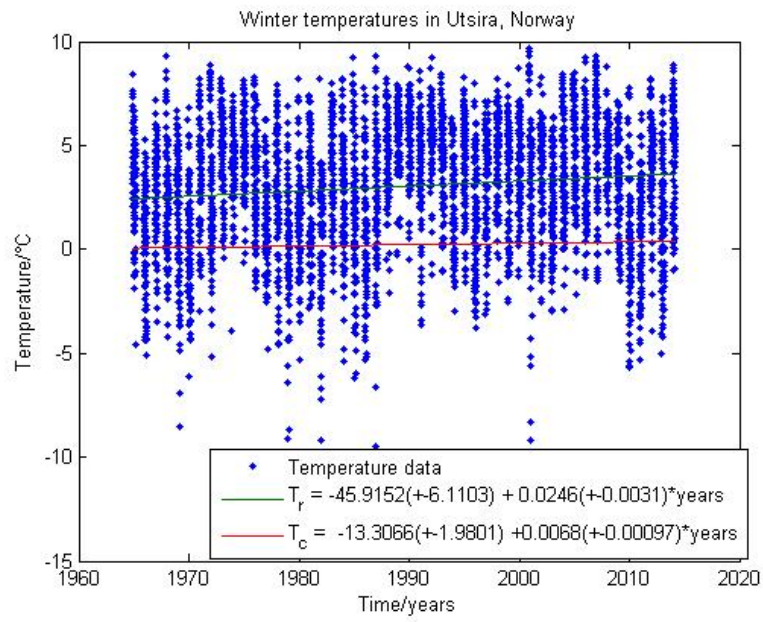


$$T_c = 31.1589(+ - 2.9946) - 0.0157(+ - -0.0015) \cdot \text{years}$$

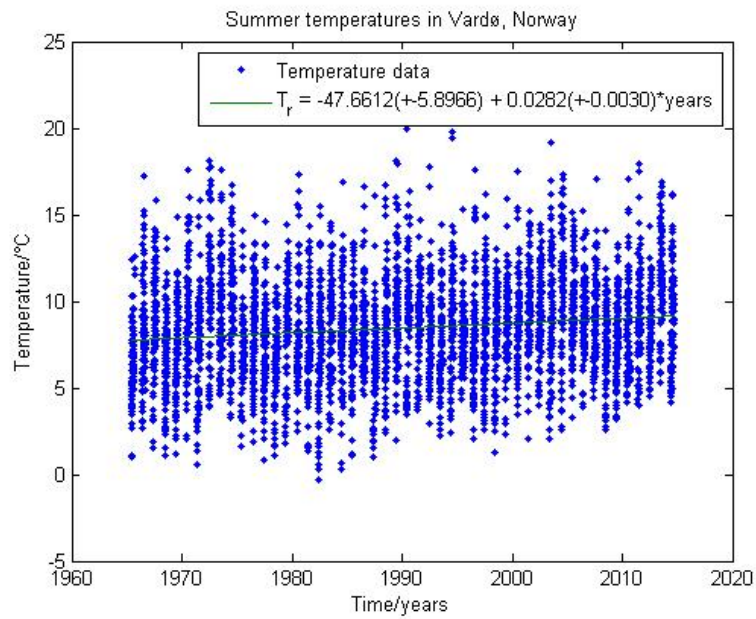
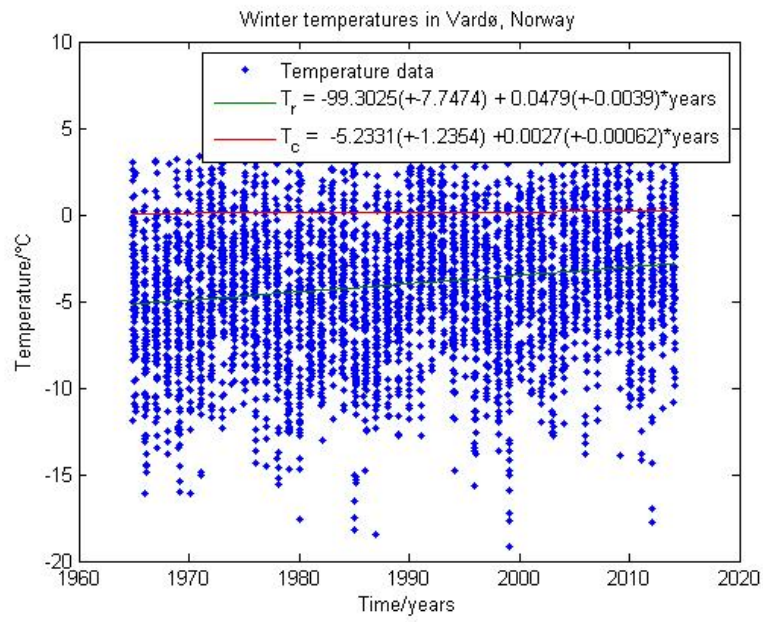


$$T_c = 17.6321(+ - 2.3589) - 0.0089(+ - -0.0012) \cdot \text{years}$$

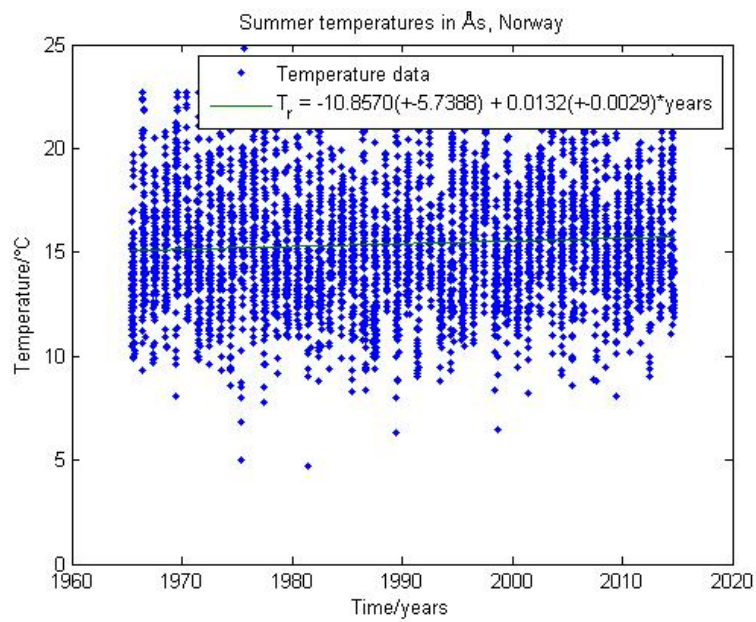
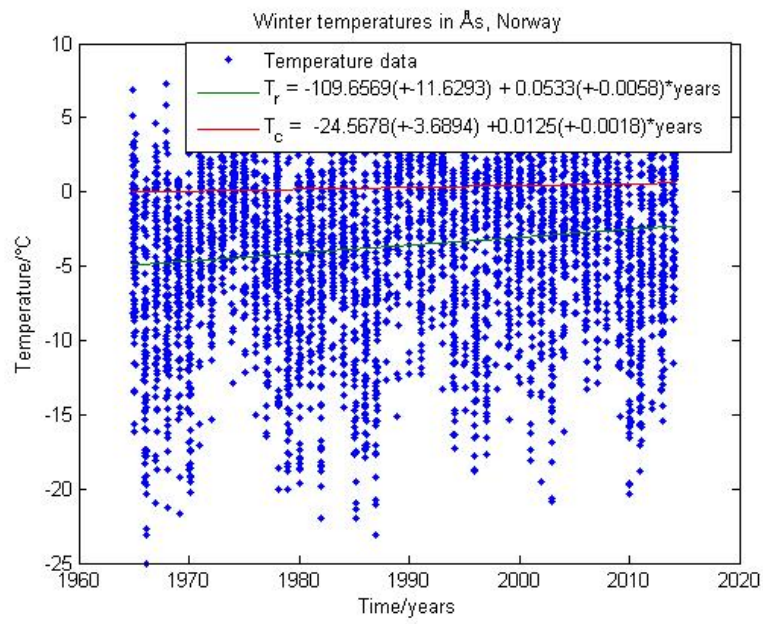




