Temperature analysis

MNXB01 Project

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1 Introduction

Temperature measurements are made all over the world every day. The data is used for a lot of different purposes, e.g. weather broadcasts, but the one we all think about is probably confirming global warming and the greenhouse effect.
SMHI (Swedish Metrological and Hydrological Institute) measures the temperature on various locations. This data can be found on their website [?]. The temperatures are measured between one and three times per day. Several locations has datasets that started about 60 years ago (e.g. Lund), but the Uppsala dataset contains average daily temperatures since 1722. In this report we analyze this data in ROOT and present the results. These results are: the temperature of a given day, the warmest and coldest day of each year, the mean temperature of each year and the beginning of the seasons.
As mentioned above, ROOT is used for the data analysis, which is a scientific software written in C++. Our code is structured in several different parts, with a class that contains all our functions. The common functions are: read data, print data, detect leap years and one that returns the day number given the date. In addition, each of the four produced results has a separate .cpp-file.

2 The temperature of a given day

Knowing the temperature of a given day does not confirm global warming by itself, but it can be interesting with more detailed data on certain days for other reasons. For example, is the weather the same on midsummer and christmas?
Two functions were created, both giving the temperature of a certain day. The difference is that one takes the date (month, day) as input and the other one takes the day number as input. To make it as simple as possible, the function that takes day number as input first coverts it into month and day, so that the functions thereafter are identical.
The algorithm itself is straightforward. First, the dates in the data that matches the input date are found. Then, the temperatures for all years are stored in a vector, which is plotted in a histogram. This process is shown in a flow chart in Fig. 1.
A histogram for the 19th of July in Uppsala, for the years from 1722 to 2013, is shown in Fig. 2. From the histogram it is possible to get both the mean and the standard deviation. For Fig. 2, the mean is 16.88 and the standard deviation is 2.96. If we want to know the probability for a certain temperature on the given day, we can use the mean and the standard deviation and assume a Gaussian distribution. The black line

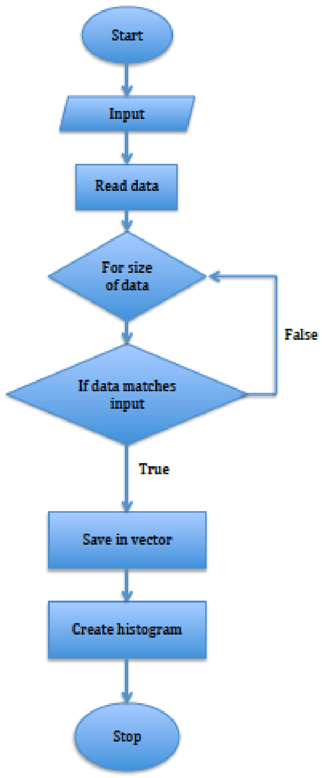


Figure 1: Flow chart for the function that gives the temperature of a given day.

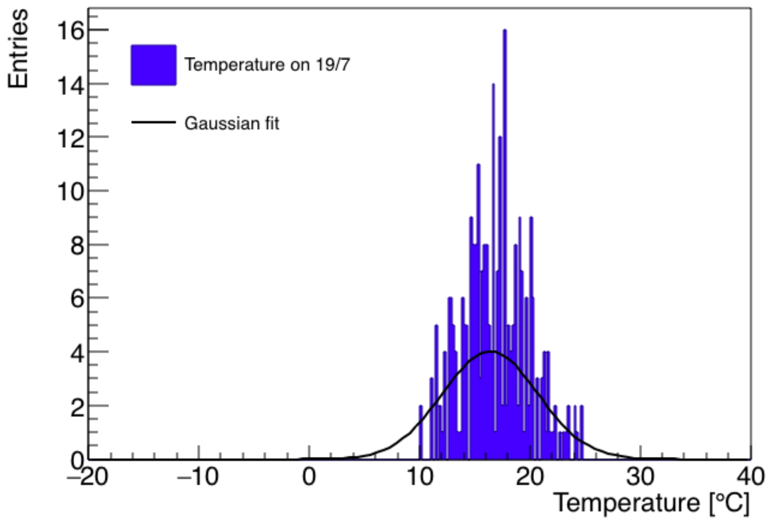


Figure 2: The temperatures on July 19$^{\text{th}}$ in Uppsala for the years between 1722 and 2013. The black line is a Gaussian fitted to the histogram.