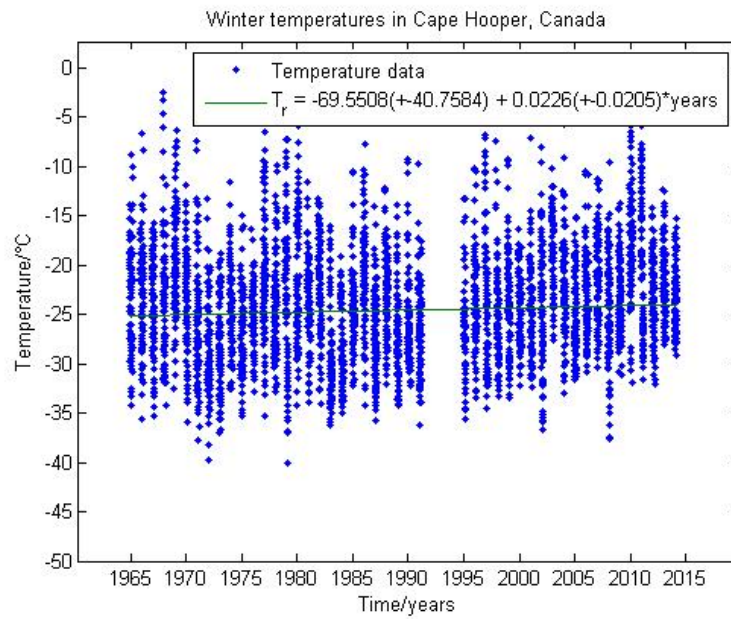
$$T_c = 22.3927(+ - 2.1520) - 0.0113(+ - -0.0011) \cdot \text{years}$$



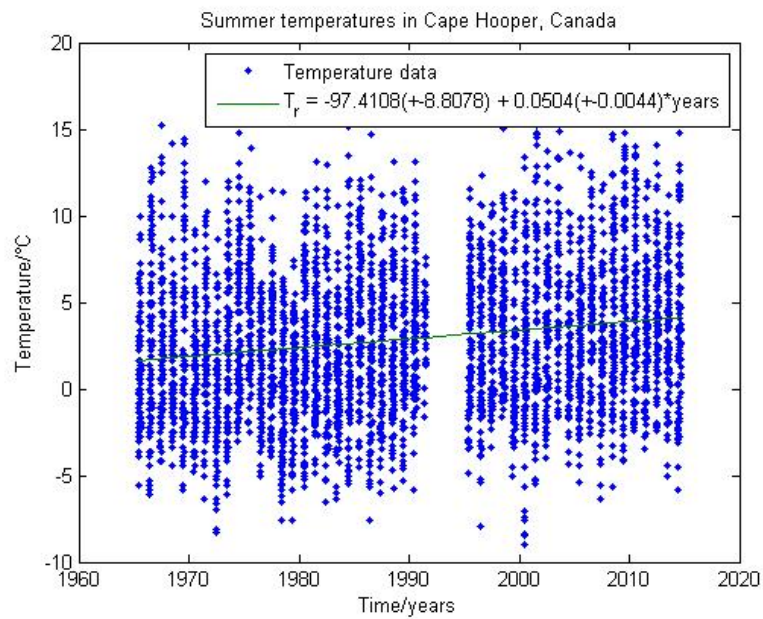
$$T_c = 8.8819(+ - 1.8170) - 0.0045(+ - -0.00091) \cdot \text{years}$$



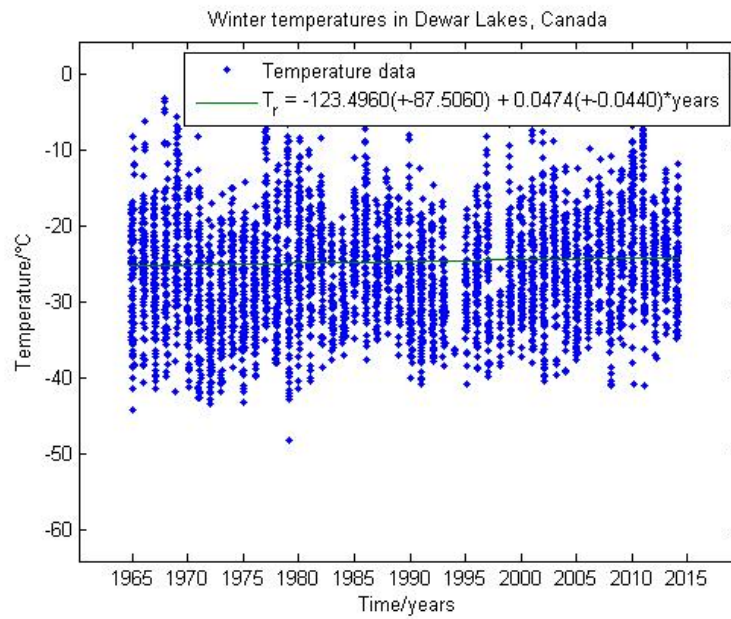
$$T_c = 41.3685(+ - 4.0578) - 0.0209(+ - -0.0020) \cdot \text{years}$$



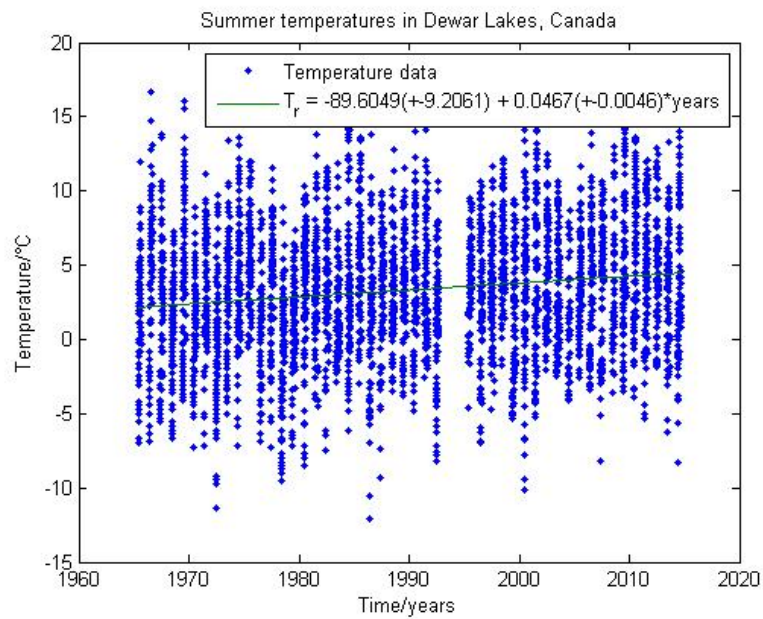
$$T_c = 22.2559(+ - 3.3841) - 0.0114(+ - -0.0017) \cdot \text{years}$$