in Fig. 2 is a Gaussian fitted to the histogram, to see if it is a reasonable assumption. For Uppsala, the data contains enough years to give 274 counts, so the Gaussian fit should be sensible. This is not true, given that the fit has a χ^2 of 2, which is not good at all. Some of the other data sets would give a lot less data points, as in Fig. 3. The histogram contains only 35 entries for the 19$^{\text{th}}$ of July in Lund, and the Gaussian fit is definitely not a good approximation. Therefore, the conclusion is that it is not possible to calculate the probability of a certain temperature by approximating with a Gaussian.

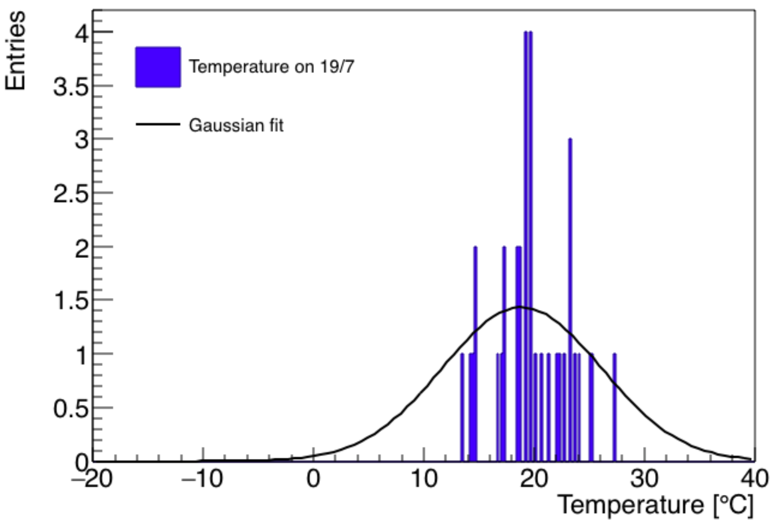
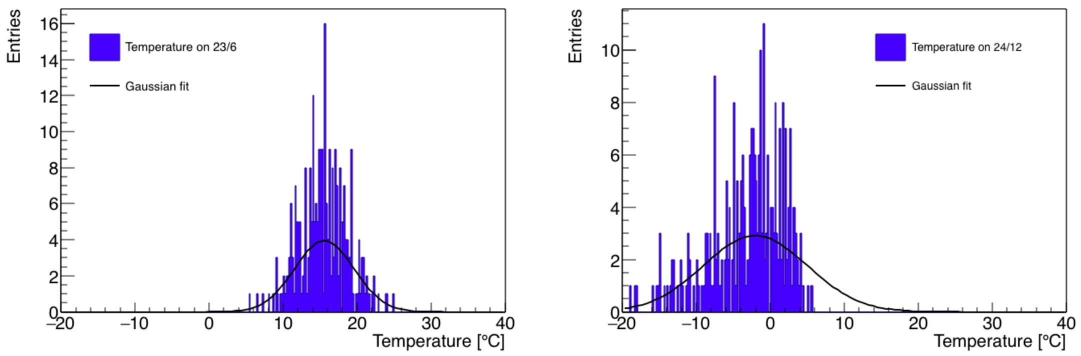


Figure 3: The temperatures on July 19$^{\text{th}}$ in Lund between 1961 and 2014. The black line is a Gaussian fitted to the data.