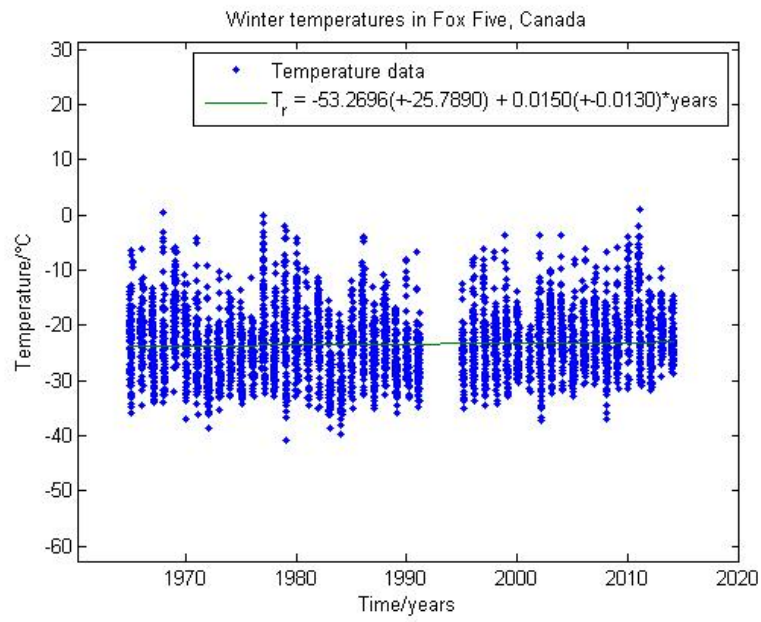
$$T_c = -5.3478(+ - 1.6286) + 0.0027(+ - -0.0008) \cdot \text{years}$$



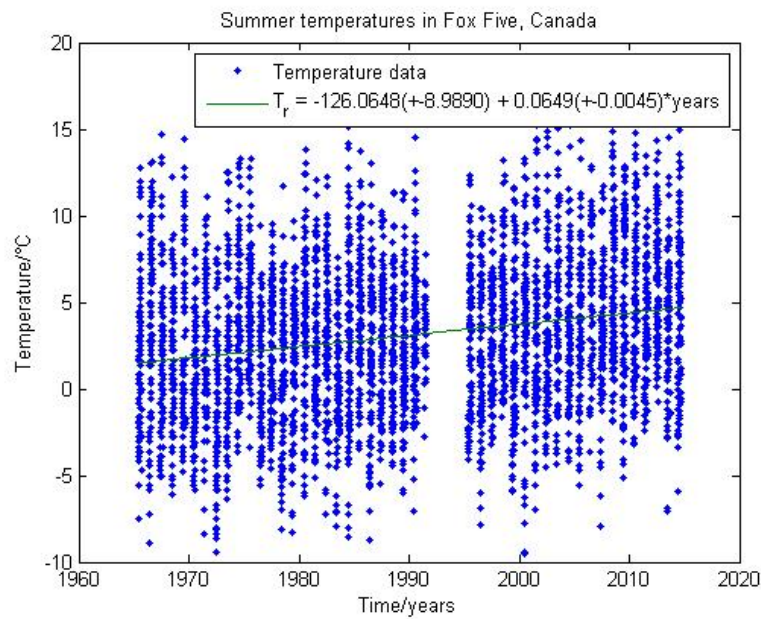
$$T_c = 34.7256(+ - 5.1573) - 0.0177(+ - -0.0025) \cdot \text{years}$$



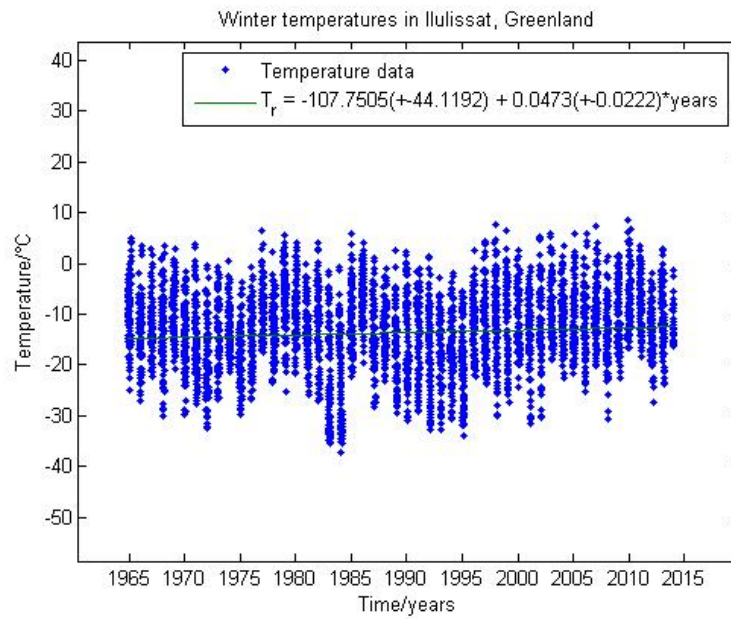
$$T_c = -21.1028(+ - 2.1014) + 0.0107(+ - 0.0010) \cdot \text{years}$$



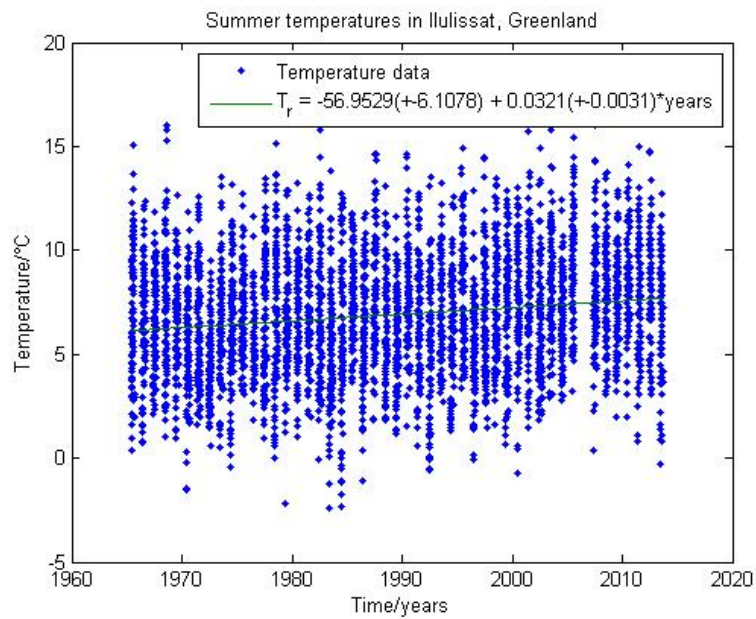
$$T_c = -48.0497(+ - 73.7087) + 0.0220(+ - 0.0375) \cdot \text{years}$$



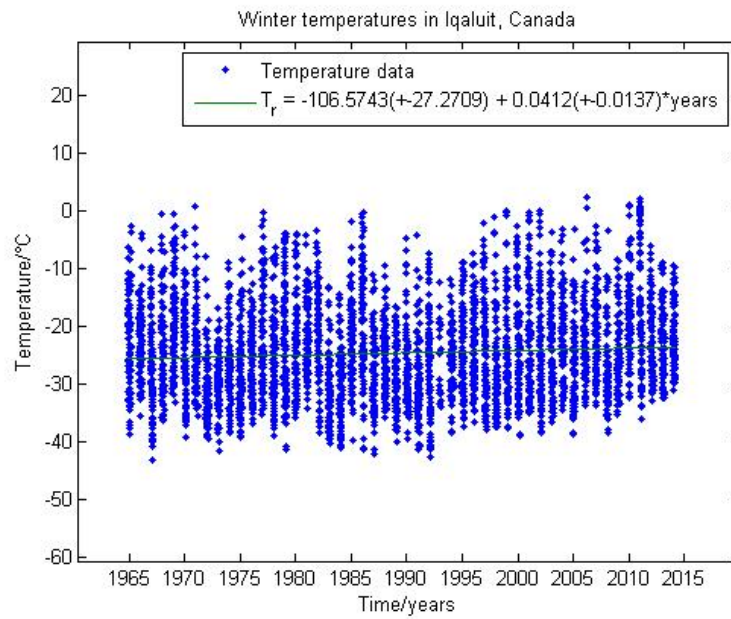
$$T_c = -11.0397(+ - 1.7566) + 0.0056(+ - 0.0009) \cdot \text{years}$$