Midsummer is celebrated in Sweden on a day between June 19$^{\text{th}}$ and June 26$^{\text{th}}$. Historically, beginning in the 4th century, Midsummer was celebrated on the 24$^{\text{th}}$ of June. Therefore, June 23$^{\text{rd}}$ is chosen for the comparison since we celebrate on midsummers eve (we now celebrate on the Friday between June 19$^{\text{th}}$ and June 26$^{\text{th}}$). The weather on midsummers eve is compared to the weather on christmas eve, both using the dataset from Uppsala, seen in Fig. 4. Clearly there is a large difference in the temperatures on midsummer and christmas eve. The mean for midsummers eve (Fig. 4(a)) is 15.4 °C and the mean for christmas eve (Fig. 4(b)) is -3.1 °C.



(a) Midsummers eve

(b) Christmas eve

Figure 4: The temperatures on midsummers eve (a) and christmas eve (b), in Uppsala, for the years between 1722 and 2013.

3 The beginning of the seasons

A recent article by SVT Nyheter showed which season is was on the 1st of November for different areas in Sweden, as can be seen in Fig. 5. According to this article it was already winter in the north of Sweden while in the most south part, including Lund, it was still summer. This did not seem to correspond to what one might observe when looking out the window in Lund, the ground was already covered with red leaves even though it was still summer according to SVT Nyheter. So which definitions of the season are there? Using one of these definitions when do the seasons start in Lund and how does the start of each season vary over a number of years?

Figure 5: The season in different areas in Sweden on the 1st of November. Image from [1].

3.1 Definition of the Seasons

Sveriges meteorologiska och hydrologiska institut (SMHI) uses two different definitions of the seasons, a definition based on the calendar and a meteorological definition [2]. According to the definition based on the calendar spring is always from March to May, summer from June to August, fall from September to November and winter from December to February. This is clearly the same for each year and is not dependent on temperature of any other parameter. The meteorological definition of the seasons is based on the average temperature of each day and the seasons can therefore be start on different dates each year. The meteorological winter starts when the average temperature of a day is equal to or below zero for 5 days in a row. The first day of winter is then the first of these 5 days. The definition for the meteorological summer is similar, but the average temperature needs to be 10 degrees or higher. The meteorological spring starts when the average temperature of a day is between zero and 10 degrees for 7 days in a row. The definition for the meteorological fall is similar, but the temperature only need to be between zero and 10 degrees for 5 days in a row. The seasons do of course need to occur in the right order, which means that spring has to start after winter and fall has to start after summer. SMHI's meteorological definition of the seasons will be used for the data analyses.

3.2 Method

The temperature data of Lund from Sveriges meteorologiska och hydrologiska institut (SMHI) will be used to determined to beginning of the meteorological season for the years in the dataset. The code used to produce the results on the beginning of the seasons can be found in `tempSeasons.cpp`, a number of member functions defined in `tempTrender.cpp` are also used. The main function, which calls all other functions, of the section is `tempTrender::startDaySeasons`. The first thing this function does is reading the data on Lund into a 2D vector with the use of `tempTrender::readData`. Since the meteorological definition of the seasons depends on the average temperature of a day, this is then calculated for every day in the dataset by `calcAverageTemp`. Using the resulting average temperatures each first day of a season is determined for all seasons and years in the dataset. This is done using the function `tempTrender::beginningWinterSummer` for both winter and summer and `tempTrender::beginningSpringFall` for both spring and fall. These functions are member variables since they use a member funtion `tempTrender::getDayOfYear`. The general flowchart of how each first day of all seasons is determined can be seen in 6. With the right temperature the temperature condition for a certain season is meant, which is smaller or equal to 0 degrees for winter, greater or equal to 10 degrees for summer and between 0 and 10 degrees for spring and fall. With the right day the condition on the number of subsequent is meant, which is 7 days for spring and 5 days for all other seasons. When a new season starts differs a lot between the seasons, for summer the only condition is that it occurs in a different year than the previous summer, because there is one summer per year. For spring and fall there is another condition that also needs to be satisfied, namely spring needs to occur after the first day of winter and fall needs to occur after the first day of summer. Because winter can cover part of the end of one year as well as the beginning of the next, winter does not always start once per year. There are four ways the first day of two consecutive winters can succeed each other.