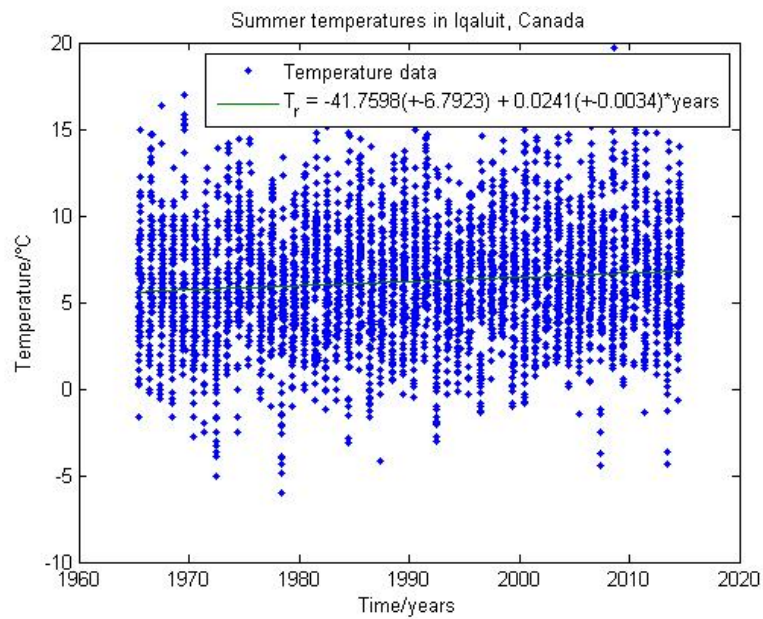
$$T_c = -44.8465(+ - 128.3172) + 0.0148(+ - 0.0653) \cdot \text{years}$$



$$T_c = -14.8290(+ - 1.5916) + 0.0075(+ - 0.0008) \cdot \text{years}$$

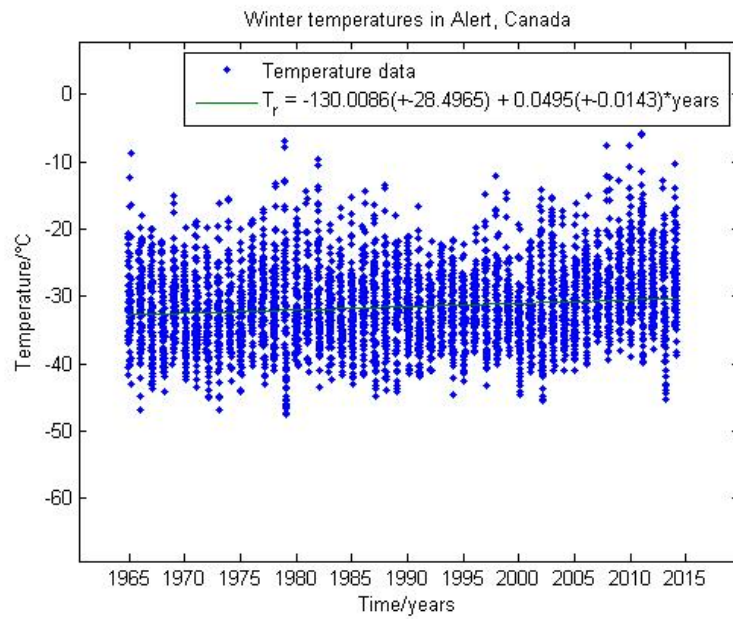


$$T_c = -2.0147(+ - 68.9128) - 0.0013(+ - -0.0351) \cdot \text{years}$$

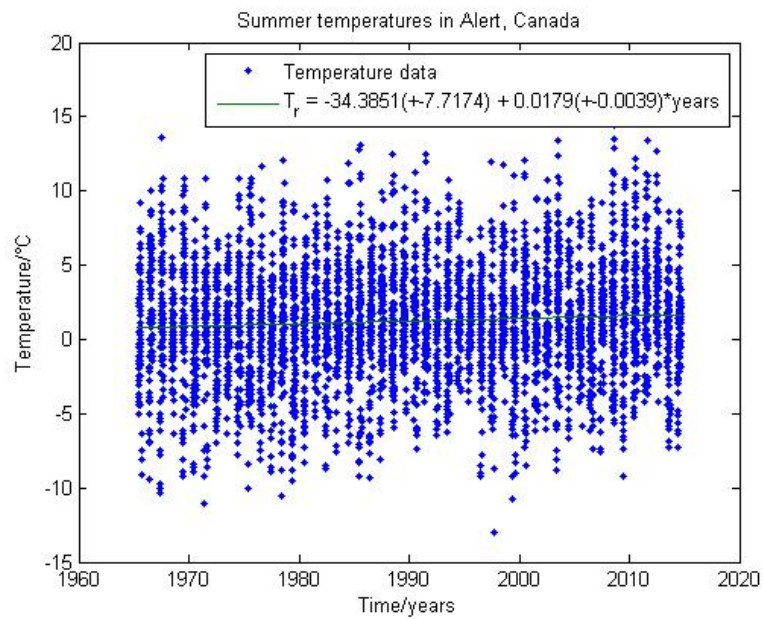


$$T_c = -0.7570(+ - 1.0550) + 0.0003(+ - 0.0005) \cdot \text{years}$$

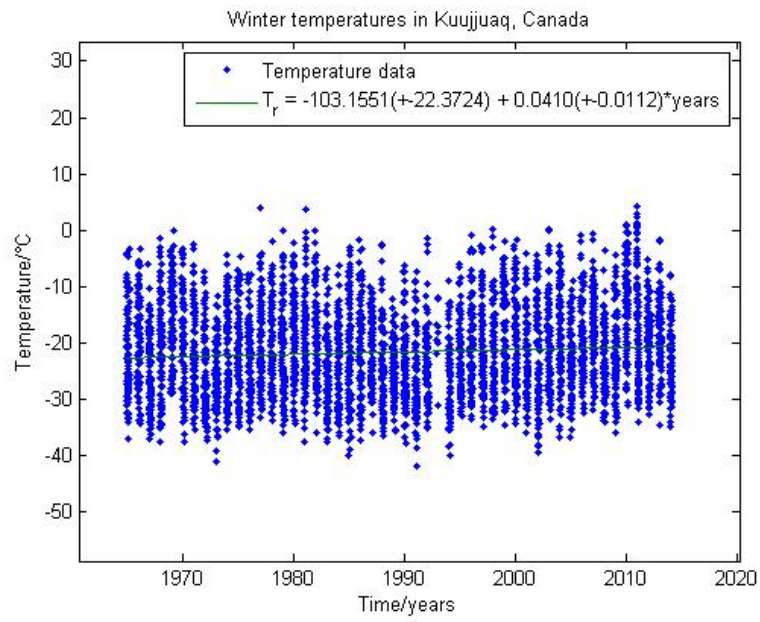




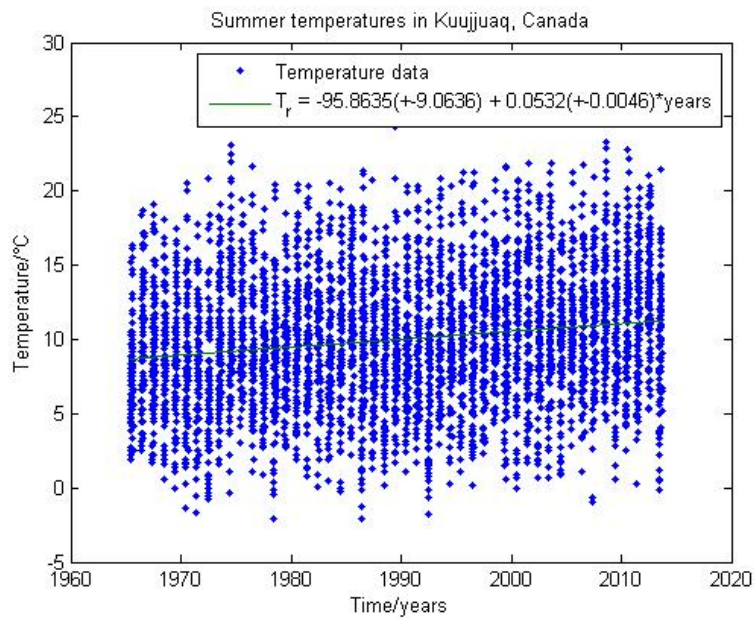
$$T_c = -178.0412(+ - 85.8766) + 0.0874(+ - -0.0351) \cdot \text{years}$$