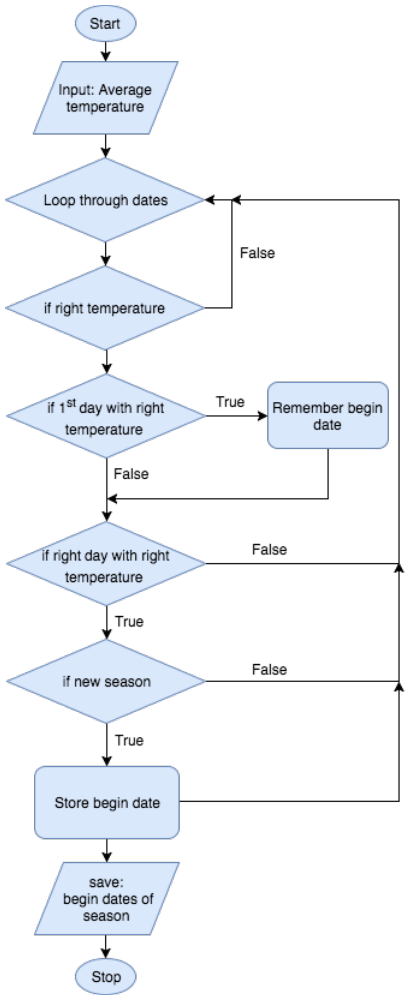


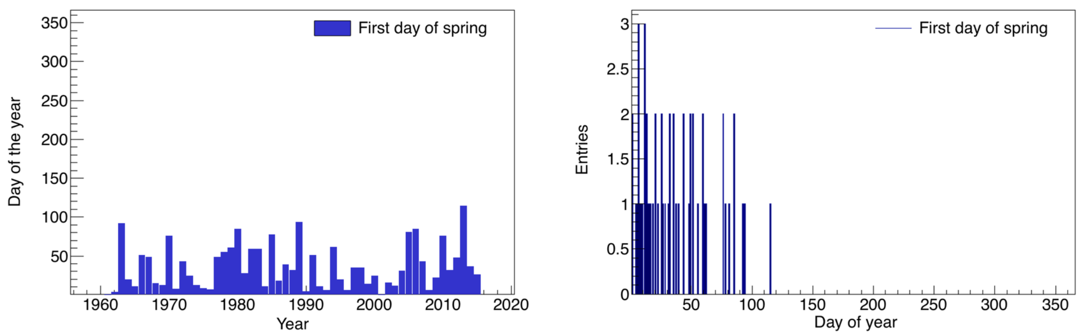
Figure 6: The code used for the calculation of the start of a season represented in a flowchart.

1. The successive winters are both early in the year (before June)
2. The successive winters are both late in the year (after June)
3. The successive winters are in the same year (one early in the year, the other late)
4. The successive winters skip a year (one winter late in the year, the next early)

If one of these cases is satisfied it is a new winter. Using the result for each season a bar graph showing the first day of the season as a function of the year is created by `plotSeason`. Histograms of the results are also created for each season using `histogram`.

3.3 Results and Conclusion

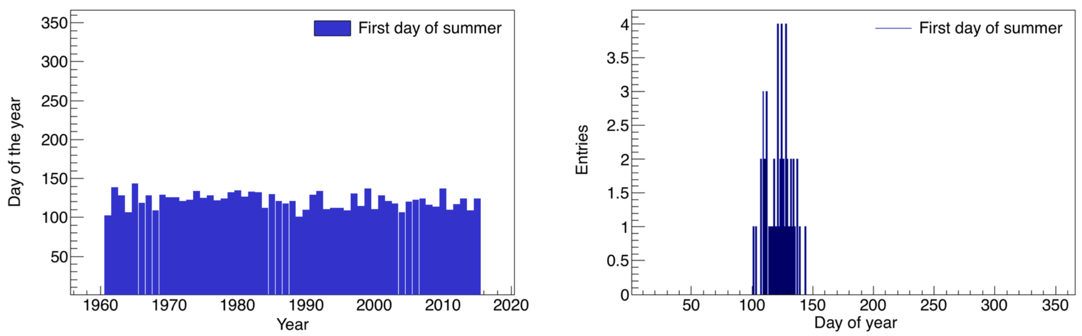
The first day of a season is plotted in a bar graph as a function the year. The date of the beginning of the season is represented by the day of the year (i.e. from 1 to 365 or 366 for a leap year). A histogram with the first days of the season is also plotted. The result for spring can be seen in Fig. 7.



(a) Bar graph **(b)** Histogram

Figure 7: The first day on which spring starts for each year in Lund is shown in (a). While (b) shows the number of times spring starts on a certain day in the year.

There is no clear trend visible in the bar graph, clear increase or decrease as a function of year. There is however quite a large difference between the start of spring for different years. In the histogram this spread can also be seen. Spring is most frequently at the beginning of the year.

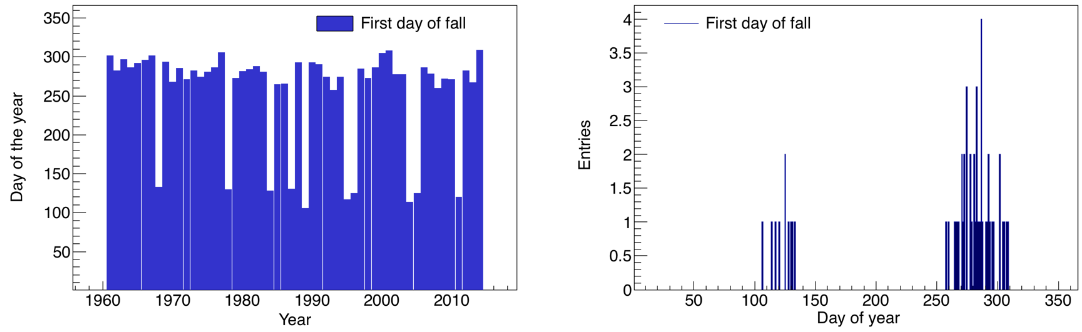


(a) Bar graph **(b)** Histogram

Figure 8: The first day on which summer starts for each year in Lund is shown in (a). While (b) shows the number of times summer starts on a certain day in the year.

The results for summer are shown in Fig. 8. Again there is no trend in the first day of summer as a function of year. It is however interesting that the first day of summer does not vary much per year, it is very consistent. This can also be seen in the histogram, which shown a fairly narrow peak.

Fig. 9 shows the result for fall. The bar graph shows a strange spread in the first day of fall which is not clearly correlated to the year. The histogram shows the peculiar divide of the first day of fall in two peaks, one between the 100th and 150th day and the other at the 250th to the

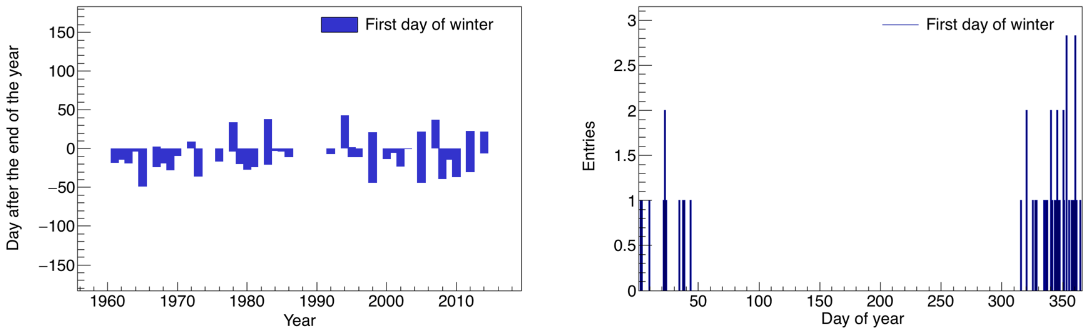


(a) Bar graph

(b) Histogram

Figure 9: The first day on which fall starts for each year in Lund is shown in (a). While (b) shows the number of times summer starts on a certain day in the year.

300$^{\text{th}}$ day of the year.