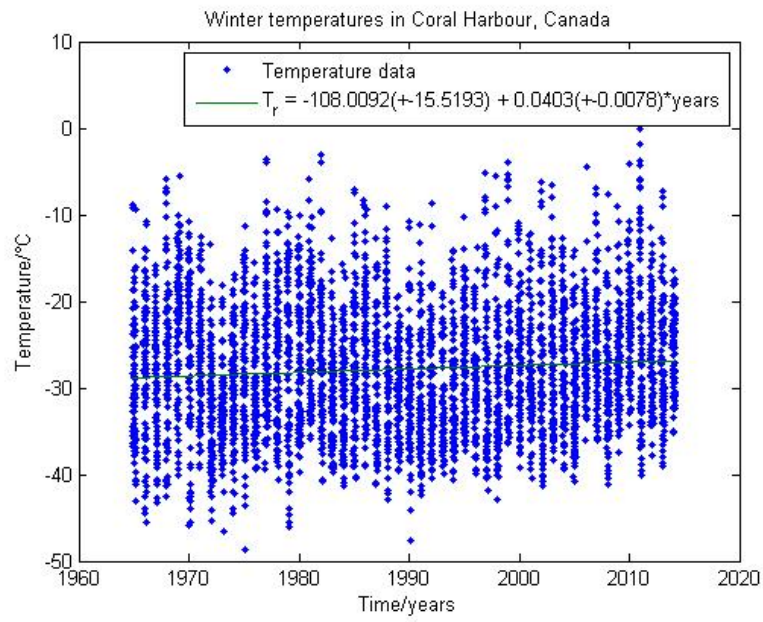
$$T_c = -22.5664(+ - 2.1983) + 0.0114(+ - 0.0011) \cdot \text{years}$$



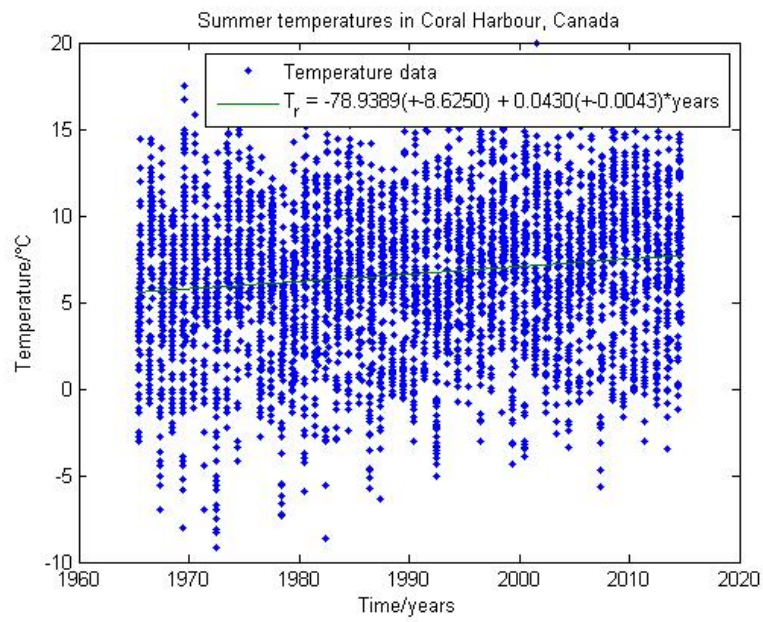
$$T_c = 53.1134(+ - 49.0736) - 0.0282(+ - -0.0250) \cdot \text{years}$$



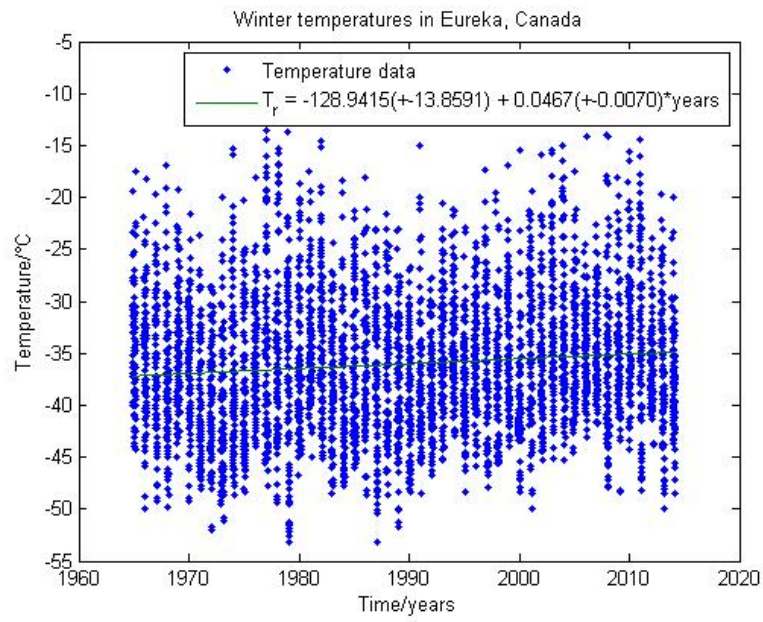
$$T_c = 0.5033(+ - 1.5964) - 0.0003(+ - -0.0008) \cdot \text{years}$$



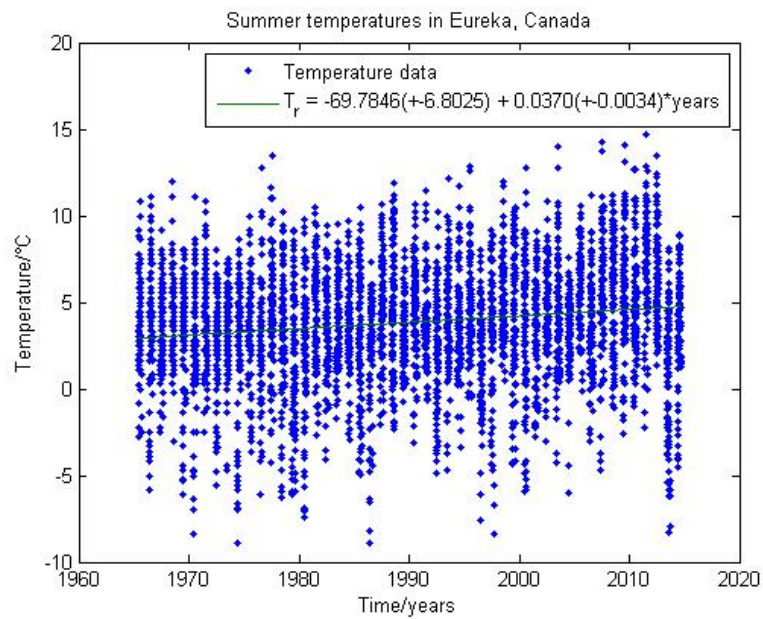
$$T_c = 20.3040(+ - 3.4081) - 0.0104(+ - -0.0017) \cdot \text{years}$$