(a) Bar graph

(b) Histogram

Figure 10: The first day on which winter starts for each year in Lund is shown in (a). The day is given relative to the start of a new year, all negative numbers are before the 1$^{\text{st}}$ of January and all the positive numbers are on or after the 1$^{\text{st}}$ of January. The number of times spring starts on a certain day in the year in given in (b).

The bar graph and histogram for winter are shown in Fig. 10. The bar graph shows the first day of winter relative to the start of the year, negative numbers are at the end of the year while positive numbers correspond to a day at the beginning of the year. There is no clear trend visible. However the graph shows that not every year has a winter according to the used definition, only 44 winters where found in 54 full years. The histogram shows that winter occurs at most frequently at the end of the year.

4 Hot and Cold

This is the hot and cold part

5 tempExtrap

Global climate change and the greenhouse effect is often a reocurring political subject. From 1722-2013, the Swedish Meteorological and Hydrological Institute (SMHI) has collected daily temperature measurements from uppsala, Sweden. This data will be used to show the distribution of the yearly average temperature in uppsala from 1723-2013. Further more, analysis of this data will provide a moving average of the yearly average temperature. The moving average will be fitted with a $a(x - 1840) \cdot cos(bx)$ function, trying to se if the future temperature is not only increasing, but actually oscillating more violently correlated to the human development since the industrial revolution in 1840.

5.1 Method

Dailytemperatures were read from raw data and put into a multi dimensional vector according to the readData function. After this was called from `tempExtrap` a simple for loop converted this into a 2-D data vector containing year and temperature, with one entry for each day. This data vector was made in two different variants. One containing all values from the uppsala data set, assuming a measurement was taken for every day. Another containing only the measurements from the uppsala location.

The next step was to calculate the yearly averages from the data. For the uppsala only data, this was done by `averages1`. This iterated through all the elements of the data vector. If the year of the current element was not larger than the previous, then the temperature of the current element was added to a temperature sum and the number of days counted was incremented. When the current year became larger than the previous, the previous year was pushed into a dummy vector along with the average temperature. This dummy vector was then pushed into another vector, creating a 2D averages vector containing one element per year with that year's average temperature.

For the complete set of data, the first year, 1722, was skipped because its measurement started after the 1st of January. After 1722 the data vector was iterated in steps of the years with two nested for loops. In the outer loop, if the year was a leap year, an inner for loop iterated from day 1 to 366 and pushed the average temperature and the year into a dummy vector, into an averages vector. And similarly if the year was not a leap year, it was then iterated 365 times and the average was calculated appropriately.

With the data of yearly averages at hand, it was processed for plotting. To do this, the total average temeperature from all the yearly average temperatures was calculated. With a for loop iterating through the data elements and simple if statements, the average temperatures and corresponding year were pushed into one vector containing all temperatures above the total average, and one vector containing those below. These two new vectors are not used for further analysis, but purely used for plotting.

The average temperature vector was then used to calculate a moving average. The goal of this moving average is to take the yearly averages in groups and take the average yearly temperature for that group. This will make it easier to fit. Similarly ot the other average functions, this iterated through the average vector and for each element added the temperature. If the iteration counter was the size of the desired group size, then the average of the average temperatures was pushed into a vector for the y-values. For the x-values, the current year, the middle of the group, corresponded to the initial year, plus the number of groups so far times the group size. Plus half a group size. If the number of years is not divisible by the group size then the last years will not be represented. This is accomodated by outside the for loop push the current value of the sum.

These moving average y- and x-values were then put into a `TGraph` object, and a fit function was added to this graf. The function was of the form $A * (x - 1840) * cos(B * x))$, where A and B are parameters. The graph, the fit were then plotted together with the above and belov vectors, as bar graphs, mentioned earlier.

The main function `tempEx` then returned the value of the fit function evaluated at the desired year.

5.2 Results and Conclusion

The results show a somewhat periodically oscillating average yearly temperature around 5.9 Celcius. The fit achieves a $\chi^2 = 1.2$, which is surprisingly good for such a simplistic model. Extrapolating with this function, $0.005(x - 1840)cos(0.125x)$ gives an average temperature of 5.88 Celcius year 2050. In conclusion, the yearly temperatures do in fact oscillate over time. However, it is clearly seen in the data that at in the more recent years have been concistently warmer and a more proper model, using global data could most likely show proof of global warming. It is interesting to see that such a simple model as ours does make a good fit with the data. It is also interesting that such a temperature increase can be seen in data just obtained in the Stockholm region.

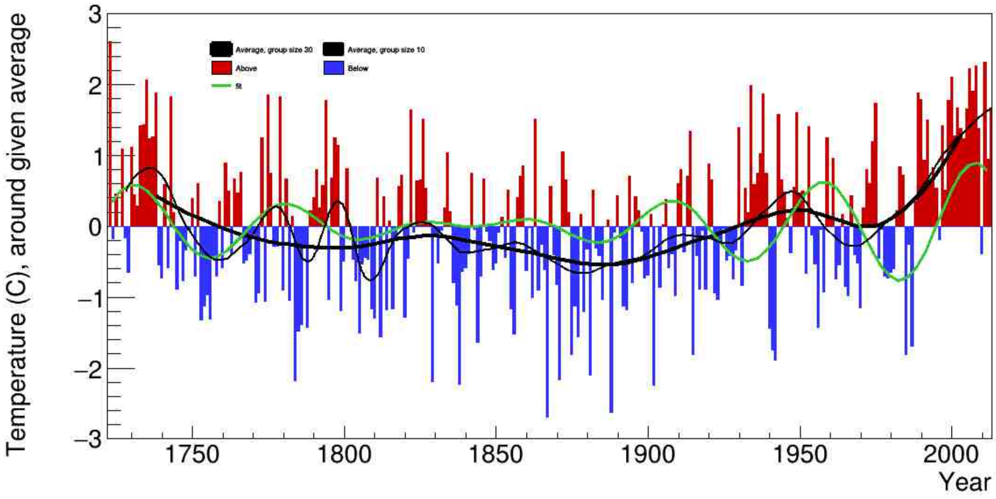


Figure 11

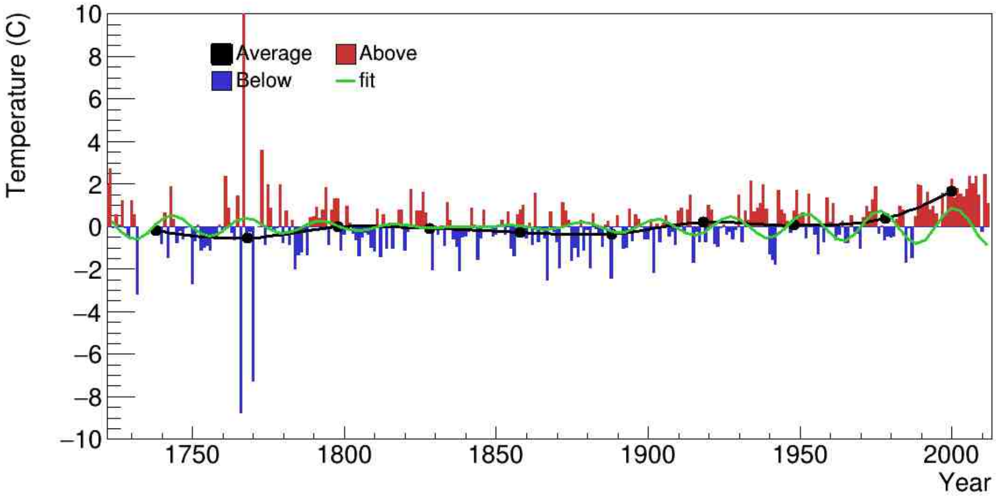


Figure 12

References

[1] SVT Nyheter. Vintern 2017-2018. `https://www.svt.se/vader/vintern20172018`. Accessed: 2017-11-09.

[2] Sveriges meteorologiska och hydrologiska institut (SMHI). Årstider. `https://www.smhi.se/kunskapsbanken/meteorologi/arstider-1.1082`. Accessed: 2017-11-09.