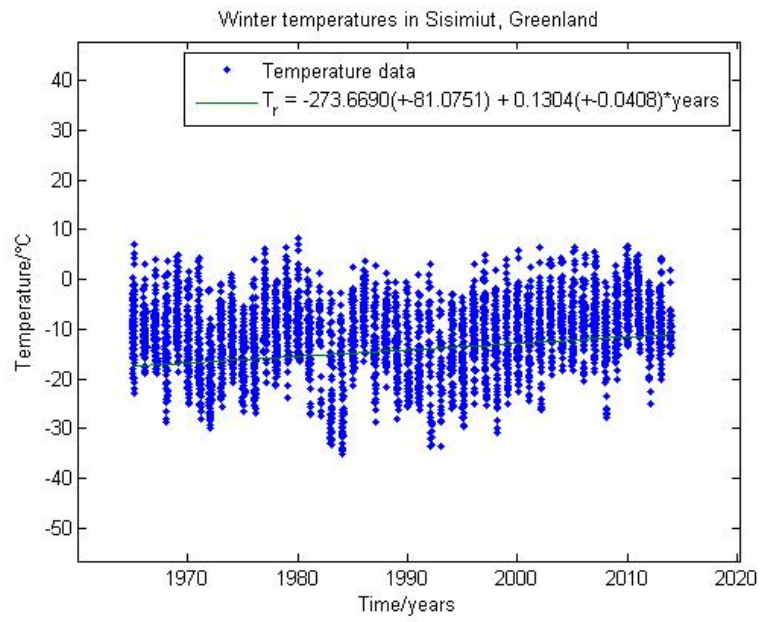
$$T_c = -4.4150(+ - 1.0640) + 0.0022(+ - 0.0005) \cdot \text{years}$$



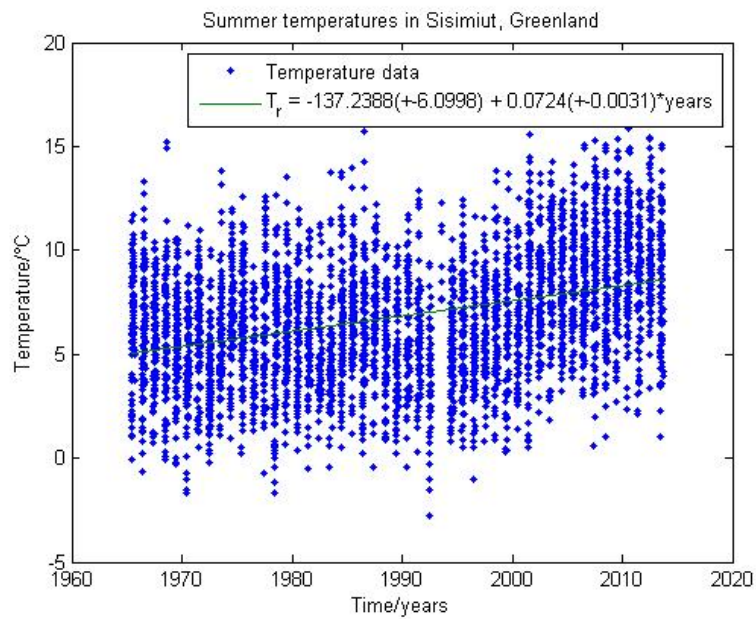
$$T_c = 20.8102(+ - 3.3863) - 0.0106(+ - -0.0017) \cdot \text{years}$$



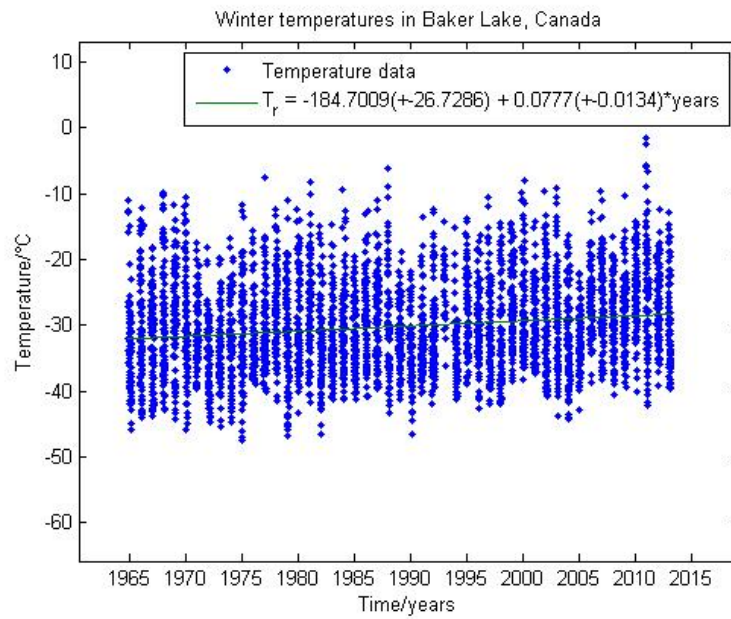
$$T_c = -20.5271(+ - 1.8940) + 0.0104(+ - 0.0009) \cdot \text{years}$$



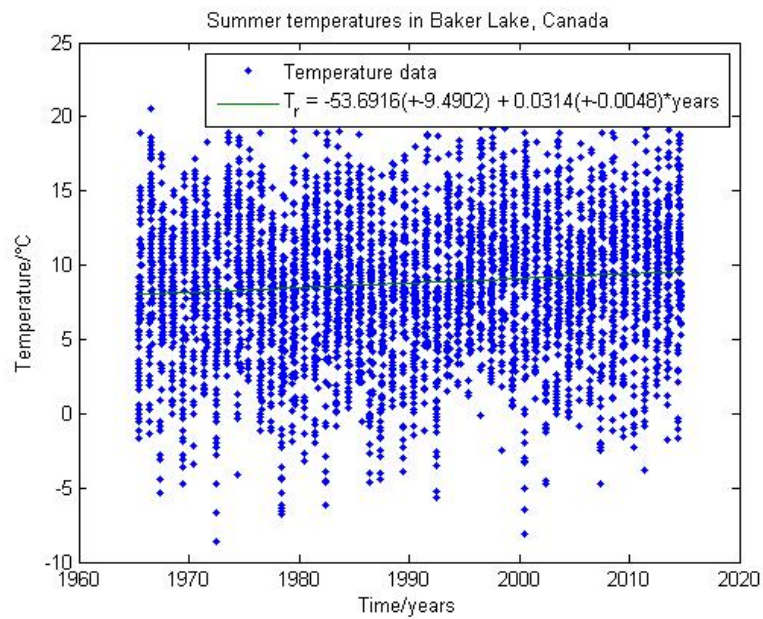
$$T_c = -222.4998(+ - 254.3984) + 0.0836(+ - 0.1295) \cdot \text{years}$$



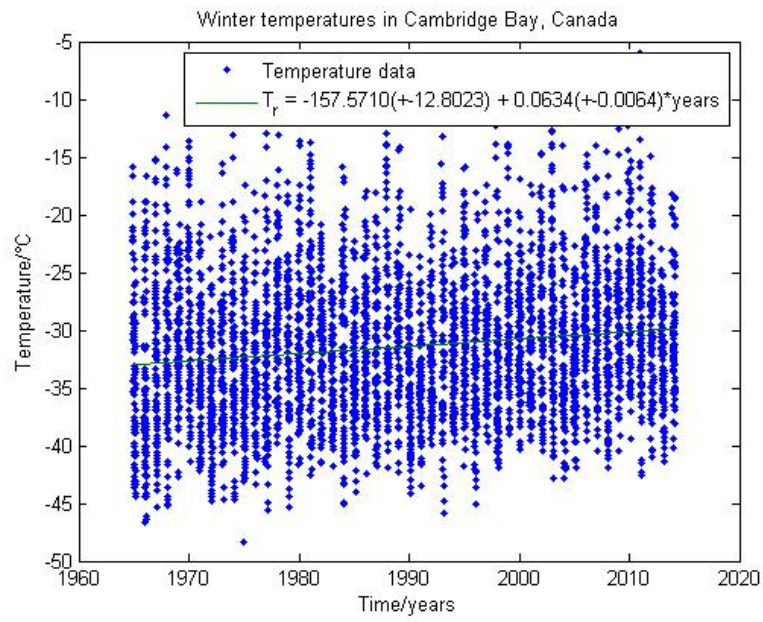
$$T_c = -16.6051(+ - 1.7274) + 0.0084(+ - 0.0009) \cdot \text{years}$$



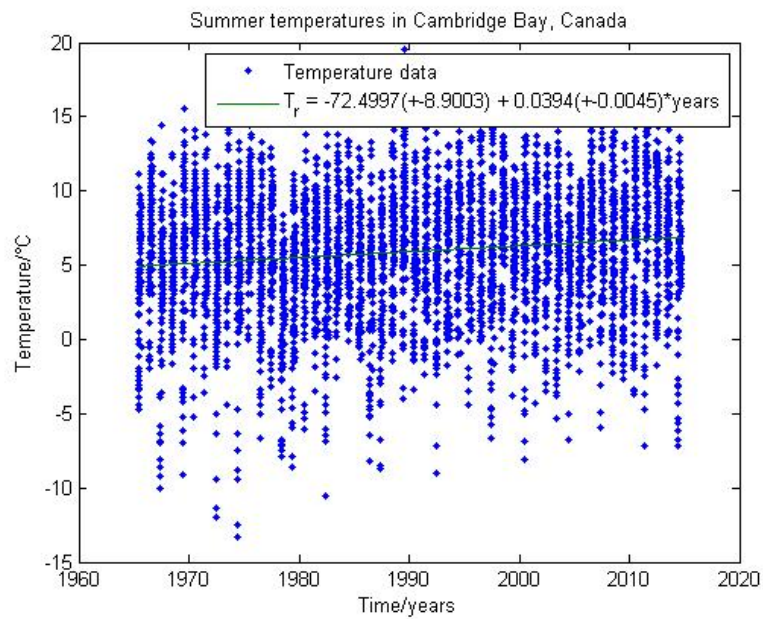
$$T_c = 87.3924(+ - 71.0089) - 0.0469(+ - -0.0361) \cdot \text{years}$$



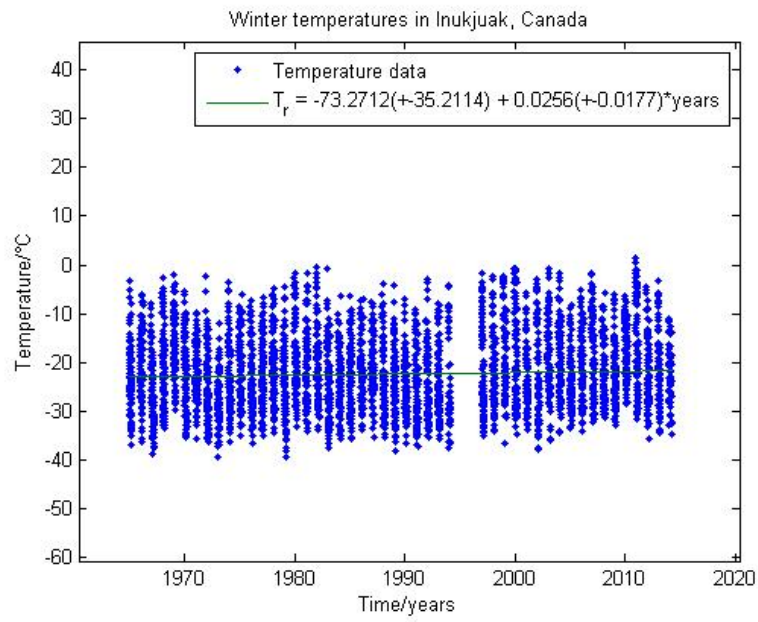
$$T_c = -3.2618(+ - 1.2690) + 0.0016(+ - 0.0006) \cdot \text{years}$$



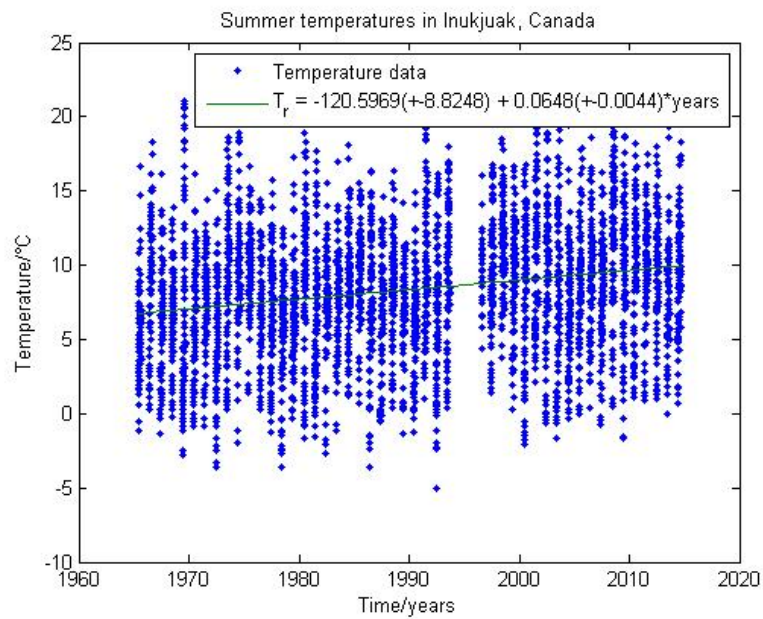
$$T_c = 2.8455(+ - 1.6521) - 0.0015(+ - -0.0008) \cdot \text{years}$$



$$T_c = -14.6202(+ - 1.6225) + 0.0074(+ - 0.0008) \cdot \text{years}$$

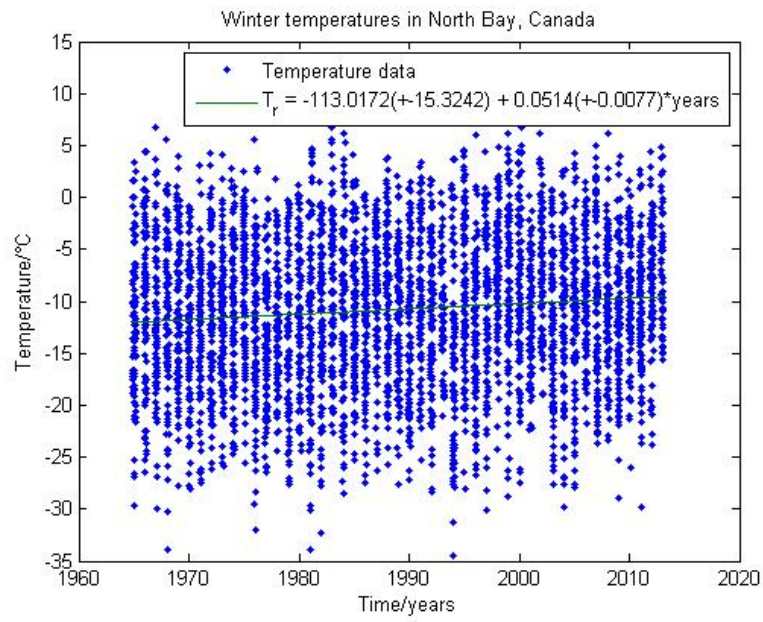


$$T_c = 2.8898(+ - 101.7299) - 0.0063(+ - -0.0518) \cdot \text{years}$$

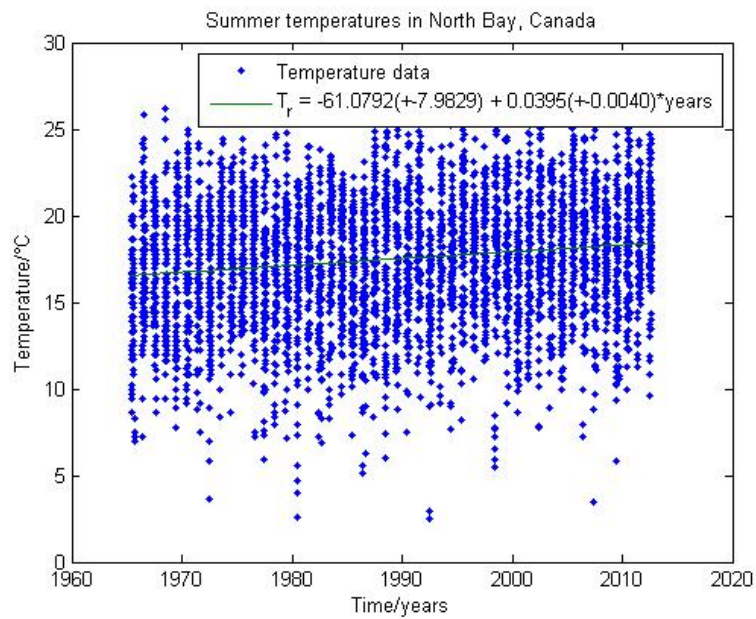


$$T_c = -18.0266(+ - 1.9845) + 0.0091(+ - 0.0010) \cdot \text{years}$$

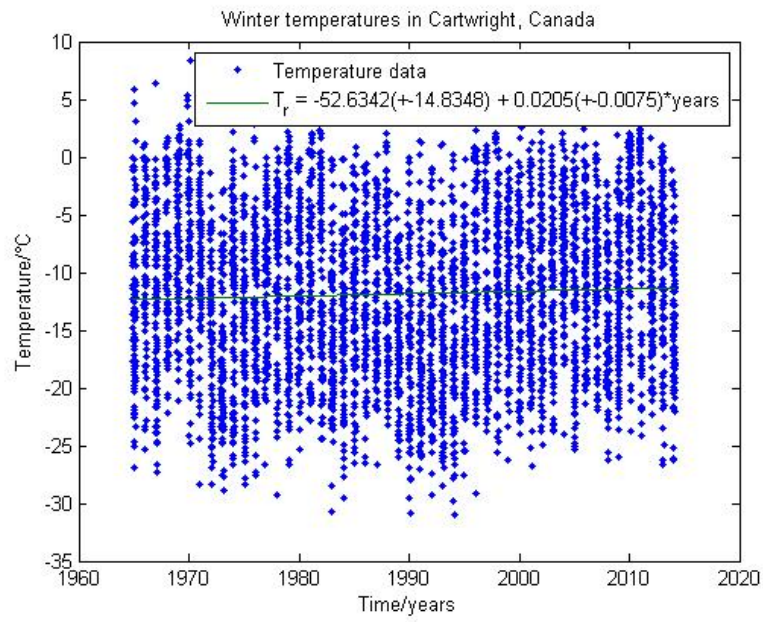




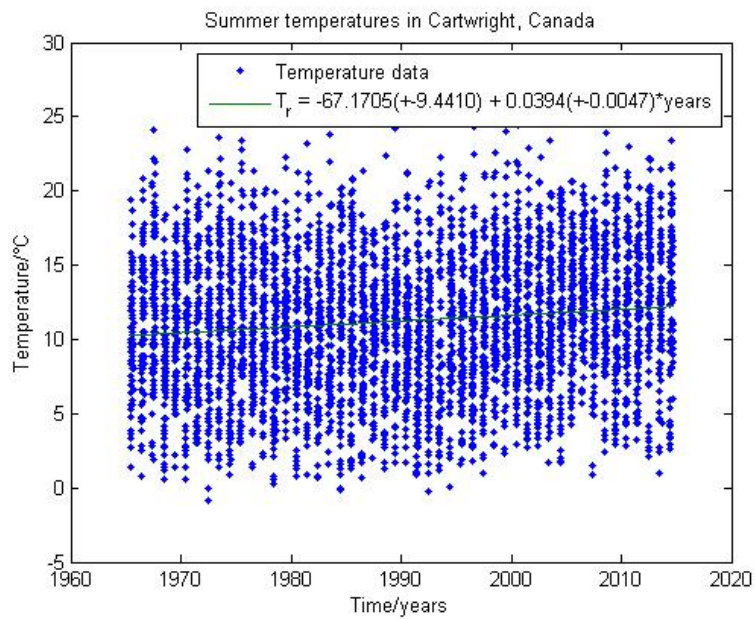
$$T_c = -11.5892(+ - 2.5325) + 0.0059(+ - 0.0013) \cdot \text{years}$$



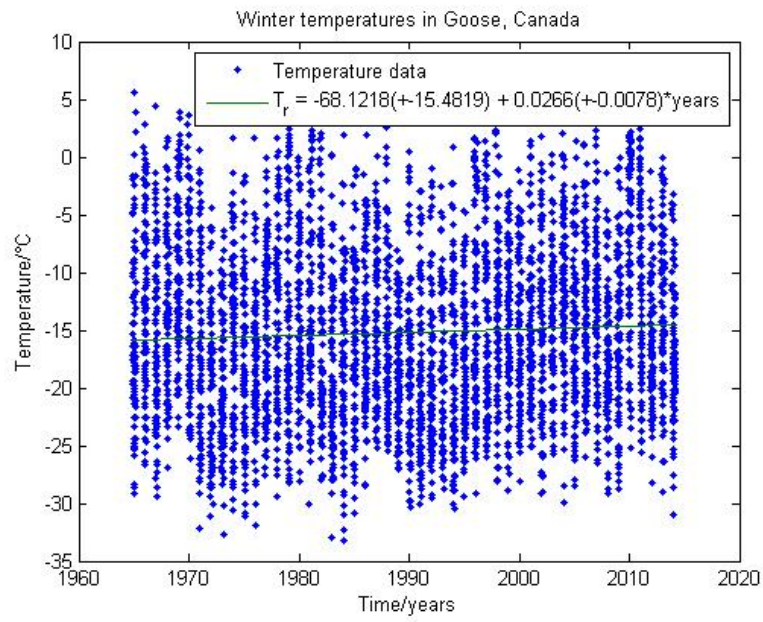
$$T_c = 2.9013(+ - 1.5276) - 0.0015(+ - -0.0008) \cdot \text{years}$$



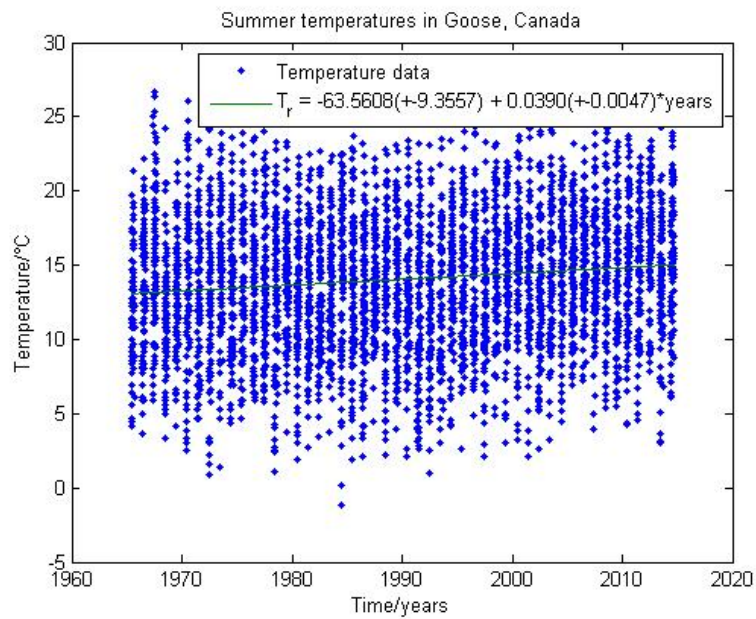
$$T_c = 24.1751(+ - 3.8260) - 0.0123(+ - -0.0019) \cdot \text{years}$$



$$T_c = 18.8637(+ - 2.3473) - 0.0095(+ - -0.0012) \cdot \text{years}$$



$$T_c = 18.7200(+ - 3.2546) - 0.0096(+ - -0.0016) \cdot \text{years}$$



$$T_c = 14.9292(+ - 2.1049) - 0.0076(+ - -0.0011) \cdot \text{years}$$